National Aeronautics and Space Administration

FY 2022 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2020	Enacted 2021	Request 2022	2023	2024	2025	2026
			Fiscal Year				
NASA Total	**22,629.0**	**23,271.3**	**24,801.5**	**25,314.9**	**25,869.3**	**26,441.0**	**27,027.9**
Deep Space Exploration Systems	**5,959.8**	**6,517.4**	**6,880.4**	**7,014.1**	**7,263.7**	**7,514.9**	**7,772.8**
Exploration Systems Development	4,512.8	4,544.6	4,483.7	4,384.0	4,219.0	3,888.0	3,867.0
Exploration Research & Development	1,447.0	1,972.8	2,396.7	2,630.1	3,044.7	3,626.9	3,905.8
Space Technology	**1,100.0**	**1,100.0**	**1,425.0**	**1,454.5**	**1,486.4**	**1,519.2**	**1,552.9**
Space Operations	**4,134.7**	**3,988.2**	**4,017.4**	**4,109.3**	**4,103.3**	**4,103.3**	**4,103.3**
International Space Station	1,516.1	1,321.6	1,327.6	1,309.7	1,279.4	1,284.5	1,284.5
Space Transportation	1,746.2	1,872.9	1,771.7	1,827.1	1,849.0	1,843.7	1,843.7
Space and Flight Support (SFS)	857.4	776.6	817.0	786.4	788.8	789.0	789.0
Commercial LEO Development	15.0	17.0	101.1	186.1	186.1	186.1	186.1
Science	**7,143.1**	**7,300.8**	**7,931.4**	**8,095.6**	**8,272.9**	**8,455.7**	**8,643.4**
Earth Science	1,971.8	2,000.0	2,250.0	2,343.5	2,398.3	2,573.0	2,702.3
Planetary Science	2,712.6	2,699.8	3,200.0	3,196.3	3,266.5	3,226.9	3,168.7
James Webb Space Telescope	423.0	414.7	175.4	172.5	172.0	172.0	172.0
Astrophysics	1,306.2	1,356.2	1,400.2	1,461.8	1,491.5	1,512.3	1,594.1
Heliophysics	724.5	751.0	796.7	803.3	816.6	833.6	858.5
Biological and Physical Sciences	5.0	79.1	109.1	118.1	128.0	137.9	147.8
Aeronautics	**783.9**	**828.7**	**914.8**	**933.7**	**954.1**	**975.2**	**996.8**
STEM Engagement	**120.0**	**127.0**	**147.0**	**150.0**	**153.3**	**156.7**	**160.2**
Safety, Security, and Mission Services	**2,913.3**	**2,936.5**	**3,049.2**	**3,112.3**	**3,180.5**	**3,250.8**	**3,323.0**
Mission Services & Capabilities	1,849.7	1,918.3	2,028.8	2,070.8	2,113.7	2,157.6	2,202.4
Engineering, Safety, & Operations	1,063.6	1,018.2	1,020.4	1,041.5	1,066.8	1,093.2	1,120.6
Construction and Environmental Compliance and Restoration	**432.5**	**428.5**	**390.3**	**398.4**	**407.1**	**416.1**	**425.3**
Construction of Facilities	357.8	370.4	315.6	322.2	329.3	336.7	344.2
Environmental Compliance and Restoration	74.7	58.1	74.7	76.2	77.8	79.4	81.1
Inspector General	**41.7**	**44.2**	**46.0**	**47.0**	**48.0**	**49.1**	**50.2**
NASA Total	**22,629.0**	**23,271.3**	**24,801.5**	**25,314.9**	**25,869.3**	**26,441.0**	**27,027.9**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

FY 2022 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2020	Enacted 2021	Request 2022	2023	2024	2025	2026
NASA Total	**22,629.0**	**23,271.3**	**24,801.5**	**25,314.9**	**25,869.3**	**26,441.0**	**27,027.9**
Deep Space Exploration Systems	**5,959.8**	**6,517.4**	**6,880.4**	**7,014.1**	**7,263.7**	**7,514.9**	**7,772.8**
Exploration Systems Development	**4,512.8**	**4,544.6**	**4,483.7**	**4,384.0**	**4,219.0**	**3,888.0**	**3,867.0**
Orion Program	**1,406.7**	**1,403.7**	**1,406.7**	**1,340.0**	**1,239.0**	**1,084.0**	**1,084.0**
Crew Vehicle Development	1,396.2	1,387.8	1,388.3	1,321.4	1,230.0	1,065.0	1,065.0
Orion Program Integration and Support	10.5	15.9	18.4	18.6	9.0	19.0	19.0
Space Launch System	**2,528.1**	**2,560.9**	**2,487.0**	**2,486.0**	**2,466.0**	**2,290.0**	**2,270.0**
Launch Vehicle Development	2,468.0	2,494.3	2,413.6	2,413.3	2,408.9	2,202.9	2,182.9
SLS Program Integration and Support	60.1	66.6	73.4	72.7	57.1	87.1	87.1
Exploration Ground Systems	**578.0**	**580.0**	**590.0**	**558.0**	**514.0**	**514.0**	**513.0**
Exploration Ground Systems Development	558.7	569.2	583.7	552.4	514.0	494.0	493.0
EGS Program Integration and Support	19.3	10.8	6.3	5.6	--	20.0	20.0
Exploration Research & Development	**1,447.0**	**1,972.8**	**2,396.7**	**2,630.1**	**3,044.7**	**3,626.9**	**3,905.8**
Advanced Exploration Systems	**208.9**	**176.2**	**195.0**	**195.0**	**195.0**	**195.0**	**195.0**
Advanced Cislunar and Surface Capabilities	**38.0**	**54.5**	**91.5**	**217.9**	**360.2**	**627.9**	**1,088.6**
Gateway	**421.0**	**698.8**	**785.0**	**810.5**	**765.0**	**670.0**	**670.0**
Human Landing System	**654.1**	**928.3**	**1,195.0**	**1,266.7**	**1,579.5**	**1,989.0**	**1,807.2**
Human Research Program	**125.0**	**115.0**	**130.2**	**140.0**	**145.0**	**145.0**	**145.0**
Space Technology	**1,100.0**	**1,100.0**	**1,425.0**	**1,454.5**	**1,486.4**	**1,519.2**	**1,552.9**
Early Stage Innovation and Partnerships	**119.8**	**117.5**	**145.0**	**147.9**	**150.8**	**153.9**	**157.0**
Agency Technology and Innovation	9.4	8.4	9.4	9.6	9.8	10.0	10.2
Early Stage Innovation	90.8	89.2	115.6	117.9	120.2	122.7	125.2
Technology Transfer	19.6	19.9	20.0	20.4	20.8	21.2	21.6
Technology Maturation	**179.2**	**227.1**	**491.2**	**501.0**	**511.1**	**521.3**	**531.7**
Technology Demonstration	**575.5**	**528.4**	**501.8**	**512.9**	**525.9**	**539.4**	**553.5**
Laser Comm Relay Demo (LCRD)	28.5	15.1	--	--	--	--	--
Solar Electric Propulsion (SEP)	67.0	26.2	24.2	18.5	15.9	17.8	5.8
Restore & SPIDER (OSAM-1)	227.2	227.0	227.0	227.0	227.0	103.6	25.4
Small Spacecraft, Flight Opportunities & Other Tech Demo	252.9	260.1	250.6	267.4	283.0	418.0	522.3
SBIR and STTR	**225.5**	**227.0**	**287.0**	**292.7**	**298.6**	**304.6**	**310.7**
Space Operations	**4,134.7**	**3,988.2**	**4,017.4**	**4,109.3**	**4,103.3**	**4,103.3**	**4,103.3**

FY 2022 PRESIDENT'S BUDGET REQUEST SUMMARY

	Fiscal Year						
Budget Authority ($ in millions)	Op Plan 2020	Enacted 2021	Request 2022	2023	2024	2025	2026
International Space Station	**1,516.1**	**1,321.6**	**1,327.6**	**1,309.7**	**1,279.4**	**1,284.5**	**1,284.5**
International Space Station Program	**1,516.1**	**1,321.6**	**1,327.6**	**1,309.7**	**1,279.4**	**1,284.5**	**1,284.5**
ISS Systems Operations and Maintenance	1,056.0	1,013.8	1,048.2	1,043.9	1,013.5	1,013.5	1,013.5
ISS Research	460.1	307.8	279.4	265.8	265.9	271.0	271.0
Space Transportation	**1,746.2**	**1,872.9**	**1,771.7**	**1,827.1**	**1,849.0**	**1,843.7**	**1,843.7**
Crew and Cargo Program	**1,511.3**	**1,573.2**	**1,617.2**	**1,763.6**	**1,784.1**	**1,778.7**	**1,778.7**
Commercial Crew Program	**234.9**	**299.7**	**154.5**	**63.5**	**64.9**	**64.9**	**64.9**
Space and Flight Support (SFS)	**857.4**	**776.6**	**817.0**	**786.4**	**788.8**	**789.0**	**789.0**
Space Communications and Navigation	**598.7**	**506.0**	**522.6**	**489.8**	**483.8**	**483.8**	**483.8**
Space Communications Networks	478.1	398.3	390.5	378.6	374.2	374.0	373.8
Space Communications Support	120.7	107.7	132.1	111.2	109.6	109.9	110.1
Human Space Flight Operations	**99.9**	**97.8**	**101.8**	**104.8**	**105.3**	**105.4**	**105.4**
Launch Services	**94.4**	**91.9**	**102.7**	**92.7**	**92.9**	**92.9**	**92.9**
Rocket Propulsion Test	**46.7**	**47.6**	**47.8**	**47.8**	**48.0**	**48.0**	**48.0**
Communications Services Program	**2.7**	**23.4**	**42.0**	**51.2**	**58.9**	**58.9**	**58.9**
Commercial LEO Development	**15.0**	**17.0**	**101.1**	**186.1**	**186.1**	**186.1**	**186.1**
Science	**7,143.1**	**7,300.8**	**7,931.4**	**8,095.6**	**8,272.9**	**8,455.7**	**8,643.4**
Earth Science	**1,971.8**	**2,000.0**	**2,250.0**	**2,343.5**	**2,398.3**	**2,573.0**	**2,702.3**
Earth Science Research	**472.9**	**479.7**	**537.5**	**535.9**	**551.6**	**588.0**	**600.1**
Earth Science Research and Analysis	321.2	344.4	363.8	359.9	365.6	384.7	393.2
Computing and Management	151.7	135.3	173.6	176.0	186.0	203.3	206.8
Earth Systematic Missions	**858.9**	**780.5**	**836.1**	**1,004.8**	**988.8**	**1,068.7**	**1,120.0**
Surface Water and Ocean Topography Mission (SWOT)	98.2	63.9	32.8	47.5	10.5	10.6	6.5
NASA-ISRO Synthetic Aperture Radar (NISAR)	201.6	75.5	73.3	58.6	28.9	24.2	15.7
Landsat 9	37.9	86.5	2.8	2.9	3.0	3.0	3.1
Sentinel-6	13.4	8.0	22.8	40.3	63.9	55.2	25.6
PACE	131.0	145.1	119.4	100.3	67.0	20.1	12.0
Other Missions and Data Analysis	376.8	401.6	585.0	755.2	815.6	955.5	1,057.2
Earth System Explorers	**--**	**--**	**6.6**	**23.4**	**34.3**	**92.0**	**150.2**
Earth System Science Pathfinder	**273.6**	**316.1**	**375.3**	**273.9**	**282.1**	**238.0**	**225.2**
Venture Class Missions	222.5	263.6	326.9	225.4	242.1	198.1	184.7
Other Missions and Data Analysis	51.1	52.5	48.4	48.4	39.9	39.9	40.5
Earth Science Data Systems	**243.5**	**278.6**	**330.7**	**338.0**	**368.4**	**377.5**	**392.8**
Earth Science Technology	**69.6**	**82.2**	**91.1**	**93.3**	**95.9**	**108.1**	**110.2**
Applied Sciences	**53.3**	**62.9**	**72.7**	**74.2**	**77.3**	**100.8**	**103.7**

FY 2022 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2020	Enacted 2021	Request 2022	2023	2024	2025	2026
				Fiscal Year			
Planetary Science	**2,712.6**	**2,699.8**	**3,200.0**	**3,196.3**	**3,266.5**	**3,226.9**	**3,168.7**
Planetary Science Research	**286.0**	**304.1**	**306.9**	**290.1**	**300.1**	**301.9**	**301.2**
Planetary Science Research and Analysis	209.8	223.2	221.9	203.6	206.3	203.6	203.6
Other Missions and Data Analysis	76.2	80.9	85.0	86.5	93.8	98.4	97.7
Planetary Defense	**150.0**	**151.0**	**197.2**	**220.7**	**226.5**	**224.2**	**170.6**
DART	72.4	66.4	11.1	4.0	--	--	--
Other Missions and Data Analysis	77.6	84.6	186.1	216.7	226.5	224.2	170.6
Lunar Discovery and Exploration	**300.0**	**443.5**	**497.3**	**501.3**	**458.3**	**458.3**	**458.3**
VIPER	54.9	99.1	107.2	102.0	30.6	--	--
Discovery	**508.7**	**451.3**	**364.8**	**227.6**	**303.8**	**529.4**	**750.5**
Lucy	208.6	143.6	77.3	18.0	20.2	24.5	41.7
Psyche	214.0	169.6	139.7	28.7	29.0	32.0	32.0
Other Missions and Data Analysis	86.1	138.1	147.8	180.8	254.6	472.9	676.8
New Frontiers	**136.8**	**160.0**	**271.7**	**446.8**	**500.4**	**494.9**	**372.3**
Dragonfly	41.0	86.0	201.1	370.3	411.4	332.3	257.2
Other Missions and Data Analysis	95.8	74.0	70.6	76.5	89.0	162.6	115.1
Mars Exploration	**565.7**	**334.8**	**267.8**	**251.9**	**249.1**	**228.1**	**229.8**
Other Missions and Data Analysis	565.7	334.8	267.8	251.9	249.1	228.1	229.8
Mars Sample Return	**--**	**246.3**	**653.2**	**772.3**	**800.0**	**700.0**	**600.0**
Outer Planets and Ocean Worlds	**632.0**	**462.5**	**494.8**	**331.2**	**265.5**	**135.7**	**115.7**
Jupiter Europa	592.6	434.8	472.1	305.0	240.0	110.1	90.1
Other Missions and Data Analysis	39.4	27.7	22.7	26.2	25.5	25.6	25.6
Radioisotope Power	**133.5**	**146.3**	**146.4**	**154.6**	**162.8**	**154.4**	**170.4**
James Webb Space Telescope	**423.0**	**414.7**	**175.4**	**172.5**	**172.0**	**172.0**	**172.0**
Astrophysics	**1,306.2**	**1,356.2**	**1,400.2**	**1,461.8**	**1,491.5**	**1,512.3**	**1,594.1**
Astrophysics Research	**231.2**	**249.3**	**285.5**	**328.0**	**339.0**	**344.1**	**345.3**
Astrophysics Research and Analysis	86.6	91.1	107.4	94.9	95.2	95.2	95.2
Balloon Project	44.8	44.8	45.8	45.7	46.3	46.3	46.3
Science Activation	45.6	45.6	55.6	55.6	55.6	55.6	55.6
Other Missions and Data Analysis	54.3	67.8	76.7	131.8	141.9	147.0	148.2
Cosmic Origins	**202.7**	**203.8**	**115.0**	**126.3**	**114.7**	**115.1**	**126.9**
Hubble Space Telescope	90.8	93.3	98.3	98.3	98.3	98.3	98.3
Other Missions and Data Analysis	111.9	110.5	16.7	28.0	16.4	16.8	28.6
Physics of the Cosmos	**132.8**	**146.4**	**156.0**	**160.0**	**169.1**	**159.8**	**167.6**
Exoplanet Exploration	**554.2**	**552.4**	**543.3**	**547.6**	**525.8**	**489.2**	**431.5**
Nancy Roman Space Telescope	510.7	505.2	501.6	501.8	485.1	448.5	385.7

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Budget Authority ($ in millions)	Op Plan 2020	Enacted 2021	Request 2022	2023	2024	2025	2026
			Fiscal Year				
Other Missions and Data Analysis	43.5	47.2	41.7	45.8	40.7	40.7	45.8
Astrophysics Explorer	**185.3**	**204.4**	**300.4**	**300.0**	**342.9**	**404.1**	**522.9**
SPHEREx	66.6	68.5	89.9	96.7	75.0	24.0	6.0
Heliophysics	**724.5**	**751.0**	**796.7**	**803.3**	**816.6**	**833.6**	**858.5**
Heliophysics Research	**251.7**	**280.8**	**210.6**	**213.2**	**212.0**	**219.5**	**221.5**
Heliophysics Research and Analysis	66.6	77.0	52.0	52.6	52.6	54.6	56.6
Sounding Rockets	69.7	73.6	60.1	60.1	60.1	65.1	65.1
Research Range	31.0	32.0	26.4	26.8	26.9	26.9	26.9
Other Missions and Data Analysis	84.4	98.2	72.0	73.7	72.4	72.9	72.9
Living with a Star	**146.0**	**148.2**	**115.3**	**146.1**	**170.2**	**235.8**	**278.9**
Other Missions and Data Analysis	146.0	148.2	115.3	146.1	170.2	235.8	278.9
Solar Terrestrial Probes	**126.8**	**132.2**	**253.3**	**252.6**	**228.8**	**197.6**	**120.4**
Interstellar Mapping and Acceleration Probe (IMAP)	52.0	66.2	169.6	151.6	112.2	67.4	15.2
Other Missions and Data Analysis	74.7	66.0	83.8	101.0	116.6	130.3	105.2
Heliophysics Explorer Program	**184.1**	**170.7**	**189.2**	**151.6**	**157.9**	**162.9**	**226.3**
Other Missions and Data Analysis	184.1	170.7	189.2	151.6	157.9	162.9	226.3
Heliophysics Technology	**15.9**	**19.2**	**28.3**	**39.8**	**47.7**	**17.8**	**11.4**
Biological and Physical Sciences	**5.0**	**79.1**	**109.1**	**118.1**	**128.0**	**137.9**	**147.8**
Aeronautics	**783.9**	**828.7**	**914.8**	**933.7**	**954.1**	**975.2**	**996.8**
Aeronautics	**783.9**	**828.7**	**914.8**	**933.7**	**954.1**	**975.2**	**996.8**
Airspace Operations and Safety Program	**96.2**	**92.0**	**104.5**	**106.3**	**108.1**	**108.1**	**108.1**
Advanced Air Vehicles Program	**188.1**	**211.4**	**243.7**	**254.6**	**270.9**	**288.5**	**269.5**
Integrated Aviation Systems Program	**261.5**	**278.7**	**301.5**	**305.5**	**310.7**	**309.2**	**349.9**
Low Boom Flight Demonstrator	126.5	97.3	74.6	36.8	15.3	--	--
Electrified Powertrain Flight Demonstration	25.0	76.9	91.2	128.6	98.6	25.0	--
Integrated Aviation Systems Program	110.0	104.5	135.7	140.1	196.8	284.2	349.9
Transformative Aero Concepts Program	**121.1**	**129.7**	**148.0**	**150.3**	**147.4**	**152.4**	**152.4**
Aerosciences Evaluation and Test Capabilities	**117.0**	**116.9**	**117.0**	**117.0**	**117.0**	**117.0**	**117.0**
STEM Engagement	**120.0**	**127.0**	**147.0**	**150.0**	**153.3**	**156.7**	**160.2**
Safety, Security, and Mission Services	**2,913.3**	**2,936.5**	**3,049.2**	**3,112.3**	**3,180.5**	**3,250.8**	**3,323.0**

FY 2022 PRESIDENT'S BUDGET REQUEST SUMMARY

	Fiscal Year						
Budget Authority ($ in millions)	**Op Plan 2020**	**Enacted 2021**	**Request 2022**	**2023**	**2024**	**2025**	**2026**
Mission Services & Capabilities	1,849.7	1,918.3	2,028.8	2,070.8	2,113.7	2,157.6	2,202.4
Information Technology (IT)	475.0	548.6	612.2	624.9	637.8	651.0	664.6
Mission Enabling Services	697.0	702.5	731.5	746.5	761.9	777.6	793.7
Infrastructure & Technical Capabilities	677.8	667.2	685.1	699.4	714.0	728.9	744.1
Engineering, Safety, & Operations	1,063.6	1,018.2	1,020.4	1,041.5	1,066.8	1,093.2	1,120.6
Agency Technical Authority	184.0	182.8	186.8	190.6	194.6	198.6	202.8
Center Engineering, Safety, & Operations	879.6	835.4	833.7	850.9	872.2	894.6	917.8
Construction and Environmental Compliance and Restoration	432.5	428.5	390.3	398.4	407.1	416.1	425.3
Construction of Facilities	357.8	370.4	315.6	322.2	329.3	336.7	344.2
Institutional CoF	211.8	262.9	205.8	322.2	329.3	336.7	344.2
Exploration CoF	109.9	60.3	89.3	--	--	--	--
Space Operations CoF	20.0	23.9	20.5	--	--	--	--
Science CoF	16.1	23.3	--	--	--	--	--
Environmental Compliance and Restoration	74.7	58.1	74.7	76.2	77.8	79.4	81.1
Inspector General	41.7	44.2	46.0	47.0	48.0	49.1	50.2
NASA Total	22,629.0	23,271.3	24,801.5	25,314.9	25,869.3	26,441.0	27,027.9

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

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FY 2022 BUDGET REQUEST EXECUTIVE SUMMARY

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MESSAGE FROM THE ADMINISTRATOR

President Biden's Fiscal Year (FY) 2022 Budget for NASA demonstrates the Administration's commitment to the Agency and the role NASA plays in combating climate change, inspiring science and engineering innovation, strengthening the United States' standing around the world, and expanding economic opportunities in the aviation and space fields. The President's FY 2022 Budget for NASA will help ensure American leadership in space, while also equipping us to better protect our home planet.

NASA's budget truly is an investment in America's future. In fiscal year 2019 alone, Agency activities contributed to economies local and national, helped small businesses grow, and supported good-paying jobs nationwide. These economic benefits were driven by the Agency's many accomplishments that advanced our knowledge and capabilities, improved life on Earth, and inspired the next generation of engineers and scientists. And there's so much more to do.

Addressing climate change is a top priority of the Biden Administration and is reflected in the President's funding request for NASA Earth science activities. Given the dangers to humanity posed by climate change, including the economic and national security impacts of this threat, this budget increases our ability to better understand our own planet and how it works as an integrated system, from our oceans to our atmosphere.

NASA is uniquely positioned to help address the climate crisis as a global leader in Earth system science, with our first space-based observations of our planet starting in the 1960s. Since that time, much of what scientists have learned about our changing climate is built on NASA's satellite observations and research. Today, NASA's Earth science expertise provides the leading-edge observations that help us understand and adapt to our changing planet. This funding request allows NASA to go further and build the next generation platform: the Earth System Observatory, an array of space-based satellites, instruments, and missions that will deliver the highest priority data to create a 3D view of our Earth, from atmosphere to bedrock, helping us better understand Earth as a system.

The President's funding request also gives us the resources to advance America's bipartisan Moon to Mars space exploration plan, keeping us on the path to landing the first woman and first person of color on the Moon under the Artemis program. With this goal, America sets an example for the world of the power of diversity; how, as human beings, there always will be more that unites us than divides us.

With NASA's Space Launch System rocket and Orion spacecraft and U.S. commercial partnerships for a human landing system and Gateway lunar outpost, the United States will return to the Moon not just to visit but to live and work sustainably, allowing NASA and our partners to do the research necessary to eventually land Americans on Mars.

This funding request furthers the development of cutting-edge space technologies, as well as robotic exploration of the universe, allowing America to remain at the forefront of discovery. NASA also will continue to be a catalyst for the growth of a healthy and vibrant commercial space industry, expanding opportunities in low-Earth orbit. We are investing in aviation to make our skies safer and our fuels cleaner, and to get you to your destination faster than ever before. Taken together, all these efforts feed the economy and create good paying American jobs.

The President's request includes new funding for NASA's STEM engagement, investing in and inspiring the next generation of scientists, engineers, mathematicians, and explorers and helping equip our Nation with the workforce of the future.

With continued support for the International Space Station and the Artemis program, the President also welcomes the international community to join us as we push human exploration deeper into space.

MESSAGE FROM THE ADMINISTRATOR

I am confident that this FY 2022 budget, along with continued bipartisan support for our mission, will empower NASA and the United States to lead humanity into the next era in exploration – an era in which government and the private sector partner to take us farther than ever before: to the Moon, to Mars, and beyond.... and to expand science, economic growth, and prosperity.

Bill Nelson

NOTES ON THE BUDGET

Despite the COVID-19 pandemic creating difficult circumstances across NASA's portfolio of missions, the Agency's workforce and its partners have proven they will overcome any trial. With the resources provided last fiscal year, NASA achieved success by: launching three crews of American astronauts from American soil on American rockets to the International Space Station; successfully completing the construction of the Orion spacecraft and hot fire test of the Space Launch System for the Artemis I mission; contracting with commercial industry to build a Human Landing System; successfully landing the Perseverance Rover on the surface of Mars, and completing the first powered flight on another planetary body; and continuing work on groundbreaking science research missions expected to expand humanity's knowledge of the Earth.

NASA is a unique and powerful source of national inspiration and international leadership, and the Agency stands ready to bring its expertise and capability to meet the challenges and opportunities facing our Nation: conducting research utilizing key data from our climate observation missions to understand and mitigate climate change; supporting innovation and technology development in aviation and space; expanding key sectors of the economy while creating STEM jobs and inspiring students to pursue STEM careers; and providing American leadership and global engagement through the Artemis program with a growing set of international partners. As we expand exploration of the Moon, Mars, and the universe beyond, we strengthen U.S leadership for a new age of human and robotic exploration and discovery.

The Administration's strong support and vision for NASA are reflected in the FY 2022 President's Budget. NASA's historic and enduring purpose is captured in four major strategic thrusts outlined in our Strategic Plan: Discover, Explore, Develop, and Enable. These correspond to our missions of scientific discovery of our world, of other worlds, and of the cosmos as a whole; missions of exploration in our solar system with humans and robotic probes that expand the frontiers of human experience; and missions that develop and advance new technologies in exploration and aeronautics that allow American industry to increase market share and create new markets, on Earth, and in the near-Earth region of space.

Discover

NASA's Science program epitomizes the Agency's history of momentous discovery and funds on-going discovery and exploration of our planet, other planets and planetary bodies, our star system, our galaxy, and the universe beyond. Through the development of space observatories and probes, NASA will continue to conduct groundbreaking research that inspires the next generation of scientists, engineers, and explorers; provide U.S. leadership in space; and expand human knowledge. NASA Science includes over 100 missions, many of which involve collaboration with international partners or other U.S. agencies.

NASA Earth Science missions continue to collect data enhancing our understanding of the Earth's changing climate, and NASA makes this detailed climate data available to the global community to inform policies and actions to address the threat climate change poses to our economic prosperity and our national security. This budget requests an increase of $250 million from the FY 2021 enacted level for FY 2022, providing $2.25 billion for a robust Earth science portfolio. With this budget, NASA increases our ability to understand Earth and how it works as an integrated system, from our oceans to our atmosphere and how it is changing over time. The budget supports a robust Venture Class mission cadence and the launch of several upcoming missions, including Landsat-9, NASA-ISRO Synthetic Aperture Radar (NISAR), and Surface Water and Ocean Topography (SWOT). This budget requests funding for the PACE and CLARREO Pathfinder missions, and provides funding for Earth System Explorer class missions. With the Earth Systems Observatory, NASA will design a new set of Earth-focused missions to provide key information to guide efforts related to climate change, disaster mitigation, fighting forest fires, and improving real-time agricultural processes.

This budget continues to reinvigorate robotic exploration of the solar system by providing $3.2 billion for Planetary Science. Following the successful landing of the Perseverance Rover, this budget funds a Mars Sample Return mission, plans for a future Mars Ice Mapper mission, and supports continued work on Europa Clipper, which will explore a moon of Jupiter. This budget supports Discovery projects such as Lucy and Psyche, New Frontiers projects such as Dragonfly, as well as planetary defense measures to detect objects near Earth. These Planetary missions will continue to inspire the next generation of explorers while aiding and informing a future sustained human presence in the solar system.

This budget reflects a transition from development to operations for the James Webb Space Telescope, planned for launch in Fall of 2021. Providing $1.4 billion for Astrophysics, the budget continues such projects as IXPE, SPHEREx, GUSTO, SunRISE and XRISM, each exploring aspects of the cosmos. The budget proposed includes funding for the Nancy Grace Roman Space telescope (formerly WFIRST), and proposes to conclude the SOFIA mission in order to focus resources on missions with higher scientific return. The next Decadal Survey on Astronomy and Astrophysics, Astro 2020, is currently underway and is scheduled for release by the National Academies of Science, Engineering and Medicine in 2021. NASA looks forward to the final recommendations and working to implement them.

The budget provides $796 million for Heliophysics, supporting the IMAP mission, balloon explorers, and increased funding for Heliophysics Technology. The Heliophysics Space Weather Science and Applications project continues to coordinate with other agencies to enhance space weather prediction capabilities. In order to support science in the Artemis program, Heliophysics is developing a space weather instrument suite for the Gateway.

Explore

The FY 2022 budget request includes nearly $9 billion for Exploration, Space Technology, and the Lunar Discovery and Exploration (LDEP) program in Science to implement the Artemis program that will land the first woman and the first person of color on the Moon. The Artemis program will develop a sustainable lunar exploration program to prepare for the ultimate goal of crewed flights to Mars. NASA looks forward to these historic moments and advancing equity for all of humanity on the Moon and in cislunar space. NASA will evolve its core capabilities through continued technical advancements, and new approaches to industrial partnerships to maintain U.S. leadership in human spaceflight. This effort spurs the development of systems and assets, ensuring a strategic and sustainable American presence on the Moon. The technologies, systems, and operational capabilities proved around and on the Moon will support NASA in an eventual human mission to Mars.

NASA continues to follow a consistent technical strategy for the Artemis program. That strategy includes mission planning and flight testing of the Space Launch Sysetem (SLS), Orion, Exploration Ground Systems (EGS), and Human Landing System (HLS) to support preparations for the first lunar landing; development of the Gateway to provide a platform in lunar orbit to sustain surface operations; implementing a regular cadence of crewed missions to the lunar surface; and developing the surface systems with commercial and international partners necessary to conduct science and demonstrate technologies and operations in preparation for crewed missions to Mars. As part of the Artemis effort, NASA will also leverage interagency partnerships, expanding relationships with other U.S. Government agencies to take advantage of their expertise, create mutually beneficial synergies, and ensure ongoing coordination in the pursuit and achievement of the Nation's space goals. NASA will maintain and grow mutually beneficial international partnerships to lead a global community dedicated to expanding peaceful exploration and use of the Moon and then ultimately to Mars.

The Exploration Systems Development programs are creating transportation systems for human exploration beyond low Earth orbit. Orion (with a Service Module developed in partnership with the European Space Agency) will take humans to cislunar space atop the SLS, the heavy-lift rocket that is supported by EGS for integration and launch. With these NASA systems, we will send astronauts to the Moon, building our capabilities and gaining needed experience for future missions.

This budget supports development of both the Gateway lunar outpost and the HLS. Gateway will be an outpost in orbit around the Moon and a platform for sustainable human space exploration, science, and technology development. U.S. leadership on the Gateway program has inspired Canada, Europe, and Japan to expand their partnerships with NASA to extend human presence from low-Earth orbit to the Moon. NASA's HLS contract award, with a goal of a human demonstration mission to the lunar surface by 2024, is under protest as of this publication. Through this award, NASA intends to work with a commercial partner to develop an integrated landing system that will transport crew to and from the lunar surface. Subsequent to that first lunar landing in 50 years, the Artemis program will support a regular cadence of crewed missions – using the HLS, SLS, Orion, and Gateway systems – to the lunar surface, and the capabilities developed will enable a sustainable long-term presence on the lunar surface in preparation for human missions to Mars.

To enable the Artemis program, Advanced Exploration System funding focuses on reducing operational risk, validating operational concepts, leveraging partner capabilities, and lowering lifecycle costs to help enable lunar and deep space missions. AES is employing a stepping-stone approach by testing on the ground, in low-Earth orbit (LEO), and in cislunar space, with the goal of validating the entire habitation capability for long-duration exploration missions. NASA will conduct lunar missions to test systems and concepts, paving the way for long-duration human space exploration. Opening the space frontier requires expansion of technical and scientific knowledge to tackle complex problems and create new solutions for meeting demands never before encountered by humans.

NASA's Lunar Discovery and Exploration Program is working with several American companies to deliver science and technology to the lunar surface through the Commercial Lunar Payload Services (CLPS) initiative. Under the Artemis program, early commercial delivery missions will perform science experiments, test technologies, and demonstrate capabilities to help NASA explore the Moon and prepare for human missions. The first two CLPS launches are targeted for late 2021, and in 2023 NASA will deliver the Volatiles Investigating Polar Exploration Rover (VIPER) payload to the Moon's South Pole. By searching for water ice and other potential resources, VIPER will help pave the way for astronaut missions to the lunar surface and will bring NASA a step closer to developing a sustainable, long-term presence on the Moon as part of the Agency's Artemis program.

The International Space Station (ISS) is the world's most technologically complex and visible example of multinational cooperation in space. NASA will continue to leverage its mission aboard the ISS in LEO to identify risks to human health, develop countermeasures, and test technologies that protect astronauts, with a continued focus on reducing operations and maintenance costs. NASA is making technological advances aboard ISS in autonomous rendezvous and docking, advanced communications systems, human health and behavior in space, life support systems for habitats, and space suit systems, as well as biological and physical sciences research. NASA is also laying the groundwork for continuous access to a crewed space station in the decades to come. Through the Commercial LEO Development program, NASA is supporting the development of commercially-owned and operated LEO destinations to enable continuous American presence in LEO and yield numerous benefits here on Earth. As these new space stations are being developed, NASA will be working with the ISS National Laboratory and private companies to accelerate the growth of the commercial space industries that will use the ISS today and will join NASA in using commercial destinations in the future.

After multiple successful Commercial Crew flights in FY 2021, NASA will continue its partnership with the U.S. commercial space industry to operate safe, reliable, and affordable transportation to and from ISS, and any future commercial space stations in low Earth orbit. NASA requests $1.8 billion to continue to purchase commercial crew and commercial cargo services in FY 2022; provide stability to NASA, ISS, our international partners, and the U.S. space transportation industry, and ensure NASA's continued ability to launch astronauts and cargo from U.S. soil on American rockets.

Develop

Through its missions and sponsored research, NASA provides access to the farthest reaches of space and time, and helps generate essential information about our home planet. NASA's cutting-edge developments have a direct impact on our quality of life and the economy here on Earth. From scientific discovery and expanding human presence in space, to improving the quality of life, NASA and the nation benefit from developing new technologies that propel this exploration.

With this budget, the Aeronautics Research Mission Directorate (ARMD) will increase investments in research and development to enhance U.S. competitiveness in the global aviation industry while making aviation safer, more efficient, and more environmentally friendly. To meet aggressive climate goals, ARMD will establish a new Sustainable Flight National Partnership (SFNP) with U.S. industry to enable the next generation single-aisle transport to be a game-changing, ultra-efficient, and low-carbon emitting design at least 25 percent more fuel-efficient than today's airliners. Under the SFNP, ARMD will demonstrate the first-ever high-power hybrid electric propulsion for large transport aircraft and ultra-high-efficiency long and slender wings, as well as advanced composite structures produced four to six times faster than current state-of-the-art advanced engine technologies. The iconic centerpiece of SFNP will be a full-scale technology demonstrator X-plane to test and validate integrated systems and their benefits. This partnership is a strong response to international challenges to U.S. technological leadership for next-generation subsonic transports and ensures the U.S. remains at the forefront of the transition to sustainability, supporting good paying jobs.

NASA is leading transformation in other aspects of the civil aviation enterprise. The Agency is connecting the world through high-speed commercial flight, demonstrating quiet supersonic flight with NASA's X-59 Low Boom Flight Demonstrator. Through Advanced Air Mobility (AAM), Unmanned Aircraft Systems, and use of electric vertical takeoff and landing vehicles, NASA is working to enable a transformation of the way people and goods move around the Nation's communities and regions. NASA is establishing partnerships with industry to mature AAM concepts and technologies for safe operations, and preparing for AAM National Campaign demonstrations of new air vehicles and airspace management technologies. Early in FY 2022, NASA will be flying the all-electric X-57 Maxwell aircraft to better inform standards development for small electric aircraft that will be common in an AAM environment.

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The budget supports development of the next evolution of the global air traffic management system to safely increase operational efficiency at the vehicle, fleet, and system-wide levels while reducing fuel burn, CO2 emissions, contrail formation, and ozone impact. NASA will expand our partnership with the Nation's universities to develop technologies to achieve the industry's long-term climate goals while training and inspiring our future aerospace workforce. NASA will also continue to invest in critical fundamental technologies for hypersonic flight.

The Space Technology Mission Directorate (STMD) rapidly develops, demonstrates, and infuses revolutionary, high-payoff, cross-cutting technologies that lead to technology breakthroughs to enable NASA's missions while also supporting commercial and other Government agencies' needs. This budget supports the Administration's priorities of developing new technologies to enable human and robotic exploration of the Moon, Mars and beyond, and enhances research and development at NASA to maintain and enhance U.S. leadership in space technology. STMD's investment decisions advance development and demonstration of transformative capabilities for space transportation and propulsion; entry, descent and landing, including return of robots, crew and cargo; sustainable resource utilization and manufacturing; and robotic mobility systems.

STMD will continue demonstrating the foundational capabilities of on-orbit servicing, assembly, and manufacturing and take the next step in optical communications using infrared lasers to send data to and from space, enabling NASA to collect more science data and explore farther into the universe than ever before. STMD will also continue investments in In-Situ Resource Utilization (ISRU), Sustainable Power systems, lunar robotic mobility systems, research in Lunar Dust Mitigation, and small spacecraft technologies that are more rapid, affordable, and capable than previously achievable.

STMD will continue to develop technologies that have broad application and address multiple stakeholder needs. NASA's investments will continue to target technologies that benefit both human and robotic exploration, actively engaging with NASA Centers, industry, academia, and other Federal Government agencies to help define program content. STMD contributes to growing the U.S. industrial and academic base, continuing the Nation's economic leadership, and strengthening our national security. The Early Stage Innovation portfolio will lead innovation by sourcing ideas from a broad, diverse base of organizations and transferring space technology into the space economy. Efforts include expanding the number of NASA Innovative Advance Concepts awards and exploring innovation pilots to enable breakthrough technology R&D in support of U.S. competitiveness. These areas are part of a comprehensive approach to efficiently support innovative discovery, progress toward important goals, and the development of transformative new capabilities.

Technological leadership remains vital to our national security, economic prosperity, and global competitiveness. The Nation's continued economic leadership is, in part, due to the technological investments made in earlier years, through the work of the engineers, scientists, and policy makers who had the wisdom and foresight to make investments our country required to emerge as a global technological leader. That commitment accelerated the economy with the creation of new industries, products, and services that yielded lasting benefits. A technology-driven NASA will continue to help fuel our Nation's economic engine for decades to come, while also providing valuable breakthroughs for NASA's missions and the commercial industry.

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Enable

NASA's workforce continues to be its greatest asset for enabling missions in space and on Earth. The civil service staffing levels proposed in the FY 2022 Budget support NASA's scientists, engineers, researchers, managers, technicians, and business professionals. NASA's workforce includes civil service personnel at NASA Centers, Headquarters, and NASA-operated facilities. The Agency will apply the valued civil service workforce to high priority and enduring mission work, adjusting the mix of skills where appropriate. Centers will use a range of tools available to reshape the workforce, and to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.

Building on the addition of Inclusion as one of NASA's five Core Values, the funding requested in FY 2022 will help NASA focus on strengthening our diversity, equity and inclusion policies and practices. NASA will leverage existing grant programs, small business and university partnerships, and its STEM Engagement efforts to empower underserved populations to participate in NASA research, training, and programming. NASA will examine its hiring practices to ensure equitable access in everything from applying for internships through executive positions. NASA has long understood that diversity and inclusion is not only a matter of justice or fairness, but also a source of strength, innovation and critical thinking.

NASA's Office of STEM Engagement continues to create unique opportunities for a diverse set of students, and engage students in unique, authentic learning experiences that contribute to building a diverse future STEM workforce. NASA will expand initiatives to attract and retain underserved and underrepresented students in engineering and other STEM fields, in partnership with minority serving institutions and other higher education institutions. This request expands funding for NASA's STEM engagement efforts to equip our Nation for the future, by investing in and engaging the next generation of scientists, engineers, mathematicians, and explorers.

NASA's Mission Support Directorate enables the agency's portfolio of missions in space exploration, science, technology and aeronautics. With installations in 14 states, NASA manages $43 billion in assets with an inventory of over 5,000 buildings and structures. Over 80 percent of NASA facilities are beyond their constructed design life and NASA faces a challenging deferred maintenance backlog of over $2.6 billion. The Safety, Security, and Mission Services (SSMS) account funds the essential day-to-day technical and business operations required to safely operate and maintain NASA centers and facilities and the independent technical authorities required to reduce risk to life and program objectives for all missions. These mission support activities provide the essential services, tools, and equipment to complete essential tasks, protect and maintain the security and integrity of information and assets, and ensure that personnel work under safe and healthy conditions.

Planning, operating, and sustaining our missions, our infrastructure, and our essential services requires a number of critical institutional capabilities including management of: human capital; finance; information technology; infrastructure; acquisitions; security; real and personnel property; occupational health and safety; equal employment opportunity and diversity; small business programs; external relations; strategic internal and external communications; stakeholder engagement; and other essential corporate functions. Across this array of infrastructure and essential functions, NASA continuously seeks opportunities to improve effectiveness and increase efficiency while sharing information with NASA's labor unions to ensure their voice in the workplace. NASA will continue to provide strategic and operational planning and management over a wide range of services to help NASA operate in a more efficient and sustainable manner.

Additionally, the programs in HEO's Space and Flight Support theme provide essential services to missions from any part of NASA, and many partner organizations as well. Data uplinks and downlinks,

NOTES ON THE BUDGET

unified launch service procurements that take full advantage of NASA's collective buying power to secure the best price for the government, and other support programs represent important national capabilities that maintain NASA's leadership in space exploration and discovery.

The Construction and Environmental Compliance and Restoration (CECR) account enables NASA to manage the Agency's facilities with a focus on reducing infrastructure burdens, implementing high performance upgrades to increase efficiency, and prioritizing necessary repairs. In FY 2022, NASA will continue to consolidate facilities via institutional construction projects to achieve greater operational efficiency, replacing old, obsolete, costly facilities with fewer, higher performance facilities. Programmatic construction of facilities projects provide the specialized technical facilities required by the missions. To protect human health and the environment, and to preserve natural resources for future missions, environmental compliance and restoration projects will clean up pollutants released into the environment during prior NASA activities.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

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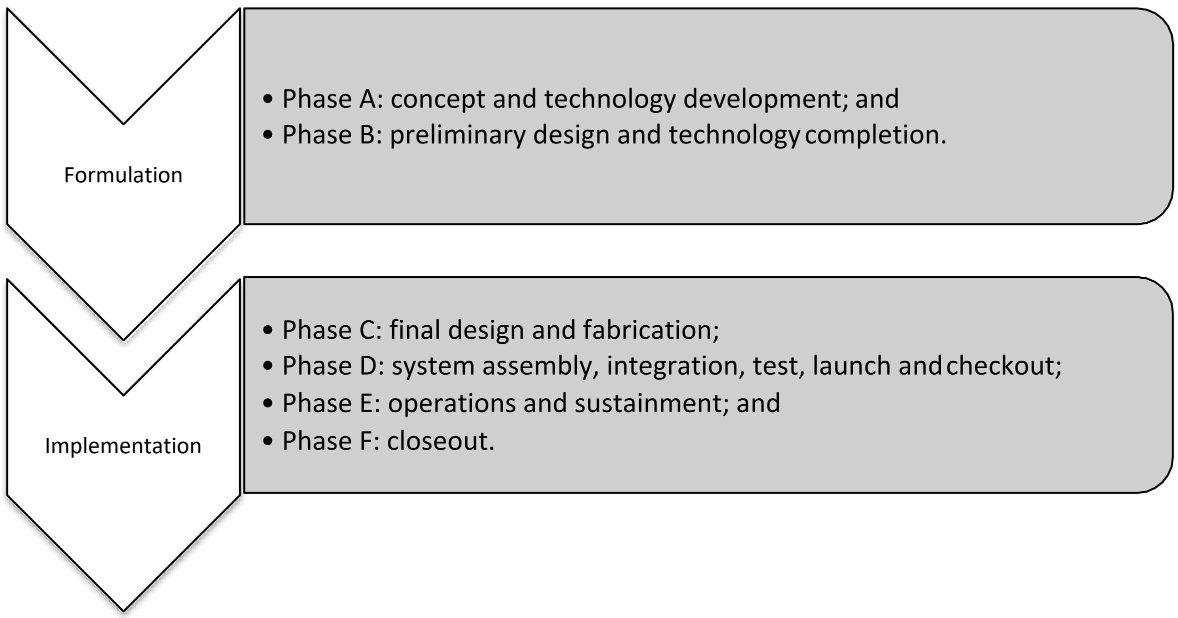
EXPLANATION OF BUDGET TABLES AND SCHEDULES

EXPLANATION OF PROJECT SCHEDULE COMMITMENTS AND KEY MILESTONES

Programs and projects follow their appropriate life cycle. The life cycle is divided into phases. Transition from one phase to another requires management approval at Key Decision Points (KDPs). The phases in program and project life cycles include one or more life-cycle reviews, which are considered major milestone events.



A life-cycle review is designed to provide the program or project with an opportunity to ensure that it has completed the work of that phase and an independent assessment of a program's or project's technical and programmatic status and health. The final life-cycle review in a given life-cycle phase provides essential information for the KDP that marks the end of that life-cycle phase and transition to the next phase if successfully passed. As such, KDPs serve as gates through which programs and projects must pass to continue.

The KDP decision to authorize a program or project's transition to the next life-cycle phase is based on a number of factors, including technical maturity; continued relevance to Agency strategic goals; adequacy of cost and schedule estimates; associated probabilities of meeting those estimates (confidence levels); continued affordability with respect to the Agency's resources; maturity and the readiness to proceed to the next phase; and remaining program or project risk (safety, cost, schedule, technical, management, and programmatic). At the KDP, the key program or project cost, schedule, and content parameters that govern the remaining life-cycle activities are established.

For reference, a description of schedule commitments and milestones is listed below for projects in Formulation and Implementation. A list of common terms used in mission planning is also included.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Formulation

NASA places significant emphasis on project Formulation to ensure adequate preparation of project concepts and plans and mitigation of high-risk aspects of the project essential to position the project for the highest probability of mission success. During Formulation, the project explores the full range of implementation options, defines an affordable project concept to meet requirements, and develops needed technologies. The activities in these phases include developing the system architecture; completing mission and preliminary system designs; acquisition planning; conducting safety, technical, cost, and schedule risk trades; developing time-phased cost and schedule estimates and documenting the basis of these estimates; and preparing the Project Plan for Implementation.

Formulation Milestone	Explanation
KDP-A	The lifecycle gate at which the decision authority determines the readiness of a program or project to transition into Phase A and authorizes Formulation of the project. Phase A is the first phase of Formulation and means that: • The project addresses a critical NASA need; • The proposed mission concept(s) is feasible; • The associated planning is sufficiently mature to begin activities defined for formulation; and • The mission can likely be achieved as conceived.
System Requirements Review (SRR)	The lifecycle review in which the decision authority evaluates whether the functional and performance requirements defined for the system are responsive to the program's requirements on the project and represent achievable capabilities
System Definition Review or Mission Definition Review	The lifecycle review in which the decision authority evaluates the credibility and responsiveness of the proposed mission/system architecture to the program requirements and constraints on the project, including available resources, and determines whether the maturity of the project's mission/system definition and associated plans are sufficient to begin the next phase, Phase B.
KDP-B	The lifecycle gate at which the decision authority determines the readiness of a program or project to transition from Phase A to Phase B. Phase B is the second phase of Formulation and means that: • The proposed mission/system architecture is credible and responsive to program requirements and constraints, including resources; • The maturity of the project's mission/system definition and associated plans is sufficient to begin Phase B; and • The mission can likely be achieved within available resources with acceptable risk.
Preliminary Design Review (PDR)	The lifecycle review in which the decision authority evaluates the completeness/consistency of the planning, technical, cost, and schedule baselines developed during Formulation. This review also assesses compliance of the preliminary design with applicable requirements and determines if the project is sufficiently mature to begin Phase C.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Implementation

Implementation occurs when Agency management establishes baseline cost and schedule commitments for projects at KDP-C. The projects maintain the baseline commitment through the end of the mission. Projects are baselined for cost, schedule, and programmatic and technical parameters. Under Implementation, projects are able to execute approved plans development and operations.

Implementation Milestone	Explanation
KDP-C	The lifecycle gate at which the decision authority determines the readiness of a program or project to begin the first stage of development and transition to Phase C and authorizes the Implementation of the project. Phase C is first stage of development and means that: • The project's planning, technical, cost, and schedule baselines developed during formulation are complete and consistent; • The preliminary design complies with mission requirements; • The project is sufficiently mature to begin Phase C; and • The cost and schedule are adequate to enable mission success with acceptable risk.
Critical Design Review (CDR)	The lifecycle review in which the decision authority evaluates the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. This review also determines if the design is appropriately mature to continue with the final design and fabrication phase.
System Integration Review (SIR)	The lifecycle review in which the decision authority evaluates the readiness of the project and associated supporting infrastructure to begin system assembly, integration, and test. The lifecycle review also evaluates whether the remaining project development can be completed within available resources, and determine if the project is sufficiently mature to begin Phase D.
KDP-D	The lifecycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase C to Phase D. Phase D is a second phase in Implementation; the project continues in development and means that: • The project is still on plan; • The risk is commensurate with the project's payload classification; and • The project is ready for assembly, integration and test with acceptable risk within its Agency baseline commitment.
Launch Readiness Date (LRD)	The date at which the project and its ground, hardware, and software systems are ready for launch.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Other Common Terms for Mission Planning

Term	Definition
Decision Authority	The individual authorized by the Agency to make important decisions on programs and projects under their authority.
Formulation Authorization Document	The document that authorizes the formulation of a program whose goals will fulfill part of the Agency's Strategic Plan and Mission Directorate strategies. This document establishes the expectations and constraints for activity in the Formulation phase.
Key Decision Point (KDP)	The lifecycle gate at which the decision authority determines the readiness of a program or project to progress to the next phase of the life cycle. The KDP also establishes the content, cost, and schedule commitments for the ensuing phase(s).
Launch Manifest	A list that NASA publishes (the "NASA Flight Planning Board launch manifest") periodically, which includes the expected launch dates for NASA missions. The launch dates in the manifest are the desired launch dates approved by the NASA Flight Planning Board, and are not typically the same as the Agency Baseline Commitment schedule dates. A launch manifest is a dynamic schedule that is affected by real world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. Moreover, the launch dates are a mixture of "confirmed" range dates for missions launching within approximately six months, and contractual/planning dates for the missions beyond six months from launch. The NASA Flight Planning Board launch manifest date is typically earlier than the Agency Baseline Commitment schedule date to allow for the operationally driven delays to the launch schedule that may be outside of the project's control.
Operational Readiness Review	The lifecycle review in which the decision authority evaluates the readiness of the project, including its ground systems, personnel, procedures, and user documentation, to operate the flight system and associated ground system(s), in compliance with defined project requirements and constraints during the operations phase.
Mission Readiness Review or Flight Readiness Review (FRR)	The lifecycle review in which the decision authority evaluates the readiness of the project, ground systems, personnel and procedures for a safe and successful launch and flight/mission.
KDP-E	The lifecycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase D to Phase E. Phase E is a third phase in Implementation and means that the project and all supporting systems are ready for safe, successful launch and early operations with acceptable risk.
Decommissioning Review	The lifecycle review in which the decision authority evaluates the readiness of the project to conduct closeout activities. The review includes final delivery of all remaining project deliverables and safe decommissioning of space flight systems and other project assets.
KDP-F	The lifecycle gate at which the decision authority determines the readiness of the project's decommissioning. Passage through this gate means the project has met its program objectives and is ready for safe decommissioning of its assets and closeout of activities. Scientific data analysis may continue after this period.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

For further details, go to:

- NASA Procedural Requirement 7102.5E NASA Space Flight Program and Project Management Requirements: http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5E.
- NASA Procedural Requirement NPR 7123.1B - NASA Systems Engineering Processes and Requirements: http://nodis3.gsfc.nasa.gov/npg_img/N_PR_7123_001B_/N_PR_7123_001B_.pdf.
- NASA Launch Services Web site: http://www.nasa.gov/directorates/heo/launch_services/index.html.

NASA AND COVID-19

Since March 2020, NASA (along with the rest of the world) has adapted to the historic challenges of the COVID-19 pandemic. As COVID-19 cases surged across the country, most NASA activities pivoted to telework operations, with minimal impact to products and services. NASA converted numerous workshops, peer-review panels, and other essential collaborative sessions with external scientific and technical stakeholders into virtual events, minimizing interruptions while maintaining high standards. For personnel who needed on-site access to NASA facilities to ensure safety of personnel, flight hardware, and critical mission operations, NASA prioritized safety by utilizing the best available science and public health safeguards. Similar procedures were implemented at NASA contractor facilities consistent with state and Federal mandates.

Throughout the pandemic, NASA and its partners have demonstrated remarkable innovation and adaptability. NASA has accomplished extraordinary things under extraordinary circumstances over the past fifteen months, including the first launches of the commercial crew program, the launch and successful landing of the Mars Perseverance mission (including the first flight of a helicopter and the first production of oxygen on another world), and the successful hot fire test of the SLS core stage.

In response to the pandemic, Congress passed the Coronavirus Aid, Relief, and Economic Security (CARES) Act (P.L. 116-136) in March 2020. As part of the CARES Act, NASA received $60 million to support continued Agency operations. This supplemental funding is being used to support activities related to contractor impact claims, operational information technology services, operational cleaning and supplies, personal protective equipment, operational surge support, and restarts within the Safety, Security, and Mission Services (SSMS) account. CARES Act supplemental funding is not intended, planned, or used to support programmatic impacts.

Although the CARES Act support provided important funding for certain mission support activities during COVID-19, the most significant cost and schedule impacts from the pandemic in the long term will likely be to the Agency's projects and missions. Specifically, the COVID-19 pandemic created unprecedented pressure on most of NASA's projects and missions, including through: facility shutdowns, restarts, and reduced on-site access due to social distancing and cleaning protocols; carrying workforce and other resources in response to schedule delays; interruptions to test and construction efforts; disruptions in travel to both domestic and international partners locations; and pressures on the overall aerospace supply chain.

It is difficult to project a specific estimate of the total long term impact of COVID-19 on Agency programs and missions at this time. NASA has experienced increased pressure on cost reserves and schedule margins as projects utilize some of those resources to offset COVID-19-related impacts. These pandemic-related pressures, in turn, leave fewer reserves and margins to address other risks that are expected in development of NASA's complex missions. As a result, there is increased overall risk to the Agency's cost and schedule commitments for the foreseeable future.

While the NASA Office of the Inspector General noted that the total Agency impact due to COVID-19 could be nearly $3 billion[1], that estimate did not take into account flexibilities that projects and the Agency are exercising to offset these costs, including use of project and Headquarters-held cost and schedule margin. A final accounting of the full impact of the COVID-19 pandemic on Agency activities will not be available until well after the Agency and its contractors have resumed normal operations.

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[1] *COVID-19 Impacts on NASA's Major Programs and Projects, IG-20-016, March 31, 2021*

DEEP SPACE EXPLORATION SYSTEMS

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Exploration Systems Development	4,512.8	4,544.6	**4,483.7**	4,384.0	4,219.0	3,888.0	3,867.0
Exploration Research & Development	1,447.0	1,972.8	**2,396.7**	2,630.1	3,044.7	3,626.9	3,905.8
Total Budget	**5,959.8**	**6,517.4**	**6,880.4**	**7,014.1**	**7,263.7**	**7,514.9**	**7,772.8**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

DEEP SPACE EXPLORATION SYSTEMS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Exploration Systems Development	4,512.8	4,544.6	**4,483.7**	4,384.0	4,219.0	3,888.0	3,867.0
Exploration Research & Development	1,447.0	1,972.8	**2,396.7**	2,630.1	3,044.7	3,626.9	3,905.8
Total Budget	**5,959.8**	**6,517.4**	**6,880.4**	**7,014.1**	**7,263.7**	**7,514.9**	**7,772.8**
Change from FY 2021			**363.0**				
Percentage change from FY 2021			**5.6%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The FY 2022 budget request includes $6,880.4 million for Deep Space Exploration Systems to pursue the Artemis Program, which is focused on returning humans to the Moon and enabling eventual missions to Mars and beyond. In a series of Artemis missions, NASA will land the first woman and first person of color on the Moon and will explore more of the lunar surface than ever before. In collaboration with our commercial and international partners, NASA will create the capabilities necessary to sustainably explore the Moon. The operational knowledge, technological advances, and scientific discoveries we gain from exploring the Moon in collaboration with international and commercial partners will position us to take the next giant leap - sending astronauts to Mars.

Deep Space Exploration Systems will leverage the Science Mission Directorate's development of smaller landers for capabilities such as navigation and precision landing as well as for the data about the lunar surface that they will provide. It will also leverage investments through the Space Technology Mission Directorate's lunar exploration activities.

The Deep Space Exploration Systems account consists of two themes, Exploration Systems Development (ESD) and Exploration Research and Development (ERD), which provide for the development of systems and capabilities needed for human exploration of space.

ESD's mission is to develop a launch vehicle, spacecraft, and ground support systems necessary to send crew beyond low-Earth orbit (LEO). ESD consists of three programs: Orion, Space Launch System (SLS), and Exploration Ground Systems (EGS). The Orion spacecraft will carry humans beyond LEO, provide emergency abort capability, sustain the crew during space travel, and provide safe re-entry from deep space. The SLS will safely launch crew in Orion to an orbit around the Moon. EGS develops and operates the systems and facilities needed to process and launch rockets and spacecraft during assembly, transport, and launch. This space transportation system supports NASA's strategy for exploration in cislunar space, and it will have its first un-crewed test flight (Artemis I) and crewed test flight (Artemis II) in the near future; launch dates are currently under review.

ERD is comprised of five programs: Advanced Cislunar and Surface Capabilities (ACSC), Advanced Exploration Systems (AES), Gateway, the Human Landing System (HLS) and the Human Research Program (HRP). The overarching goal of ERD is to develop human exploration technologies, capabilities, and missions that enable the return of humans to the Moon for long-term exploration and utilization and help prepare for eventual human missions to Mars. ERD programs pursue these goals using a combination of unique in-house activities and public-private partnerships.

ACSC funding focuses on utilizing innovative procurement approaches to develop strategies and systems for future missions to the lunar surface and beyond.

HLS funding focuses on establishing commercial partnerships to develop and deploy the integrated systems that will transport humans to and from the surface of the Moon and stay sustainably.

Gateway funding focuses on developing a small platform that will orbit the Moon and enable lunar landers and surface activities, to include a Power and Propulsion Element and Habitation and Logistics Outpost (HALO).

AES funding focuses on reducing operational risk, validating operational concepts, leveraging partner capabilities, and lowering lifecycle costs of technologies such as deep space habitation and environmental control and life support systems that enable lunar and deep space missions.

HRP funding focuses on discovering the best methods and technologies to support safe, productive human space travel. From the challenges of managing the environmental risks posed by radiation and lunar dust, to providing appetizing food and optimal nutrition, HRP scientists and engineers work to predict, assess, and solve the problems that humans encounter in space. Artemis missions will dramatically increase the scope of the challenges and demands that face NASA's astronauts. HRP is working to improve astronauts' ability to collect data, solve problems, respond to emergencies, and remain healthy during and after extended space travel.

For more information, go to: http://www.nasa.gov/directorates/heo/home/index.html

EXPLORATION SYSTEMS DEVELOPMENT

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Orion Program	1,406.7	1,403.7	**1,406.7**	1,340.0	1,239.0	1,084.0	1,084.0
Crew Vehicle Development	1,396.2	1,387.8	**1,388.3**	1,321.4	1,230.0	1,065.0	1,065.0
Orion Program Integration and Support	10.5	15.9	**18.4**	18.6	9.0	19.0	19.0
Space Launch System	2,528.1	2,560.9	**2,487.0**	2,486.0	2,466.0	2,290.0	2,270.0
Launch Vehicle Development	2,468.0	2,494.3	**2,413.6**	2,413.3	2,408.9	2,202.9	2,182.9
SLS Program Integration and Support	60.1	66.6	**73.4**	72.7	57.1	87.1	87.1
Exploration Ground Systems	578.0	580.0	**590.0**	558.0	514.0	514.0	513.0
Exploration Ground Systems Development	558.7	569.2	**583.7**	552.4	514.0	494.0	493.0
EGS Program Integration and Support	19.3	10.8	**6.3**	5.6	0.0	20.0	20.0
Construction & Envrmtl Compl Restoration	109.9	60.3	**89.3**	0.0	0.0	0.0	0.0
Exploration CoF	109.9	60.3	**89.3**	0.0	0.0	0.0	0.0
Total Budget	**4,622.7**	**4,604.9**	**4,573.0**	**4,384.0**	**4,219.0**	**3,888.0**	**3,867.0**
Change from FY 2021			**-31.9**				
Percentage change from FY 2021			**-0.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The core stage for the first flight of NASA's Space Launch System rocket is seen in the B-2 Test Stand during a second hot fire test, Thursday, March 18, 2021, at NASA's Stennis Space Center near Bay St. Louis, Mississippi. The four RS-25 engines fired for the full-duration of eight minutes during the test and generated 1.6 million pounds of thrust. The hot fire test is the final stage of the Green Run test series, a comprehensive assessment of the Space Launch System's core stage prior to launching the Artemis I mission.

NASA's Exploration Systems Development (ESD) programs are working together to build the space transportation system made up of the Orion crew vehicle, the Space Launch System (SLS) rocket, and the Exploration Ground Systems (EGS). This system will enable the Agency's Artemis missions, extending human presence into the solar system by transporting crews to the Gateway or to the Moon's surface in the Human Landing System for long-term exploration and in preparation for future missions to Mars. These program objectives support Agency Strategic Goal 2, which seeks to extend human presence deeper into space and to the Moon for sustainable, long-term exploration and utilization.

NASA's Orion spacecraft is designed to support human exploration missions to deep space, with a crew of four, with habitation and life support onboard for missions up to 21 days. Building upon more than 50 years of spaceflight research and development, Orion's versatile design will not only carry crew to space, but also provide emergency abort capability, sustain crew during space travel, and provide safe reentry at deep space return velocities. The Orion systems are designed to operate in a contingency mode to augment life support systems in other space transport systems.

The SLS rocket is a heavy-lift launch vehicle that will launch astronauts in the Orion spacecraft on missions to cislunar space so they can return to the surface of the Moon and visit other destinations. The Block 1 configuration, which is the configuration for Artemis I, stands at 322 feet and features a lift capability of 95 metric tons to low-Earth orbit (LEO), with 8.8 million pounds of maximum thrust. The evolution of the architecture, currently planned for first use on Artemis IV, will include an Exploration Upper Stage (EUS), associated Universal Stage Adapter (USA) and Payload Adapter (PLA) which provides space for co-manifested payloads (CPLs). This Block 1B configuration will be capable of delivering at least 37.3 metric tons of net payloads to Trans-Lunar Injection (TLI) on crewed missions. The 37.3 metric ton total includes Orion, which weighs 27 metric tons.

The objective of EGS is to enable Kennedy Space Center (KSC) to process and launch Orion and SLS in support of the Artemis missions. To achieve this transformation, NASA is developing new ground systems while refurbishing and upgrading infrastructure and facilities to meet tomorrow's demands.

The Artemis Program is the next step in human exploration of our solar system. It is a part of NASA’s Moon to Mars exploration approach, in which we will pursue our next giant leap, sustained human exploration of the Moon to develop the skills, systems, and operational capabilities to enable a human mission to Mars. As NASA works towards a sustainable Moon to Mars campaign, it is essential the Agency and its contractors reduce production and operations costs for ESD systems and NASA is examining options to achieve this goal. Through a reduction in ESD program costs, the Agency can focus on the many other capabilities needed for future deep space systems and successful exploration missions.

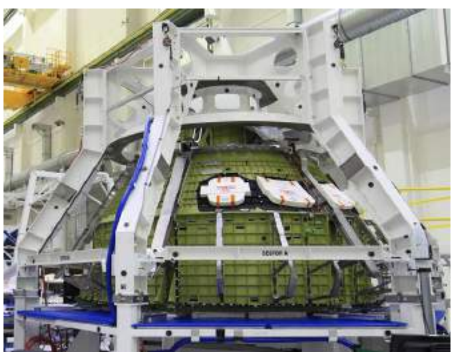
ORION PROGRAM

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Crew Vehicle Development	1,396.2	1,387.8	**1,388.3**	1,321.4	1,230.0	1,065.0	1,065.0
Orion Program Integration and Support	10.5	15.9	**18.4**	18.6	9.0	19.0	19.0
Total Budget	**1,406.7**	**1,403.7**	**1,406.7**	**1,340.0**	**1,239.0**	**1,084.0**	**1,084.0**
Change from FY 2021			**3.0**				
Percentage change from FY 2021			**0.2%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.


Artemis II crew module's capsule being moved from KSC's Operations and Closeout (O&C) clean room to external work stand for assembling the environmental control and life support and propulsion system.

The Orion spacecraft will play an integral role in the Artemis Program, serving as an exploration vehicle that will carry crew to space, sustain crew during space travel, provide emergency abort capability, and provide safe re-entry from deep space return velocities for Artemis This capsule-shaped vehicle has a familiar look, but it incorporates numerous technology advancements and innovations. The spacecraft will enable extended duration missions beyond Earth's orbit and to the Moon.

Orion's design, development, testing (including the flight tests), and evaluation (DDT&E) will have the spacecraft ready to carry crew on Artemis II with a current launch date of no earlier than (NET) September 2023 and ready to support subsequent Artemis missions. The budget request supports launches at the earliest technically feasible date.

For more information, go to: http://www.nasa.gov/orion

Program Elements

ORION PROGRAM INTEGRATION AND SUPPORT

Orion Program Integration and Support activities manage the program interfaces between the Space Launch System (SLS) and the Exploration Ground System (EGS). This effort is critical to ensuring Orion's performance meets technical and safety specifications, and it supports programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the Orion integration

ORION PROGRAM

effort is vital to managing interfaces with other Human Exploration and Operations Mission Directorate (HEOMD) activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across the programs is aimed at mitigating the impacts of potential design overlaps, schedule disconnects and delays, and cost overruns.

CREW VEHICLE DEVELOPMENT

Orion will be capable of transporting humans to orbit around the Moon, sustaining them for longer durations than ever before, providing emergency abort capability, and returning them safely to Earth. See the Crew Vehicle Development section starting on the next page for additional details.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	4,502.4	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	4,502.4
Development/Implementation	5,498.4	977.8	702.2	**335.2**	135.3	3.4	0.0	0.0	0.0	7,652.3
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2021 MPAR LCC Estimate	**10,000.8**	**977.8**	**702.2**	**335.2**	**135.3**	**3.4**	**0.0**	**0.0**	**0.0**	**12,154.7**
Total Budget	**10,209.0**	**1,396.2**	**1,387.8**	**1,388.3**	**1,321.4**	**1,230.0**	**1,065.0**	**1,065.0**	**0.0**	**19,062.7**
Change from FY 2021				**0.5**						
Percentage change from FY 2021				**0.0%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of Artemis II and excludes CoF; LCC only includes Artemis II content, including CoF.

The total budget prior line represents FY 2011 pre-formulation and FY 2012 - FY 2019 budgets, excluding CoF and additional expenditures from 2005-2011 under the Constellation program.

Artemis I was transferred from the O&C Building to the Multi-Payload Processing Facility (MPPF) where it will be fueled for flight.

PROJECT PURPOSE

Orion will be capable of transporting humans to orbit around the Moon, sustaining them for longer durations than ever before, providing emergency abort capability, and returning them safely to Earth. Drawing from more than 50 years of human spaceflight research and development and stimulating new and innovative manufacturing and production capabilities, Orion's design will meet the evolving needs of our Nation's space program.

For more information, go to http://www.nasa.gov/orion

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2022

The FY 2022 President's Budget proposes funding to support the Nation's next lunar landing. The current launch readiness date (LRD) for Artemis I is no earlier than (NET) November 2021 and the current LRD for Artemis II is NET September 2023.

Due to the latest of Space Launch System (SLS) core stage delivery to Kennedy Space Center (KSC), Artemis I and II launch dates are going through an additional review. NASA Leadership will evaluate the results of the assessment during Orion's Systems Integration Review (SIR) in May 2021 leading to Key Decision Point D (KDP-D) review in July 2021 before updating the Artemis I and II LRD.

PROJECT PARAMETERS

Orion is the vehicle that will fly astronauts to and from the Moon. Orion will be able to carry a crew of four astronauts to cislunar space and beyond, as well as provide habitation and life support for up to 21 days. The spacecraft's four elements are the Crew Module (CM), the Crew Module Adaptor (CMA), the European Service Module (ESM), and the Launch Abort System (LAS). The European Space Agency (ESA) is designing and developing the ESM, which provides in-space power, propulsion, and other life support systems. The CM, which is the pressure vessel, will mount to the CMA and ESM to become the Crew and Service Module (CSM). Atop the CSM will sit the LAS, which will activate within milliseconds to propel the CM to safety away from the launch vehicle in the event of an emergency during launch or ascent to orbit. The abort system also provides a protective shell that shields the CM from dangerous atmospheric loads and heating during ascent. Once Orion is out of the atmosphere and safely on its way to orbit, the spacecraft will jettison the LAS.

The first mission is Artemis I, an uncrewed flight test that will demonstrate key Orion spacecraft capabilities. The next mission, Artemis II, is a crewed test flight, with a current mission profile of transporting up to four crewmembers on a free return trajectory around the Moon. For a lunar landing mission, the Orion spacecraft will rendezvous and dock with Gateway or the Human Landing System (HLS) spacecraft. The crew and necessary equipment will transfer from the Orion spacecraft, potentially via Gateway, into the HLS, which will then undock, descend, and land on the lunar surface. At the conclusion of the lunar surface operations, the HLS will lift off from the lunar surface. The HLS will re-dock with Gateway or the Orion spacecraft where the crew will transfer back to Orion for their return to Earth. Although the module has a familiar visual shape, its interior and exterior capabilities far exceed any geometrically-similar predecessors. The state-of-the-art crew systems will provide a safe environment for astronauts to live and work for long durations far from Earth. Orion's advanced heat shield will protect the crew during a high-speed reentry into Earth's atmosphere, heating that will exceed that experienced by any human spacecraft in more than four decades. For lunar missions beyond the initial lunar mission, Orion will dock with the Gateway in a Near-Rectilinear Halo Orbit around the Moon, giving astronauts access to more areas of the lunar surface and better communication capabilities than the Apollo programs.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2020

The Orion program completed assembly of the CMA-1 primary structure in October 2019 at the Operations and Checkout (O&C) Facility at KSC. In November 2019, NASA shipped the CMA-1 to Glenn Research Center-Plum Brook Station (GRC-PBS) for in-space environmental testing. At GRC-PBS, the spacecraft underwent structural analysis and thermal vacuum, vibration, acoustic, and electromagnetic interference testing to confirm all components and systems work properly under in-space conditions, a crucial step towards launch readiness. Orion successfully completed this environmental testing in March 2020. CMA-1 then returned to KSC where the Orion program completed additional tasks include verifying side hatch seal integrity, developmental flight instrumentation testing, final leak checks, and installing the Spacecraft Adapter and Solar Array Wings.

NASA successfully completed the final qualification tests on the Artemis I LAS, conducted the System Acceptance Review (SAR), and accepted delivery of the flight hardware on November 2019.

The Structural Test Article (STA) test campaign successfully completed all Artemis I tests in June 2020. The STA test campaign used a full-scale replica of the Orion spacecraft, ensuring the vehicle would be able to withstand pressure and loads during launch, flight, and landing. In continuing to build-up to the Artemis II mission, ESA delivered the Orbital Maneuvering System (OMS) engine in March 2020. The OMS engine is the Orion spacecraft's main engine that is used for major maneuvers by the spacecraft, such as entering and departing lunar orbit and abort scenarios.

Orion completed a series of planned engineering and operations reviews in preparation for Artemis I. The program conducted the CSM-1 Design Certification Review (DCR) and SAR in August 2020. The DCR certified the spacecraft's hardware and software meet specified design-to-performance, and the design is ready for operational use. The SAR established the as-built baseline for the Artemis I Orion spacecraft, ensures readiness to integrate with SLS, and confirmed the Orion vehicle was ready to be transferred from Lockheed Martin to NASA. The Artemis I Flight Operations Review (FOR) was held in September 2020. The FOR reviewed the flight plan, mission planning ground rules and constraints, flight rules, and procedures to prepare for the mission.

Orion also completed several critical software development and testing milestones. In July 2020, Lockheed Martin delivered the 28E patch 8 Artemis I Orion flight software to NASA. Over the course of FY 2020, the Integrated Test Lab (ITL) completed the Artemis I software verification campaign and neared completion of software validation. The ITL simulates the flight environment to test flight software function, including ascent abort, safe mode, fault detection, isolation and recovery, optical navigation, maneuver plan management, and propulsion failure detection. These tests are essential for identifying software problems and validating proper functionality and performance of the spacecraft.

For the first crewed mission, KSC received the Artemis II LAS jettison, abort and attitude control motors on April 2020 and immediately started hardware integration. KSC successfully mated the jettison and abort motors in the same month. Orion also made significant progress with CM assembly, installation, and testing at KSC's O&C facility. In the fourth quarter of FY 2020, the program completed bonding the Avcoat blocks that form the Thermal Protection System's heatshield which will protect the crew during a high-speed reentry into Earth's atmosphere.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

For Artemis III, the Orion program conducted the Preliminary Mission Integration Review (MIR) in March 2020 to assess mission-specific requirements and objectives and to ensure designed system capabilities meet mission requirements.

Following MIR, the Artemis III docking system Preliminary Design Review (PDR) was conducted in April 2020. The purpose of this review was to ensure the system's architecture and operational concept are technically sound, requirements are complete and have been validated, and the system can be expected to meet functional and performance requirements.

On May 26, 2020, ESA signed a contract with Airbus to build ESM-3 for the Artemis III mission.

The program initiated long lead material purchases for Artemis III, IV, and V in the first quarter of FY 2020, enabling the program to meet an annual flight rate to support lunar exploration, while establishing a sustainable production and operations cadence. Lockheed Martin procured long-lead parts and began fabricating Artemis III structural components in March 2020.

WORK IN PROGRESS IN FY 2021

The CM STA arrived to Langley Research Center (LaRC) in Hampton, VA in November 2020 for a series of Water Impact Tests (WIT) to assess the impact to the spacecraft's primary and secondary structures under water landing conditions. The WIT campaign includes three vertical drops and one swing test. The vertical drop tests were completed on March 23, April 6, and May 6. The final test, a swing test is targeted to be completed in late May 2021. Data from the test campaign will be used as final model correlation prior to the Artemis II loads, structural verification, and flight test.

The ESM-1 Acceptance Review was completed in December 2020. This milestone event marked the transfer of ESM-1 ownership from ESA to NASA.

Lockheed Martin completed the final installations on the Artemis I CSM and handed the vehicle over to Exploration Ground Systems (EGS) in January 2021 for ground operations. The Orion spacecraft will be mated to the SLS in the Vehicle Assembly Building (VAB) at KSC and will launch from KSC's Launch Complex 39B. The mission will take the spacecraft beyond the Moon to demonstrate its performance capability during launch, transit to lunar orbit, return to Earth, re-entry, landing, and recovery.

Orion will complete delivery of Artemis II software build 203 in Spring 2021. This software build is for the entry mission and supports CSM-2 initial power-on and ITL testing. The ITL-203, integrated test campaign is planned for June through August 2021. Orion will deliver an early release of software build 204 for the orbit mission in September 2021. A formal release of software build 204 and the corresponding integrated testing in the ITL, ITL-204, will take place in FY 2022

Orion continues the Artemis II component fabrication, build-up, and testing of CM-2 Environmental Control and Life Support System (ECLSS) at KSC's O&C. This includes performing tests of the ECLSS, propulsion proof pressure and leak tests, tank installations, closeout welding, and additional leak checks and harness testing. Orion will receive all components of the core avionics in spring 2021.

Orion will complete Artemis II CMA wire harness and subsystem installations in September 2021, followed by functional testing. When the functional tests are completed in spring 2021, the CMA will be

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

ready to mate to ESM-2, which is scheduled to arrive at KSC in August 2021, to become Service Module (SM)-2. After mating, the SM-2 will undergo clean room operations for ECLSS welding, followed by proof pressure and leak tests in preparation for integrating with CM-2.

For the Artemis III mission, Orion received pressure vessel parts at the Michoud Assembly Facility (MAF), New Orleans in December 2020 in preparation for weld operations. The program started the Artemis III docking system critical design review (CDR) on March 30, 2021. The review will complete the vehicle design and determine readiness for full-scale fabrication, assembly, integration, and test.

For Artemis IV, Orion will start CM-4 pressure vessel weld operations.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

After the Artemis I mission, the Orion program will conduct a post flight analysis to assess spacecraft performance against flight test objectives. The program will recover certain non-core avionics components from the returned spacecraft for reuse in the Artemis II mission. The non-core avionics will be removed, refurbished, and delivered to KSC in spring of 2022 for installation into the CM-2. For future missions, re-use of components is planned to reduce assembly costs of subsequent Orion builds and is a key feature of the recently awarded Orion Production Operation Contract (OPOC) that is being used to deliver Orion spacecraft for the Artemis III through Artemis V missions.

The CM-2 will undergo functional tests, followed by mating to SM-2 to become CSM-2. In addition, the docking camera and translational hand controllers will be delivered and installed into CSM-2 in September 2022. These will be used by the crew in support of the Rendezvous and Proximity Operations Demonstration (RPOD) activities during the Artemis II mission. The integrated CSM will undergo final assembly, installation, and testing.

Orion will deliver formal software build 204 in fall 2021. The integrated testing of this software build, ITL-204, will be performed in the fall and winter. The program also will deliver formal software build 205, which supports ascent/abort scenarios in August 2022. A significant amount of software is used on Orion for commanding functions, monitoring and transmitting data, performing fault detection and response, and other tasks. It is critical to safety and mission success.

Lockheed Martin will complete assembly, integration, and processing of the Artemis II LAS and deliver the system to NASA in September 2022.

Orion will conduct integrated testing of ECLSS and the Orion Crew Survival System Suit (OCSS) in the Orion Life Support Integration Facility (OLIF) at the NASA Johnson Space Center (JSC) to further validate the performance of these systems in preparation for the crewed Artemis II mission.

In October 2021, the ESM-3 auxiliary engines will be shipped to the ESA prime contractor's facility in Bremen, Germany, which will then be integrated into ESM-3.

The Artemis III pressure vessel and CMA inner wall will be delivered in October 2021, followed by heatshield carrier, which will be delivered in January 2022 to KSC for primary structure build-up and assembly of the CM and CMA. The pressure vessel is Orion's primary structure that holds the pressurized atmosphere astronauts will breathe and work in while in the vacuum of deep space.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Throughout 2022, several key functional components of the RPOD system will be delivered, as well as the initial release of RPOD software, in time to support the planned Initial Power On (IPO) testing of the CM in the O&C building for Artemis III. A key high fidelity, Six-Degree-of-Freedom Test System (SDTS) of the RPOD system complete with docking cameras and sensors will be conducted at Lockheed Martin in Denver, CO. These tests will demonstrate the safety critical operation of the RPOD hardware and software in the dynamic proximity operations environment.

Work is continuing for Artemis IV and beyond to sustain human presence on the Moon. CM-4 pressure vessel parts will be delivered to Michoud Assembly Facility (MAF) for welding. The program will conduct the Preliminary MIR for Artemis V and will initiate contract authorization for Artemis VI-VIII.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
System Design Review (SDR)		Aug 2007
Preliminary Design Review (PDR)		Aug 2009
Key Decision Point-A (KDP-A)	Feb 2012	Feb 2012
Resynchronization Review		Jul 2012
KDP-B	Q1 FY 2013	Jan 2013
Delta PDR	Q4 FY 2013	Aug 2014
Exploration Flight Test-1 (EFT-1) Launch	Dec 2014	Dec 2014
KDP-C, Project Confirmation	FY 2015	Sep 2015
Critical Design Review (CDR)	Oct 2015	Oct 2015
Ascent Abort-2 (AA-2) Flight Test	FY 2020	Jul 2019
Artemis I Launch Readiness*	FY 2018	NET Nov 2021
Artemis II Launch Readiness*	Apr 2023	NET Sep 2023

** The program is currently reviewing cost and schedule impacts based on the change to the Artemis 1 and II launch readiness date.*

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2015	6,768.4	70%	2021	7,656.0	+13.1%	Artemis II	Apr 2023	NET Sept 2023	5

NASA continues to review past reporting, and estimates do not necessarily accurately incorporate actual expenditures to date. Additionally, cost and confidence levels do not reflect the cost impacts of currently anticipated schedule delays. The estimates are expected to increase as NASA assesses the impacts of further delays and updates reporting on expenditures. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)*	Change from Base Year Estimate ($M)
TOTAL:	**6,768.4**	**7,656.0**	**+887.6**
Mission Operations	281.6	269.0	-12.6
Program Management	671.5	848.3	+176.8
Safety and Mission Assurance	191.4	174.5	-16.9
Spacecraft and Payload	3,205.1	4,987.3	+1,782.2
Systems Engineering and Integration	539.3	675.3	+136
Test and Verification	460.6	578.6	+118
Other Direct Project Costs	1,418.9	123.0	-1,295.9

Program unallocated future expenses (UFE) was held in "Other" category in the base year estimate and realigned to other elements as the program matured.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

** The Current Year Development Cost Estimate and Milestone data do not accurately reflect current planning and are based on prior planning. NASA completed a successful Green Run hot fire test and delivered the core state to*

KSC. NASA Leadership is reviewing the schedule for potential updates to the Artemis I and II launch planning dates. The Agency has also provided a Section 103 notification that the Orion program will likely exceed its baseline readiness date due to a change in the Artemis II mission schedule. The cost of the program will likely also exceed the estimated baseline by 15 percent due to the change in launch readiness date, the impact of COVID-19 and the addition of Rendezvous, Proximity Operations and Docking capability to the spacecraft beginning with the Artemis III. Accordingly, the Orion program will rebaseline its Agency Baseline Commitment to adequately and transparently capture the costs of this scope.

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Crew Module	The crew module provides a safe habitat for the crew, as well as storage for consumables and research instruments, and it serves as the docking port for crew transfers.	Provider: JSC Lead Center: JSC Performing Center(s): Ames Research Center (ARC), GRC, JSC, and LaRC Cost Share Partner(s): N/A	N/A
Service Module	The service module, the powerhouse that fuels and propels the Orion spacecraft, will support the Crew Module from launch through separation before reentry.	Provider: ESA Lead Center: GRC Performing Center(s): ARC, GRC, JSC, and LaRC Cost Share Partner(s): ESA	N/A
Launch Abort System	The launch abort system maneuvers the Crew Module to safety in the event of an emergency during launch or climb to orbit.	Provider: JSC Lead Center: LaRC Performing Center(s): JSC, LaRC, and Marshall Space Flight Center (MSFC) Cost Share Partner(s): N/A	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The ESA-provided Orion ESM-2 encounters additional development issues and is further delayed in its delivery, Then: The Artemis II CSM handover date to EGS will be impacted.	The ESA Prime contractor is aggressively managing its suppliers' component delivery schedule to minimize risk for ESM-2 delivery to KSC. The contractor is also working with its major subcontractor and suppliers to implement incentives to accelerate delivery of critical path components.

Acquisition Strategy

NASA is using a contract to Lockheed Martin Corporation for Orion's design, development, test, and evaluation. The contract was awarded in 2006 and reaffirmed in 2011 as part of reformulating the Orion Crew Exploration Vehicle as the Orion program. Orion adjusted this contract to meet NASA and the Human Exploration and Operations Mission Directorate (HEOMD) requirements to include the current flight test plan and the Artemis II flight readiness date. Orion Program released a Request for Proposal (RFP) to Lockheed Martin for the production and operations effort in January 2018. OPOC was awarded as a sole-source contract with Lockheed Martin in September 2019 and will begin with Artemis III. It is an indefinite-delivery-indefinite-quantity contract that includes a commitment to order a minimum of six and a maximum of 12 Orion spacecraft over the next 10 years. The first six spacecraft (Artemis III through VIII) will be acquired by cost-plus-incentive-fee orders. NASA will negotiate firm-fixed-price orders for future missions to take advantage of the anticipated spacecraft production cost decreases.

NASA signed an implementing arrangement with ESA to provide service modules for the Orion spacecraft for Artemis I and II. Incorporating the partnership with ESA also required a contract modification with Lockheed Martin to integrate the ESA-provided service module with the Lockheed Martin portion of the spacecraft. Lockheed Martin has integrated ESM-1 with CM-1 and performed environmental testing of the integrated spacecraft. Lockheed Martin handed the vehicle over to Exploration Ground Systems (EGS) in January 2021 for ground operations. ESA is on track to deliver the ESM-2 to NASA in August 2021.On May 26, 2020 ESA signed a contract with Airbus to build ESM-3 for Artemis III. This should result in Annex 3 of the Implementing Arrangement with ESA in FY 2021.

Orion published a Request for Proposals (RFP) for the Orion Maneuvering Engine (OME) engines in March 2020, which will replace the Orbital Maneuvering System Engine (OMS-E) starting with Artemis VII. The contract award is planned for summer 2021. Orion has enough OMS engines remaining from the Space Shuttle Program to fly on the ESM through Artemis VI.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Orion Design and Development, Test and Evaluation (DDT&E)	Lockheed Martin	Littleton, CO
Orion Production and Operations Contract (OPOC)	Lockheed Martin	Littleton, CO

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Readiness Review (SRR)	Standing Review Board (SRB)	Mar 2007	To evaluate the program's functional and performance requirements, ensuring proper formulation and correlation with Agency and HEOMD's strategic objectives; assess the credibility of the program's estimated budget and schedule.	Program cleared to proceed to next phase.	N/A
System Design Review (SDR)	SRB	Aug 2007	To evaluate the proposed program requirements and architecture; allocation of requirements to initial projects; assess the adequacy of project pre-formulation efforts; determine if maturity of the program's definition and plans are enough to begin implementation.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Preliminary Design Review (PDR)	SRB	Sep 2009	To evaluate completeness and consistency of the program's preliminary design, including its projects meet all requirements with appropriate margins, acceptable risk, and within cost and schedule constraints; determine the program's readiness to proceed with the detailed design phase.	Program cleared to proceed to next phase.	N/A
Resynchronization Review	SRB	Jul 2012	The purpose of the review is to realign the program's preliminary design to the current Exploration Systems Development (ESD) requirements. NASA policies allow changes to a program's management agreement in response to internal and external events. An amendment to the decision memorandum is signed at the KDP-B review held before PDR if a significant divergence occurs.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Delta PDR	SRB	Aug 2014	To update the program's preliminary design; ensure completeness and consistency; determine the program's readiness to proceed with the detailed design phase.	Program cleared to proceed to next phase.	N/A
Critical Design Review (CDR)	SRB	Oct 2015	To evaluate the integrity of the program integrated design, including its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, and that it is planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for Exploration Mission (EM)-1.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
ESM CDR	SRB	Oct 2016	To evaluate the integrity of the program integrated design, including its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, and that it is planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for EM-1.	Program cleared to proceed to next phase.	N/A
Critical Integration Review (CIR) / System Integration Review (SIR)	N/A	Nov 2016	To evaluate the readiness of the program, including its projects and supporting infrastructure, to begin system Assembly, Integration, and Testing (AI&T) with acceptable risk, and within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Artemis II CDR	Independent Assessment (IA) / Independent Review Team (IRT)	Dec 2018	To evaluate the integrity of the program integrated design, including its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, and that it is planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for EM-2.	Program cleared to proceed to next phase.	N/A
ESD Artemis I Independent Schedule Assessment	Schedule Assessors from Office of the Chief Financial Officer (OCFO)	Jun 2019	Programmatic assessment and analysis of Artemis I schedules across all ESD programs with an emphasis on program performance and risks.	NASA leadership was briefed on Artemis I launch date options.	N/A
ESD Enterprise Integration Review (EIR)	Independent Review Team	Jan 2021	To confirm that flight and ground hardware elements, software, support equipment, facilities, and infrastructure are ready to support assembly, integration, test, and mission operations per the planned schedule for Artemis 1	The IRT confirmed the programs are sufficiently mature to proceed for integrated operations	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Integration Review (SIR)	IA/IRT	Jun 2021	To assess risks and plans for starting integration of all hardware into the structure to build up the flight vehicle.	N/A	N/A
KDP-D	IA/IRT	Jul 2021	To assess system assembly, integration, and test; verification/certification; prelaunch activities; launch; and checkout.	N/A	N/A
Operational Readiness Review/ Flight Readiness Review (ORR/FRR) for Artemis II	IA/IRT	NET Jul 2023	To evaluate the readiness of the project to operate the flight system and associated ground system; and support systems for safe and successful launch and flight/mission.	N/A	N/A
Launch Readiness Date/Initial Operations Capability (LRD/IOC) for Artemis II	IA/IRT	NET Sep 2023	To assess all capabilities of the vehicle to support the readiness to launch.	N/A	N/A

SPACE LAUNCH SYSTEM

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Launch Vehicle Development	2,468.0	2,494.3	**2,413.6**	2,413.3	2,408.9	2,202.9	2,182.9
SLS Program Integration and Support	60.1	66.6	**73.4**	72.7	57.1	87.1	87.1
Total Budget	**2,528.1**	**2,560.9**	**2,487.0**	**2,486.0**	**2,466.0**	**2,290.0**	**2,270.0**
Change from FY 2021			**-73.9**				
Percentage change from FY 2021			**-2.9%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The Agency's Space Launch System (SLS) solid motor center segments, shown here at KSC, are sporting the NASA "worm" logos as they prepare for EGS stacking operations.

NASA continues development of a heavy-lift launch vehicle to deliver crew and large volumes of cargo to deep space. The Space Launch System (SLS) program is preparing to carry humans farther into deep space than ever before.

SLS will play an integral role in the Artemis Program as a human-rated launch system intended to deliver Orion beyond low-Earth orbit. This launch system will be used in each of the Artemis missions. The Agency will continue to identify and implement affordability strategies to help SLS become a sustainable exploration capability.

The budget request supports launches at the earliest technically feasible date.

For more information, go to:

http://www.nasa.gov/exploration/systems/sls/index.html

Program Elements

SLS PROGRAM INTEGRATION AND SUPPORT

SLS program integration and support activities manage the Orion and Exploration Ground Systems (EGS) program interfaces. This effort is critical to ensuring that the performance of SLS systems meets technical and safety specifications and supports programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the SLS integration effort is vital to managing interfaces

SPACE LAUNCH SYSTEM

with other Human Exploration and Operations Mission Directorate (HEOMD) activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across the programs is aimed at mitigating the impacts of potential design overlaps, schedule disconnects and delays, and cost overruns.

LAUNCH VEHICLE DEVELOPMENT

The Launch Vehicle Development project will develop the Space Launch System (SLS) launch vehicle to enable deep space exploration. See the Launch Vehicle Development section beginning on the next page for additional details.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	2,673.9	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	2,673.9
Development/Implementation	7,980.0	511.1	462.5	**153.7**	0.0	0.0	0.0	0.0	0.0	9,107.3
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2021 MPAR LCC Estimate	**10,653.9**	**511.1**	**462.5**	**153.7**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**11,781.2**
Total Budget	**14,208.5**	**2,468.0**	**2,494.3**	**2,413.6**	**2,413.3**	**2,408.9**	**2,202.9**	**2,182.9**	**0.0**	**30,792.4**
Change from FY 2021				**-80.7**						
Percentage change from FY 2021				**-3.2%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

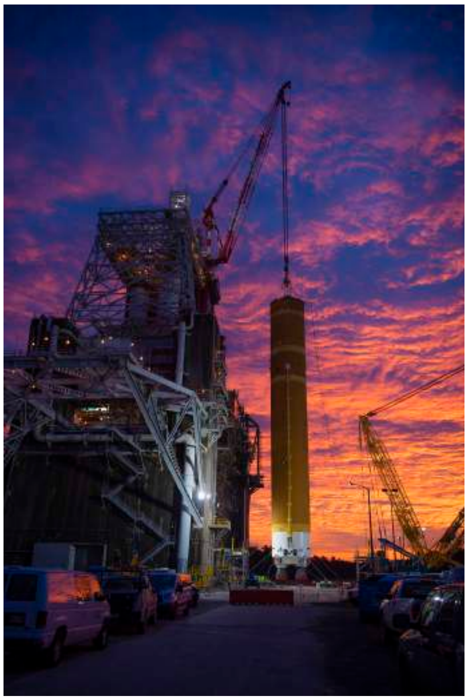
FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of Artemis I and excludes CoF; LCC only includes Artemis I content, including CoF.

With the arrival of the SLS Core Stage at KSC in April 2021, NASA is continuing to assess the schedule and work remaining for the Artemis I mission. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations



Engineers and technicians completed installation of the core stage into Stennis Space Center's (SSC) B-2 Test Stand. The core stage completed all test cases for Green Run.

PROJECT PURPOSE

In support of the Artemis mission, the Launch Vehicle Development project will enable deep space exploration with the Space Launch System (SLS) launch vehicle. For the first time since the Apollo program in 1972, American astronauts will explore space beyond low-Earth orbit (LEO) and return to the Moon, reinvigorating America's human exploration of the solar system.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The FY 2022 President's Budget proposes funding to support the Nation's Artemis Program. The current Artemis 1 Launch Readiness Date (LRD) is no earlier than (NET) November 2021. The current LRD for Artemis II is NET September 2023.

Due to the late SLS core stage delivery to Kennedy Space Center (KSC), Artemis I and II launch dates are going through an additional review. NASA leadership will review the results of these assessments before updating the Artemis I and II launch planning dates.

NASA is focusing on successful completion of Artemis I and II and preparation required for Artemis III. The first flights will feature the SLS Block 1 configuration, utilizing a human-rated Interim Cryogenic Propulsion Stage (ICPS). The Budget increases funding for continued development of the SLS Block 1B configuration with the Exploration Upper Stage (EUS). It remains an important future capability and its development will lead to a first flight on Artemis IV. This block evolution approach focuses NASA and its contractors on successfully delivering and flying the Block 1 SLS before folding in the additional Block 1B developments.

PROJECT PARAMETERS

SLS will launch Orion and the first woman and the first person of color to an orbit around the Moon. The primary components of the SLS include the Launch Vehicle Stage Adapter (LVSA), the ICPS, the core stage and avionics, two five-segment solid rocket boosters, and four RS-25 engines.

The SLS core stage is over 200 feet tall, and atop it sits the LVSA, which connects the ICPS and core stage. The LVSA provides structural support for launch and separation loads and protects propulsion system electrical components. The core stage contains five primary subcomponents, including the forward skirt, liquid oxygen tank, intertank, liquid hydrogen tank, and engine section. The engine section is the attach point for the four RS-25 engines, which combined with the boosters will produce maximum thrust

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

of 8.8 million pounds. On each side of the core stage, the five-segment solid rocket boosters will stand 17 stories tall and burn 5 tons of propellant per second. The boosters connect via the intertank and engine section attach points and will provide initial thrust for the first two minutes of flight.

The Launch Vehicle Development project leverages hardware designed for heritage programs, including adapted and refurbished Space Shuttle RS-25 main engines, five-segment Shuttle-derived solid rocket boosters, and an ICPS derived from the Delta cryogenic second stage. The program benefits from NASA's half-century of experience and knowledge of liquid oxygen and hydrogen heavy-lift vehicles, large solid rocket motors, and advances in technology and manufacturing practices, such as friction stir welding. The SLS rocket will generate a total thrust at liftoff greater than that of the Saturn V.

The launch vehicle development follows a block evolution framework where the core stage will serve as the common component in all future configurations. The Block 1 configuration, which is the configuration for Artemis I, stands at 322 feet and features a lift capability of 95 metric tons to LEO, with 8.8 million pounds of maximum thrust. With this performance, Block 1 will be able to send the 27 metric ton Orion spacecraft towards the Moon. This SLS configuration will allow Orion to demonstrate deep space technologies and hardware required for Earth-independent missions.

The planned evolution of the architecture to the Block 1B configuration will include an Exploration Upper Stage (EUS), associated Universal Stage Adapter (USA) and Payload Adapter (PLA) which provides space for Co-Manifested Payloads (CPLs). This Block 1B configuration will be capable of delivering at least 37.3 metric tons of net payloads (Orion and up to 10.3 metric tons of additional payloads) to Trans-Lunar Injection (TLI) on crewed missions

ACHIEVEMENTS IN FY 2020

Artemis I fully integrated core stage testing, also known as the Green Run, completed six of the eight key tests in FY 2020. The test series completed modal testing, vehicle power-on checks, main propulsion system and engine leak function checks, and other systems verifications. All ten Booster segments were delivered from Promontory, UT, and Exploration Ground Systems (EGS) began booster stacking in the Vertical Assembly Building (VAB). Stacking began in November 2020 and was completed as of March 2021. The LVSA assembly and check out for Artemis I has also completed at Kennedy Space Center (KSC) and is currently sitting ready for stacking in the VAB High Bay 4.

WORK IN PROGRESS IN FY 2021

The remaining two Artemis 1 Green Run tests were completed and allowed for delivery of the core stage to KSC on April 27, 2021. Specifically, the core stage was filled up with cryogenics for the first time during the wet dress rehearsal in December 2020. A first attempt at a hot-fire of the core stage's four RS-25 engines with a full load of hydrogen fuel and liquid oxygen in the B-2 test stand at SSC was conducted in January 2021 but was aborted earlier than planned. The full hot fire test was completed in March 2021. This final hot-fire test was critical to ensuring all core stage components are ready for vehicle certification and final integration at KSC. The core stage was the final piece of hardware to arrive at KSC for EGS spacecraft stacking and integration with Orion crew capsule and its components.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Prior to launch, SLS will complete the Design Certification Review (DCR) process that began in January 2021 and is scheduled to conclude in September 2021. This process will certify the vehicle in preparation for the Artemis I Flight Readiness Review.

With all Artemis I SLS hardware at KSC, SLS has handed off all launch vehicle components to EGS. EGS will integrate the launch system with the Orion crew vehicle in KSC's VAB using a co-developed design center concept. The SLS team will continue to provide subject matter expertise to support vehicle build-up and Integrated Test and Checkout.

The SLS program has shifted its focus to Artemis II and III since delivery of the first core stage to KSC. Manufacturing of Artemis II and future SLS components continues with fabrication of the forward skirt (completed in February 2021), intertank (completed in March 2021), liquid oxygen tank, liquid hydrogen tank, and engine section at Michoud Assembly Facility (MAF) in New Orleans. Teledyne Brown Engineering is assembling LVSA panel sections, and United Launch Alliance is working on the second ICPS in Decatur, AL. SLS is also continuing Artemis II hardware manufacturing with production of the Orion stage adaptor, engine delivery to MAF, and other activities. The program completed the first flight readiness analysis cycle for Artemis II and will complete the core stage forward join of the forward skirt, liquid oxygen tank, and intertank.

The program will start the flight readiness analysis cycle for Artemis II and will start core stage final assembly and integration for a FY 2022 delivery to EGS at KSC.

SLS continued design and development of Exploration Upper Stage (EUS) and held the EUS Critical Design Review (CDR) in December 2020. An Independent Review Team (IRT) is planning to review the EUS and associated activities during the summer of 2021. Component qualification testing will continue during the second half of FY 2021.

With Artemis I and II well on their way, Artemis III hardware builds will continue, including the Artemis III Orion stage adaptor, ICPS-3, and launch vehicle stage adaptor for this mission. Welding of the panels for the LVSA are continuing at AMRO Fabrication, Corp. Additionally, the program began the procurement process for long lead items for Artemis III and core stage IV and V. SLS will also initiate contract actions for the Artemis IV launch vehicle stage adaptor. RS-25 engines conducted the first hot-fire test of the restart engine 0528 at Stennis Space Center in February 2021 followed by additional tests later in the year.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

FY 2022 will be an exciting year for SLS, and the Agency, with the planned Artemis I launch NET November 2021. Artemis I will be the first uncrewed launch of the SLS rocket and the Orion spacecraft. Prior to launch, the program will complete the Preliminary Flight Readiness Review. The integrated test flight will provide critical data regarding ground systems, the launch vehicle, spacecraft performance, and human deep space exploration operations. The data from the test flight will allow the program to update the computer models for more accuracy toward future Artemis missions and planning.

SLS will also continue critical Artemis II core stage hardware manufacturing with production of the Orion stage adaptor, production of the engine section, completion of ICPS-2, RS-25 engine delivery to

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

MAF from Aerojet Rocketdyne, and others. SLS will begin the flight readiness analysis cycle for Artemis II and will start core stage final assembly and integration for a March 2022 delivery to EGS at KSC.

Artemis III hardware builds will continue, including the Artemis III Orion stage adaptor, ICPS-3, core stage components and launch vehicle stage adaptor for this mission. SLS plans to definitize the Stages Production Evolution Contract (SPEC) in early FY 2022. SLS will also initiate contract actions for the Artemis IV launch vehicle stage adaptor and SPEC once definitized to fully initiate Artemis IV hardware production.

SLS will also continue future development of evolved capabilities with production of the first Exploration Upper Stage (EUS) and continued Design Development Test and Evaluation (DDT&E) of the Booster Obsolescence and Life Extension (BOLE) project for advanced boosters. Manufacturing of the first EUS is planned to begin during the second quarter of FY 2022.

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2022 PB Request
Key Decision Point-A (KDP-A)	Nov 2011	Nov 2011
Formulation Authorization	May 2012	May 2012
System Requirements Review (SRR)	May 2012	May 2012
KDP-B Agency Project Management Council (APMC)	Jul 2012	Jul 2012
Preliminary Design Review (PDR) Board	Jun 2013	Jun 2013
KDP-C APMC	Jan 2014	Jan 2014
Critical Design Review (CDR) Board	Jul 2015	Jul 2015
Design Certification Review	Sep 2017	Sep 2021
Artemis I Launch Readiness*	Nov 2018	NET Nov 2021

**Currently under review*

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2015	7,021.4	70%	2021	9,108.3	+29.7%	Artemis I Launch Readiness	Nov 2018	NET Nov 2021	36

Note: NASA continues to review past reporting, and estimates do not necessarily accurately incorporate actual expenditures to date. Additionally, cost and confidence levels do not reflect the cost impacts of currently anticipated schedule delays. The estimates are expected to increase as NASA assesses the impacts of further delays and updates reporting on expenditures. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**7,021.4**	**9,108.3**	**+2,086.9**
Stages Element	3,138.6	5,202.7	+2,064.1
Liquid Engines Office*	1,198.3	490.4	-707.9
Booster Element	1,090.3	1,049.1	-41.2
Spacecraft Payload Integration and Evolution (SPIE)	447.1	635.5	+188.4
Other	1,147.1	1,730.6	+583.5

**The Agency Baseline Commitment previously included fixed and shared costs with the RS-25 production restart activity (in the Liquid Engines Office), which supports Artemis I and later missions. SLS removed those costs from the estimate and significantly lowered the Artemis I Liquid Engines Office and Current Year Development Cost Estimate.*

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Booster	Responsible for development, testing, production, and support for the five-segment solid rocket motor to be used on initial capability flights.	Provider: Marshall Space Flight Center (MSFC) Lead Center: MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A	N/A
Engines	Responsible for development and/or testing, production, and support for both core stage (RS-25) and upper stage liquid engines.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC; SSC Cost Share Partner(s): N/A	N/A
Block 1B Development Office	Responsible for development, testing, and production of the initial Exploration Upper stage as well as development for the Autonomous Flight Separation System (AFSS)	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC/MAF; SSC Cost Share Partner(s): N/A	New Element represents a reorganization of stages content
Stages	Responsible for development, testing, production, and support of hardware elements, including core and upper stages, liquid engine integration, and avionics integration.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC/MAF; SSC Cost Share Partner(s): N/A	N/A
Spacecraft Payloads and Integration	Responsible for development, testing, production, and support of hardware elements for integrating the Orion and payloads onto SLS, including the ICPS, Orion stage adapter, LVSA, universal stage adaptor, and payload fairings.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC, Langley Research Center (LaRC), Glenn Research Center (GRC), and KSC Cost Share Partner(s): N/A	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Project Risks

Risk Statement (Ranked in Sequential order)	Mitigation
If: Significant follow-on SLS Core Stage traveled work to EGS at KSC is required, Then: Final integration will experience additional delays.	Significant risk has been reduced with the completion of the Core Stage Hot Fire and delivery to KSC in April 2021. Traveled work remains, but mitigation efforts continue and are in-process at time of this release. These efforts include reducing post hot-fire engine refurbishments and thermal protection system repairs by reducing and eliminating inconsequential, low-risk tasks. Planned indoor engine refurbishment as traveled work to KSC will eliminate weather element exposure. VAB high-bay platforms allow for improved core stage component access versus SSC B-2 test stand access. SLS and EGS teams are assessing schedule impacts of traveled work to flow as much as work as possible into parallel, minimizing growth to the final integration critical path.
If: Core Stage verifications are delayed, Then: Schedule impacts and further delays realized.	Part of the critical path to Artemis I launch readiness for SLS is completing the Core Stage verifications in support of the SLS Block 1 design certification and completion of the integrated Artemis integrated verifications. The verification process is estimated to be completed four months after the successful completion of the Green Run Hot Fire Test.

Acquisition Strategy

MAJOR CONTRACTS/AWARDS

Procurement for SLS launch vehicle development meets the Agency's requirement to provide an evolvable vehicle within a schedule that supports various mission requirements. Procurements include use of existing assets to expedite development and further development of technologies and future competitions for advanced systems and key technology areas specific to SLS vehicle needs.

Element	Vendor	Location (of work performance)
Universal Stage Adaptor	Dynetics, Inc.	Huntsville, AL
Launch Vehicle Stage Adaptor	Teledyne Brown Engineering, Inc.	Huntsville, AL
Boosters	Northrop Grumman Innovation Systems	Magna, UT
Core Stage Engine	Aerojet Rocketdyne	Desoto Park, CA; SSC
ICPS	United Launch Alliance under contract to Boeing Aerospace	Huntsville, AL

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Element	Vendor	Location (of work performance)
Stages (Core and Upper)	Boeing Aerospace	New Orleans, LA
Upper Stage Engines	Aerojet Rocketdyne	West Palm Beach, FL

INDEPENDENT REVIEWS

NASA established a Standing Review Board (SRB) to perform the independent reviews of the Launch Vehicle Development project as required by NASA Procedural Requirements (NPR) 7120.5.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Preliminary Design Review (PDR)	Standing Review Board (SRB)	Aug 2013	To evaluate the completeness/ consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and determine if the project is sufficiently mature to begin Phase C.	The SRB evaluated the project and determined the project is sufficiently mature to begin Phase C and begin final design and fabrication.	N/A
Critical Design Review (CDR)	SRB	Jul 2015	To evaluate the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. To determine if the design is appropriately mature to continue with the final design and fabrication phase.	The SRB evaluated the project and determined the project is sufficiently mature to progress to major manufacturing, assembly, and integration.	N/A
Exploration Systems Development (ESD) Artemis I Independent Schedule Assessment	Schedule Assessors from Office of the Chief Financial Officer (OCFO)	Jun 2019	Programmatic assessment and analysis of Artemis I schedules and schedule risk across all ESD programs with an emphasis on program performance and risks.	NASA leadership was briefed on Artemis I launch date options.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
ESD Artemis I Re-baseline	Independent Review Team	Spring 2020	Programmatic assessment and analysis of Artemis I schedule and schedule risks of Artemis I launch date and JCL.	Established revised baseline and launch readiness date.	N/A
ESD Enterprise Integration Review (EIR)	Independent Review Team	Jan 2021	To confirm that flight and ground hardware elements, software, support equipment, facilities and infrastructure are ready to support assembly, integration, test and mission operations per the planned schedule for Artemis 1	The IRT confirmed the programs are sufficiently mature to proceed for integrated operations	N/A
Design Certification Review (DCR)	SLS Independent Review Team	Sep 2021	To certify the implemented design complies with applicable requirements and necessary verification activities are satisfactorily completed.	Certification of the SLS Block 1 design.	N/A
Operational Readiness Review/ Flight Readiness Review (ORR/FRR)	IA/IRT	NET Sep 2021	To evaluate the readiness of the project to operate the flight system and associated ground system; and support systems for safe and successful launch and flight/mission.	N/A	N/A
Launch Readiness Date/Initial Operations Capability (LRD/IOC)	IA/IRT	NET Nov 2021	To assess all capabilities of the vehicle to support the readiness to launch.	N/A	N/A

EXPLORATION GROUND SYSTEMS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**578.0**	**580.0**	**590.0**	**558.0**	**514.0**	**514.0**	**513.0**
Change from FY 2021			**10.0**				
Percentage change from FY 2021			**1.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

NASA's Exploration Ground Systems team has completed stacking the solid rocket boosters on Mobile Launcher-1 inside the Vehicle Assembly Building. The boosters will help power NASA's Space Launch System rocket for Artemis I.

The Exploration Ground System (EGS) program will play an integral role in the Artemis Program by enabling integration, processing, and launch of the Space Launch System (SLS) and Orion spacecraft. EGS is making all required facility and ground support equipment modifications at Kennedy Space Center (KSC) to enable the assembly, test, and launch of SLS and Orion, along with the landing and recovery activities of Orion spacecraft flight elements in support of the Artemis missions. EGS is also modernizing communication and control systems to support these activities.

The EGS program, based at KSC, develops and operates the systems and facilities necessary to process, assemble, transport, and launch spacecraft and rockets. EGS's mission is to enable the Center to handle future Artemis missions.

EGS is upgrading Launch Pad 39B, the crawler-transporters, the Vehicle Assembly Building, the Launch Control Center's Young-Crippen Firing Room 1, the mobile launcher, and other ground facilities.

For more information, go to: https://www.nasa.gov/exploration/systems/ground/index.html

Program Elements

EGS PROGRAM INTEGRATION AND SUPPORT

EGS program integration and support activities manage the SLS and Orion program interfaces. This effort is critical to ensuring ground systems' performance meets technical and safety specifications and supports the programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the EGS integration effort is vital to managing interfaces with other Human Exploration and

EXPLORATION GROUND SYSTEMS

Operations Mission Directorate (HEOMD) activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across the three programs is aimed at mitigating the impacts of potential design overlaps, schedule disconnects and delays, and cost overruns.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

EGS Development is developing the necessary ground systems as well as refurbishing and upgrading infrastructure and facilities required for assembly, test, and launch of SLS and Orion, along with the landing and recovery activities of Orion. This includes the pad, known as Launch Complex-39B (LC-39B), the Vehicle Assembly Building (VAB), the mobile launcher (ML), and other smaller facilities. See the Exploration Ground Systems Development section beginning on the following page for additional details.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	974.7	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	974.7
Development/Implementation	2,067.4	220.2	192.6	**16.3**	0.0	0.0	0.0	0.0	0.0	2,496.5
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2021 MPAR LCC Estimate	**3,042.1**	**220.2**	**192.6**	**16.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3,471.2**
Total Budget	**3,609.3**	**558.7**	**569.2**	**583.7**	**552.4**	**514.0**	**494.0**	**493.0**	**0.0**	**7,374.3**
Change from FY 2021				**14.5**						
Percentage change from FY 2021				**2.5%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

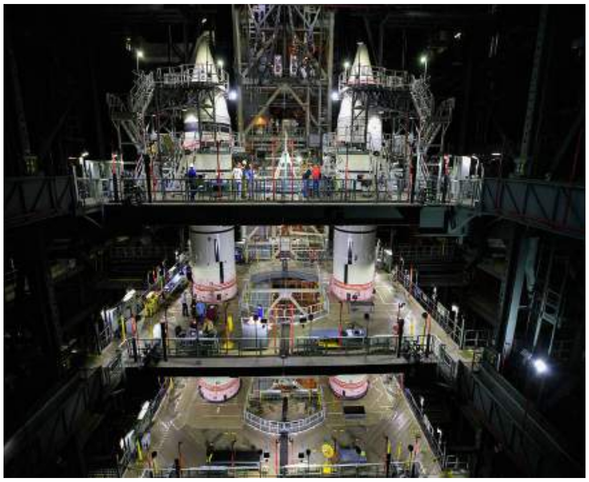
FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of Artemis I and excludes CoF; LCC only includes Artemis I content, including CoF.

With the arrival of the SLS Core Stage at KSC in April 2021, NASA is continuing to assess the schedule and work remaining for the Artemis I mission. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations


Stacking is complete for the twin Space Launch System solid rocket boosters for Artemis I mission. Over several weeks, workers used one of five massive cranes to place 10 booster segments and nose assemblies on the mobile launcher inside the Vehicle Assembly Building at NASA's Kennedy Space Center.

PROJECT PURPOSE

Exploration Ground Systems (EGS) is preparing to launch the Space Launch System (SLS) and Orion space transportation systems in support of the Artemis missions. EGS is developing the necessary ground systems while refurbishing and upgrading infrastructure and facilities required for assembly, test, and launch of SLS and Orion, along with the landing and recovery activities of Orion. This includes the pad, known as Launch Complex-39B (LC-39B), the Vehicle Assembly Building (VAB), the mobile launcher (ML), and other smaller facilities to move from a Space Shuttle focus to supporting Artemis missions. The modernization efforts maintain flexibility for LC-39B and the VAB to accommodate other potential users and commercial partners, though no other users have been identified to date. Additionally, following the Artemis I launch of SLS and Orion, the ML1, VAB, and LC-39B will undergo modifications to accommodate crewed flight. Kennedy Space Center (KSC) has more than 50 years serving as our nation's gateway to exploring the universe. Taking the knowledge and assets of NASA's successful spacefaring past, the EGS Program is helping to build a successful future in spaceflight.

For more information, go to: http://go.nasa.gov/groundsystems

EXPLANATION OF MAJOR CHANGES IN FY 2022

The FY 2022 President's Budget proposes funding to support the Nation's next lunar landing goal of 2024. The current Artemis 1 Launch Readiness Date (LRD) is no earlier than (NET) November 2021. The current LRD for Artemis II is NET September 2023. Due to the late SLS core stage delivery to KSC, Artemis I and II launch dates are going through an additional review. NASA Leadership will review the results of these assessments before updating the Artemis I and II launch planning dates.

Funding is also included for the continued construction of Mobile Launcher 2.

PROJECT PARAMETERS

EGS is focusing on the equipment, management, and operations required to safely connect Orion with the SLS, move the SLS to the launch pad, and successfully launch it into space. The work entails use of many of the facilities unique to KSC, such as the 52-story VAB and LC-39B. For the Artemis missions, the EGS team is developing procedures and protocols to process the spacecraft, the rocket stages, and the launch abort system before assembly into one vehicle. Additional work required to launch astronauts into

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

space includes modifying the ML1 and crawler-transporters, preparing LC-39B at KSC, and modernizing computers, software, tracking systems, and other network communications.

The ML1 is the ground structure used to assemble, process, and launch the SLS rocket and Orion spacecraft from LC-39B at KSC for missions to deep space destinations, such as the Moon. ML1 consists of a two-story base that is the platform for the rocket and a tower equipped with a number of connection lines, called umbilicals, and launch accessories that will provide SLS and Orion with power, communications, coolant, fuel, and stabilization prior to launch. The tower also contains a walkway for personnel and equipment entering the crew module during launch preparations. ML1 will support the Agency's Artemis I, II, and III launches, and will be available for future missions if needed.

ML2 is the ground platform structure that will launch SLS Block 1B and Block 2 configurations to the Moon, allowing the Agency to send astronauts and heavy cargo to the lunar surface as part of NASA's Artemis Program. ML2 is the primary interface between the ground launch control system and the SLS rocket and Orion spacecraft flight hardware. The mobile launcher-2 (ML2) construction contract was awarded in July 2019 and is aligned to support the first launch of a Block 1B.

A pair of machines called crawler-transporters have carried the load of taking rockets and spacecraft to the launch pad for more than 50 years at KSC. Each the size of a baseball infield and powered by locomotive and large electrical power generator engines, the crawler-transporters stand ready to keep up the work for the next generation of launch vehicles to lift astronauts into space. Crawler-Transporter 2 (CT-2) will be integral to the Artemis Program, which includes landing the first woman and first person of color on the Moon.

ACHIEVEMENTS IN FY 2020

EGS received launch hardware and teams put systems in place for the Artemis I and II missions. The program completed a punch-list of detail work inside the VAB in 2020, including cleaning the platforms and making minor repairs to platform hardware that would be near flight hardware as the facility prepares for arrival of SLS components and stacking operations.

In October 2019, the program conducted the final water flow test in a series of sound suppression tests at LC-39B in preparation for the first Artemis I launch. The brief test was one of the final checkouts between the launch pad and the ML1. At launch, the SLS will produce nearly 8.8 million pounds of maximum thrust and a lot of sound. The purpose of the sound suppression system is to dampen sound and vibrations to keep the rocket and the launch pad safe at lift-off. During the test and launch of early Artemis missions, nearly 450,000 gallons of water will be released onto the ML1 and down the launcher flame hole onto the flame deflector as well as over the sides.

In December 2019, ML1 returned to the VAB after completing the three-month long multi-element verification and validation (MEVV) at the pad which included demonstration tests of countdown activities in and around launch day, including propellant loading, sound suppression water system flows, and vehicle servicing needed to launch Artemis I.

EGS teams tested the flow of cryogenic fluids through the pad's infrastructure, those systems that will send liquid hydrogen (LH2) and liquid oxygen (LOX) to the rocket at the time of launch. These tests are

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

in preparation for the launch of SLS with the Orion spacecraft atop for the uncrewed Artemis I mission. The test verified the disposal methods for excess fluids, checked for leaks, confirmed the LOX pumps could perform appropriately, and validated piping on ML1 could handle the extremely cold temperatures of LOX and LH2. The next time these systems are used will be about two months before the Artemis I launch for the wet dress rehearsal, during which the SLS rocket deploys to the pad, is completely fueled and then drained again.

The program continued to ramp up launch countdown simulations to train and certify the launch control team for Artemis missions. The simulations walk through the final portions of the launch countdown sequence, called the terminal countdown. Integrated simulations tied in all NASA centers working the mission to ensure all members of the team are ready to work together, including Mission Control at Johnson Space Center in Texas and the SLS Engineering Support Center at Marshall Space Flight Center in Alabama. Simulations that began in February 2020 end with booster ignition for the Artemis I mission.

EGS will complete software development efforts and MEVV of the ground systems in support of Artemis I. Spacecraft processing operations for Orion will take place at the Multi-Payload Processing Facility (MPPF), followed by SLS flight hardware assembly and SLS/Orion integration and testing at the VAB in support of the Artemis I mission.

The EGS team continued to work on a new Emergency Egress System for Pad 39B where flight or ground crew could board a basket with a braking system at the crew access level of the ML1. The crew would ride the basket down a cable and come to a stop near a bunker to the west of the pad surface, providing quick escape in the unlikely event of an emergency. Construction will be complete in time to support crewed Artemis missions.

The integrated recovery team of NASA, EGS, Lockheed Martin and the U.S. Navy, along with additional contractor support, conducted URT-8 (Underway Recovery Test) at the Naval Base in San Diego to ensure the safe recovery of the Orion crew module post the Artemis I mission.

Hardware for SLS continued to arrive for processing and integration in various KSC facilities. All 10 of the solid propellant booster segments arrived by train from their Northrop Grumman manufacturing facility in Promontory, Utah. The launch vehicle stage adapter, which will connect the SLS core stage to the interim cryogenic propulsion stage, has arrived by barge. The booster aft skirts, which contain the thrust vector control system that steers the rocket, have been moved from the Booster Fabrication Facility to the Rotation, Processing and Surge Facility at KSC where they have been attached to the aft exit cones. The exit cones attach to the bottommost part of each of the twin boosters to provide extra thrust to the boosters and protect the aft skirts from the thermal environment during launch.

The program continued construction activities of the Liquid Hydrogen Sphere at LC-39B. The project involved the integration of a new 1.4 million gallon, LH2 storage sphere into the existing LC-39B system. The new LH2 sphere will work with the current LH2 sphere to supply LH2 for Artemis II and beyond. The larger tank will allow NASA to attempt SLS launches on three consecutive days, instead of opportunities of two out of three days, in the event of a scrub. The newer technology reduces liquid hydrogen burn-off, allowing more launch attempts before having to refill the larger tank. Construction began in 2019 and will be complete prior to Artemis II.

NASA began the design and construction of ML2 and will continue efforts over the next several years.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2021

Prior to launch, several key Artemis I milestones will have occurred during the fiscal year, such as Orion delivery, Core Stage delivery, Stacking Operation Readiness Review, and the start of Integrated Test and Checkout, Artemis I Design Certification Review, and the Preliminary Flight Readiness Review. EGS and prime test and operations contractor Jacobs started the integration process during Thanksgiving week by placing the two foundational pieces of the vehicle, the SLS aft booster assemblies, on ML1 in the VAB.

The program will complete URT-9 in the fall of 2021. The purpose of URT-9 is to certify the recovery personnel and related on-shore mission interfaces who will be responsible for Artemis I mission recovery operations.

Concurrent with first time processing and launch of Artemis I, EGS will continue development work via upgrades and modifications to the VAB and ML1 in support of Artemis II, the first crewed mission, and Artemis III.

Additionally, in support of Artemis II, the program will complete construction of LC-39's Liquid Hydrogen Sphere and begin verification and validation certification, as well as continue the Emergency Egress System and hardware pre-fabrication modifications and construction on ML1.

EGS will continue fabrication of Environmental Control System (ECS) in the VAB and begin upgrades at LC-39B to support the Artemis II and Artemis III missions, continue upgrades at the Compressor Converter Facility, and begin modifications to support crewed missions on ML1. The program will also continue design of the liquid Nitrogen RL-10 Chilldown system at LC-39B.

The program held the technical Program Design Review (PDR) for the ML2 in March 2021, which demonstrated the preliminary design met all system requirements and established the basis for proceeding to Critical Design Review (CDR). The programmatic PDR will be held in the summer of 2021 along with a review by an Independent Review Team (IRT).

KEY ACHIEVEMENTS PLANNED FOR FY 2022

Launch of Artemis I is currently planned for NET November 2021, though this date is under review. The landing and recovery operations will recover the Crew Module and return it to KSC.

In support of Artemis II and III, the program will begin modifications to support crewed missions on ML1 and complete construction, verification, and validation certification of LC-39's Liquid Hydrogen Sphere. The new LH2 sphere will work with the current LH2 sphere to supply LH2 for Artemis II and beyond. The newer technology reduces liquid hydrogen burn-off, allowing more launch attempts before having to refill the larger tank. Construction began in 2019 and will be complete prior to Artemis II. Construction of the LH2 Sphere Tank Fill and Remote V&V will be in June 2022.

Teams will continue work on the new Emergency Egress System (EES) for Pad 39B where flight or ground crew will board a basket with a braking system at the crew access level of ML1. The crew will ride the basket down a cable and come to a stop near a bunker to the west of the pad surface, providing

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

quick escape in the unlikely event of an emergency. The design phase began in 2019 and construction will be complete in time to support crewed Artemis missions.

The integrated recovery team of NASA, EGS, Lockheed Martin and the U.S. Navy, along with additional contractor support, will conduct URT-10 in spring 2022 at the Naval Base in San Diego to ensure safe recovery of the Orion crew module for future Artemis missions. URT-10 will be the first underway test for a crewed mission. This test will include day and night recovery testing.

The program will complete Artemis II development in September 2022 in preparations for the Artemis II launch. EGS will also perform validation of Crew Transportation Vehicle in September 2022.

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2022 PB Request
Key Decision Point-A (KDP-A)	Feb 2012	Feb 2012
Formulation Authorization	Apr 2012	Apr 2012
Systems Requirement Review (SRR) / System Design Review (SDR)	Aug 2012	Aug 2012
KDP-B Agency Project Management Council (APMC)	Nov 2012	Nov 2012
Preliminary Design Review (PDR) Board	Mar 2014	Mar 2014
KDP-C APMC	May 2014	May 2014
Critical Design Review (CDR) Board	Dec 2015	Dec 2015
System Integration Review (SIR)	Apr 2018	Jun 2018
Operational Readiness Review / Flight Readiness Review (FRR)	Jul 2019	Jul 2019
Artemis I Launch Readiness	Nov 2018	NET Nov 2021 (under review)
Mobile Launcher 2 iPDR (Technical)	Mar 2021	Mar 2021
Mobile Launcher 2 PDR (Programmatic)	Jul 2021	Jul 2021

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2015	1,843.5	80%	2021	2,496.4	33.7%	Artemis I Readiness	Nov 2018	NET Nov 2021	36

NASA continues to review past reporting, and estimates do not necessarily accurately incorporate actual expenditures to date. Additionally, cost and confidence levels do not reflect the cost impacts of currently anticipated schedule delays. The estimates are expected to increase as NASA assesses the impacts of further delays and updates reporting on expenditures. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)*	Change from Base Year Estimate ($M)
TOTAL	**1,843.5**	**2,496.4**	**+652.9**
Mobile Launcher	213.1	497.0	+283.9
LC-39B Pad	77.5	47.6	-29.9
VAB	92.7	40.8	-51.9
Command, Control, and Communications	198.0	499.0	+301.0
Offline Processing and Infrastructure	110.2	120.5	+10.3
Other	1,152.0	1,291.5	+139.5

Other includes Crawler Transporter, Launch Equipment Test Facility, Integrated Operations, Program Management, Logistics, Safety and Mission Assurance (S&MA), Integrated and Offline Operations, Construction of Facility and Systems Engineering and Integration (SE&I).

The Agency Baseline Commitment for LC-39B, VAB, and Offline Processing and Infrastructure previously integrated Operations cost which support Artemis I and later missions. EGS realigned those costs from each

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

element and moved those costs to the Other element, significantly lowering those elements' Current Year Development Cost Estimate. In addition, the program removed $27 million in costs for the VAB Utility Annex from the VAB element estimate. Those costs were covered by Center Management and Operations as that work was determined to benefit all programs at KSC.

Project Management & Commitments

EGS balances customer requirements among SLS, Orion, and other Government and commercial users. EGS is developing ground systems infrastructure necessary to assemble, test, and launch SLS and Orion, as well as land and recover Orion flight elements.

Element	Description	Provider Details	Change from Baseline
Ground Systems Implementation (GSI)	GSI is responsible for the design, development, build, hardware/software integration, verification and validation, test, and transition to operations for Program facility systems and Ground Support Equipment (GSE).	Provider: KSC Lead Center: KSC Performing Center(s): Ames Research Center Cost Share Partner(s): N/A	N/A
Operations and Test Management (O&TM)	O&TM is responsible for conducting overall planning and execution of both flight hardware and ground systems processing activities.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Command, Control, Communication (C3)	C3 is responsible for development, operation, and sustainment of End-to-End Command and Control and Communications services.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Program Management Team (PMT)	PMT includes project management, safety and mission assurance, logistics, systems engineering, utilities and facility operations, and maintenance.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The modifications to ML-1 are not completed in the planned 18-month window between Artemis I and Artemis II, Then: There is a possibility that the Emergency Egress System (EES) construction will not be completed in time to allow for V&V prior to vehicle processing for Artemis II.	There is a dependency on the ML-1 being available and modifications being completed to complete the construction and activation of the EES at the Pad. The dependencies with Artemis II ML-1 modifications may prevent timely installation and testing of the EES with ML-1. Mitigation efforts being pursued include compressing the EES design schedule, compressing the construction schedule, exploring alternate implementation methods, initiating the construction earlier, and/or reducing the overall verification and validation schedule.
If: The modifications to the Environmental Control System (ECS) ducting configuration and circuits are not completed in the planned 18-month window between Artemis I and Artemis II, Then: There is a possibility that the ECS construction will not be completed in time to allow for V&V prior to vehicle processing for Artemis II.	To support launches post Artemis I, modifications are planned to the ECS that will enable it to support a Block 1 and Block 1B vehicle. This will require modifications to the existing circuits; however, these circuits must be maintained throughout the entire Artemis I launch campaign. Mitigation efforts being pursued include compressing the design schedule, improving design package flexibility, identifying design scope that can be deferred, exploring alternate implementation methods, and/or reducing the overall verification and validation schedule.

Acquisition Strategy

EGS serves as its own prime contractor for development activities. EGS executes SLS and Orion ground infrastructure and processing requirements by leveraging center and programmatic contracts. For more routine work, EGS also uses pre-qualified indefinite-delivery, indefinite-quantity contractors while exercising full and open competition for larger or more specialized projects, such as facility systems construction contracts and associated GSE fabrication firm-fixed-price contracts. A fixed-price contracting approach is the first choice whenever possible, as it provides maximum incentive for contractors to control costs because the contractors are subject to any losses incurred. In addition, a fixed-price contract imposes minimal administrative burden on the contracting parties.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

EGS development activities will encompass projects of varying content and size. EGS does not have a prime contract; it uses the Center's institutional contracts to execute the development, engineering, construction, and programmatic activities. If the project size or scope falls outside existing Center capabilities, then a competitively bid firm-fixed-price contract will be used.

Element	Vendor	Location (of work performance)
ML1 Structural and Facility Support Modification Contract	J.P. Donovan Construction, Inc.	KSC
VAB Platform Construction	Hensel Phelps Construction, Inc.	KSC
ML2 Design Build	Bechtel National, Inc.	KSC

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Preliminary Design Review (PDR)	Standing Review Board (SRB)	Mar 2014	To evaluate completeness and consistency of program preliminary design; to determine readiness to proceed with detailed design phase.	Program cleared to proceed to next phase.	N/A
Critical Design Review (CDR)	SRB	Dec 2015	To demonstrate that program design is mature; support full-scale fabrication, assembly, integration, and test; and meet overall performance requirements within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A
System Integration Review (SIR)	KSC Independent Review Team (IRT)	Jun 2018	To evaluate the readiness of the program, including its projects and supporting infrastructure, to begin system Assembly, Integration, and Test with acceptable risk and within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Exploration Systems Development (ESD) Artemis I Independent Schedule Assessment	Schedule assessors from Office of the Chief Financial Officer (OCFO)	Jun 2019	Programmatic assessment and analysis of Artemis I schedules across all ESD programs with an emphasis on program performance and risks.	NASA leadership was briefed on Artemis I launch date options. OCFO staff briefed NASA leadership on Artemis I launch date options	N/A
ESD Artemis I Re-baseline	Independent Review Team	Spring 2020	Programmatic assessment and analysis of Artemis I schedule and schedule risks of Artemis I launch date and JCL.	Upon completion of review, establish revised baseline and launch readiness date.	N/A
ESD Enterprise Integration Review (EIR)	Independent Review Team	Jan 2021	To confirm that flight and ground hardware elements, software, support equipment, facilities and infrastructure are ready to support assembly, integration, test, and mission operations per the planned schedule for Artemis 1	The IRT will confirm the programs are sufficiently mature to proceed for integrated operations	N/A
Mobile Launcher 2 PDR (Technical)	Independent Review Team	Mar 2021	To evaluate completeness and consistency of program preliminary design; to determine readiness to proceed to CDR	Verify technical readiness for the project to initiate construction	Mobile Launcher 2 PDR (Programmatic)
Mobile Launcher 2 PDR (Programmatic)	Independent Review Team	Summer 2021	To evaluate completeness and consistency of program preliminary design; to determine readiness to proceed to CDR	Verify technical readiness for the project to initiate construction	N/A
Operational Readiness Review/ Flight Readiness Review (ORR/FRR) for Artemis I	IA/IRT	NET Sep 2021	To evaluate the readiness of the project to operate the flight system and associated ground system; and support systems for safe and successful launch and flight/mission.	N/A	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Launch Readiness Date/Initial Operations Capability (LRD/IOC) for Artemis I	IA/IRT	NET Nov 2021	To assess all capabilities of the vehicle to support the readiness to launch.	N/A	N/A
Mobile Launcher 2 CDR	IA/IRT	Mar 2022	To demonstrate that program design is mature; support full-scale fabrication, assembly, integration, and test; and meet overall performance requirements within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A

EXPLORATION RESEARCH & DEVELOPMENT

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Advanced Exploration Systems	208.9	176.2	**195.0**	195.0	195.0	195.0	195.0
Advanced Cislunar and Surface Capabilities	38.0	54.5	**91.5**	217.9	360.2	627.9	1,088.6
Gateway	421.0	698.8	**785.0**	810.5	765.0	670.0	670.0
Human Landing System	654.1	928.3	**1,195.0**	1,266.7	1,579.5	1,989.0	1,807.2
Human Research Program	125.0	115.0	**130.2**	140.0	145.0	145.0	145.0
Total Budget	**1,447.0**	**1,972.8**	**2,396.7**	**2,630.1**	**3,044.7**	**3,626.9**	**3,905.8**
Change from FY 2021			**423.9**				
Percentage change from FY 2021			**21.5%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The Near Earth Asteroid (NEA) Scout is the first CubeSat delivered and ready for integration into SLS for the Artemis I mission.

The Exploration Research and Development (ERD) theme is comprised of five programs: Advanced Exploration Systems (AES), Advanced Cislunar Surface Capabilities (ACSC), Gateway, the Human Landing System (HLS), and the Human Research Program (HRP). The overarching goal of ERD is to develop human exploration capabilities and missions using a combination of unique in-house activities, public-private partnerships, and international partnerships. ERD is both developing and testing prototype systems, as well as planning and developing flight missions to lunar orbit and the Moon to develop systems and operation capabilities that enable an eventual mission to Mars. ERD's work will create the exploration infrastructure in lunar orbit and on the lunar surface that astronauts will use during Artemis missions and that will inform future missions to Mars. These program objectives support the National Space Policy of 2020, as well as the Agency's Strategic Goal 2, which seeks to extend human presence deeper into space and to the Moon for sustainable, long-term exploration and utilization.

Through commercial partnerships, HLS will support the development and deployment of the integrated system that will land the first woman and first person of color on the surface of the Moon. The demonstration of an integrated lander is the first step to enable more permanent human access to the lunar surface.

The ACSC program is formulating the systems that NASA will use to explore the surface of the Moon. These surface systems, including surface mobility, logistics, and habitation, will provide capabilities and result in lessons learned and expertise that will support future Mars missions. In addition to systems specific to the lunar surface, ACSC will work with the Gateway program to provide lunar surface cargo transportation services for these systems and other required materials through the Deep Space Logistics activity.

ERD will also lead development of the Gateway, a small way station that will orbit the Moon and serve as an orbital platform for human and robotic missions to the lunar surface. Initial elements of the Gateway outpost will be launched together into orbit around the Moon where they will provide critical infrastructure to enable fully reusable lunar landers. The Gateway will be capable of supporting early human-class lander deployments and operations enabling lunar surface capability.

AES invests in the development and demonstration of prototype exploration systems to reduce mission risk, validate operational concepts, leverage partner capabilities, and lower lifecycle costs to help enable lunar and deep space missions. AES will continue to advance technologies related to deep space habitats by using the ISS as a test bed to advance the technology readiness of habitation systems that could be used in a future deep space integrated habitation capability. Through the completion of ground-based prototype testing, AES continues to advance technologies related to deep space habitats and identify and address knowledge gaps for lunar environments.

The goal of HRP is to provide human health and performance countermeasures, knowledge, technologies, and tools to enable safe, reliable, and productive human space exploration. As an applied research and development technology program, HRP uses research findings to develop procedures to lessen the effects of the space environment on the health and performance of humans working in that setting. With the goal of enabling a long-duration mission to Mars, the program is using ground research facilities, the International Space Station, and analog environments to develop procedures and to advance research areas that are unique to Mars.

ERD activities utilize a variety of agreements and contracts that enable NASA, private industry, academia, and international partners to share in the risks and rewards of Government investments. These shared risks include incentivizing technical performance and building future commercial markets with financial interest in developing capabilities. These programs are also utilizing the unique skills of the NASA workforce to perform risk reduction, develop life support systems, and build the missions that will take humanity back to the Moon and beyond.

The technology capabilities and processes pioneered by ERD will enable the first intrepid crews of the new space age to travel safely to and from the surface of the Moon, mature sustainability on the Moon, and land on the surface of Mars. These missions will enable new scientific discoveries and promote new technologies, research, and systems needed to sustain living in deep space for the benefit of all humankind.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ADVANCED EXPLORATION SYSTEMS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**208.9**	**176.2**	**195.0**	**195.0**	**195.0**	**195.0**	**195.0**
Change from FY 2021			**18.8**				
Percentage change from FY 2021			**10.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The Thermal Amine scrubber system being installed in the Destiny module, which will remove carbon dioxide from the International Space Station. Carbon dioxide removal is a key capability for future deep space exploration.

The Advanced Exploration Systems (AES) activities develop high-priority technologies and capabilities and infuse them into prototype systems that will form the basis for future human spaceflight missions. These activities use a combination of unique in-house activities and public-private partnerships.

To enable NASA's Artemis Program, AES is investing in development and demonstration of exploration capabilities to reduce risk, lower life cycle cost, and validate operational concepts for future human missions through habitation capabilities, life support systems, and other technologies. The Agency identifies and addresses potential risks by performing early validation and ground/flight testing of new capabilities prior to integration into planned operational systems. This approach minimizes cost growth and improves affordability of future space exploration. AES is focusing on advancing the technologies that will foster a sustainable presence on the Moon and enable a lasting and productive presence utilizing reusable systems. These technologies will provide access for a diverse community of contributing partners and sustainability for repeatable trips to multiple destinations across the lunar surface.

To test the technologies, capabilities, and systems required for deep space missions, AES is employing a phased approach by testing on the ground, in low-Earth orbit (LEO), and in cislunar space. The goal is to make exploration missions more capable, safer, and more affordable.

AES will continue to work on identifying and addressing knowledge gaps and delivering fundamental capabilities to provide astronauts with a place to live and work with integrated life support systems, radiation protection, food, fire-safety, avionics and software, logistics management, and systems to manage waste.

AES provides technologies to enable Artemis missions, including capabilities that enable sustained surface missions. The technology capabilities and processes pioneered by AES will enable the crews of the new space age to stay safe and healthy, make scientific discoveries, and sustain new homes away from Earth for the benefit of all humankind.

AES additionally funds the team that leads the integration of the human space flight elements of the Artemis missions starting with Artemis III. This integration team comprises the system engineering, safety, operations, and programmatic organizations that assures that the human spaceflight lunar mission is implemented successfully with contributions from the programs across the Human Exploration and Operations Mission Directorate (HEOMD).

EXPLANATION OF MAJOR CHANGES IN FY 2022

The AES portfolio will be more closely aligned to support landing humans on the Moon and establishing a sustainable, long-term presence on and around it. AES will be focused primarily on technology development that could be infused into flight or surface elements for the Gateway, Advanced Cislunar and Surface Capabilities (ACSC), and the Human Landing System (HLS) programs. AES funding rephasing will enable development and testing technologies for highly-reliable, closed-loop environmental control and life support systems (ECLSS) and will use the International Space Station (ISS) as a test bed for long duration reliability demonstrations to support the Artemis manifest.

ACHIEVEMENTS IN FY 2020

In FY 2020, AES continued activities to gain a fundamental understanding of novel habitation structures, integrated advanced life support systems, environmental monitoring, logistics reduction, fire-safety, crew health and radiation protection, and avionics and software for increased autonomy. AES continued work on additional technologies in the areas of synthetic biology applications, in-space manufacturing, robotic precursor missions, and vehicle systems, including modular power systems, advanced propulsion technologies, and lander technologies. Together, these technologies will close capability gaps necessary for deep space missions, including the Artemis architecture, and future human crewed missions to Mars.

AES continued to integrate advanced autonomy software, sensors, and feedback controls with advanced life support hardware to demonstrate improved overall efficiency and increased autonomy. The NASA Platform for Autonomous Systems was developed as a prototype hierarchical distributed autonomous operation capability for the Next Space Technologies for Exploration Partnerships (NextSTEP)-2 Northrup Grumman Habitat. It includes a software capability required for beyond LEO operations that does not rely on mission control from the ground.

AES continued the NextSTEP-funded activities with commercial industry to develop prototype habitats, life support systems, and other habitation technologies and conduct integrated ground and ISS-based testing to reduce risk for deep space missions.

AES began ISS flight demonstrations of life support and environmental monitoring subsystems when the Spacecraft Atmosphere Monitor (SAM) launched on SpaceX-18. The SAM is installed on ISS and is continuously monitoring concentrations of major constituents of the atmosphere such as oxygen and nitrogen. SAM is just one example of reliable, energy-efficient, and low-mass spacecraft systems that provide environmental control and life support systems that enable long-duration human missions beyond LEO.

Through ISS flight demonstrations and improvements to the current ISS life support, environmental monitoring, fire-safety, and crew health systems, AES-developed habitation capabilities are progressing. There was also continued progress in the reliability and performance of the ISS oxygen generation assembly, the ISS urine processor assembly, the ISS water processor assembly, the temperature and humidity control condensing heat exchangers, and the technologies used for carbon dioxide removal. The first of two candidate carbon dioxide removal devices was flown to ISS in 2019. Ground development of smaller, more efficient exercise devices and a crop production capability is also continuing development for upcoming ISS flight demonstrations.

AES delivered Spacecraft Fire Safety (Saffire) V to Northrup Grumman, which was launched to ISS in February 2020. The Saffire payloads help NASA understand how large-scale fires spread in microgravity and therefore help improve fire detection, suppression, and clean-up techniques. NASA will use the knowledge obtained from these experiments in detailed analysis and optimization for future fire protection systems.

WORK IN PROGRESS IN FY 2021

As NASA works to extend human space exploration beyond LEO, AES continues to develop reliable life support systems, deep space habitats, and overall capabilities to reduce logistics requirements to support sustainable human spaceflight missions that eliminate the dependencies on frequent resupply from Earth.

AES also continues ISS flight demonstrations of life support and environmental monitoring subsystems, including Spacecraft Atmosphere Monitor 2 (SAM), upgrades to the ISS urine and water processors, and advanced carbon dioxide removal systems. The Universal Waste Management System (UWMS) was launched to the ISS in October on a Northrup Grumman launch (NG-14) and the Airborne Particulate Monitor and Brine Processor Assembly (BPA) were delivered to ISS by NG-15 in February 2021. The BPA will increase the overall water recovery to 98 percent, which is the level desired for Artemis missions.

UWMS demonstrates a compact toilet and the Urine Transfer System that further automates waste management and storage saving crew member time. The smaller footprint of the UWMS supports possible expansion of the number of crew members on the space station and planning for future exploration missions. Compact, efficient waste disposal technology also has potential applications in remote areas and those not served by traditional waste treatment systems on Earth and during disasters.

Production work continues in all other life support, logistics reduction, environmental monitoring, and crew health improvements toward ISS flight demonstrations in 2021 and beyond. Additionally, AES will embark on a ground-based test campaign of life support technologies intended to complement ISS-based testing. AES is also continuing the development of ground and flight experiments to investigate the effects of low cabin pressure and high oxygen levels on the flammability of materials in partial gravity.

AES is completing development of four small CubeSats for launch on Artemis I: BioSentinel, Near Earth Asteroid (NEA) Scout, Lunar IceCube, and Lunar Infrared Imaging (LunIR). Lunar IceCube and LunIR are NextSTEP partnerships in which costs are shared with industry and universities. All four projects are nearing completion with final spacecraft integration to Space Launch System (SLS) in FY 2021. These CubeSats will not only help answer strategic knowledge gaps associated with the Moon, asteroids, and effects of space radiation on biological systems, but will also develop capabilities for deep space

CubeSats, enabling future missions for academia and industry. BioSentinel will study the effects of the deep space radiation environment on yeast deoxy-ribonucleic acid (DNA), NEA Scout will visit a small asteroid using a solar sail for propulsion, Lunar IceCube will search for water on the Moon with a broadband spectrometer, and LunIR will test an advanced infrared sensor during a lunar flyby.

AES, in support of Gateway development, is continuing to advance work on common avionics and software capabilities that are the foundation for enabling the command, control, communications, and computing capabilities needed to operate a spacecraft and subsystems in LEO and beyond.

By the end of FY 2021, the AES portfolio will be more aligned to support landing humans on the Moon and establishing a sustainable, long-term presence there. AES will be focused primarily on technology development that could be infused into flight or surface elements for the Gateway, ACSC, and the HLS programs.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

AES habitation work will continue to deliver the fundamental capabilities and systems to provide astronauts a place to live and work in space. In addition to continuing ISS flight demonstrations begun prior to FY 2022, AES, in partnership with ISS, plans to complete flight hardware and demonstrate prototype systems and sub-systems on ISS, including improved carbon dioxide removal technologies and additional improvements to the ISS urine and water processors.

AES will continue the development of low technology readiness level (TRL) technologies for increasing loop closure, conduct an initial flight demonstration of a prototype carbon dioxide scrubber on ISS, and down-select the most promising technologies for continuation. Radiation Protection activates include a demonstration of the Hybrid Electronic Radiation Assessor (HERA) on Artemis II and completion of an active shielding study to compare current work on electrostatic dipoles versus magnetic fields for deflection of galactic cosmic rays.

Work on all other advanced habitation systems will also continue, with ISS flight demonstrations by 2025. AES will continue building upon the current commercial engagement contracts to advance commercial habitation, avionics, flight software, life support, in-space refueling capabilities, and other commercial space industries.

NASA is planning to launch and deliver the Exposed Root On-Orbit Test System, Spacecraft Atmosphere Monitor Technology Demonstration Unit, and European Enhanced Exploration Exercise Device to ISS in FY 2022.

Program Elements

HABITATION

Habitation capabilities and systems deliver the fundamental capability to provide integrated life support systems, environmental monitoring, crew health, radiation protection, fire-safety, and systems to manage food, waste, clothing, and tools that enable astronauts to carry out NASA's mission in space and on other worlds. AES focuses on developing key habitation systems to enable the crews to live and work safely in space, with an initial focus on lunar missions. Activities include NextSTEP deep space habitation prototype development efforts, life support systems, logistics reduction, food and crew health systems, and radiation measurements and protection.

Experiments to improve spacecraft fire-safety are also underway to better understand how fire spreads and how to recover from fire events in microgravity. These investments will progressively move from habitation subsystems to integrated systems and then be infused into deep space exploration elements and system designs.

AES oversees the Agency's habitation strategy and serves as the central management authority for NextSTEP. In this capacity, AES is the primary interface between the external NextSTEP partners and internal stakeholders, including Exploration Technology, ISS, Orion, SLS, the Human Research Program, and the Space Communications and Navigation program.

Through the NextSTEP effort, NASA and industry identify commercial capability development for LEO that intersects with the Agency's long-duration, deep space habitation requirements, along with any potential options to leverage commercial LEO advancements and promote commercial activity in LEO. The multiple phases of NextSTEP are informing NASA's notional future deep space, long-duration habitation capability.

ROBOTIC PRECURSOR ACTIVITIES

Robotic Precursor Activities acquire strategic knowledge about potential destinations for human exploration. These efforts include the Artemis I CubeSats that will perform activities such as prospecting for lunar ice, studying the effects of space radiation, and demonstrating other instruments, research, and analysis.

Program Schedule

Date	Significant Event
Aug 2020	Upgraded ISS urine processor distillation assembly
Apr 2021	Began BPA demonstration on ISS
May 2021	Begin UWMS demonstration on ISS
Jun 2021	Delivery of Artemis I CubeSats (BioSentinel, NEA Scout, Lunar IceCube, LunIR)

Program Management & Commitments

Directorate's Associate Administrator delegated management authority, responsibility, and accountability to the AES Division at NASA Headquarters. AES Division establishes overall direction and scope, budget, and resource allocation for activities implemented by the NASA centers.

Program Element	Provider
Habitation Capabilities	Provider: NASA Centers Lead Center: Headquarters (HQ) Performing Center(s): Johnson Space Center (JSC), Marshall Space Flight Center (MSFC), Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), Kennedy Space Center (KSC), and Jet Propulsion Laboratory (JPL) Cost Share Partner(s): Bigelow Aerospace, Boeing, Lockheed Martin, Orbital ATK, Sierra Nevada, and NanoRacks (NextSTEP), Dynetics, UTAS, Paragon
Habitation Systems	Provider: NASA Centers Lead Center: HQ Performing Center(s): JSC, MSFC, ARC, GRC, Goddard Space Flight Center (GSFC), and JPL Cost Share Partner(s): N/A
Strategic Operations	Provider: NASA Centers Lead Center: HQ Performing Center(s): ARC Cost Share Partner(s): N/A
Robotic Precursors	Provider: NASA Centers Lead Center: HQ Performing Center(s): MSFC, JPL, ARC Cost Share Partner(s): N/A

Acquisition Strategy

Each year, AES evaluates how the portfolio aligns with human exploration priorities and technology gaps and either terminates or realigns activities that do not demonstrate adequate progress. AES also adds new activities to the portfolio as appropriate. AES will continue to utilize this process to identify and evaluate risk-reduction activities needed in support of Gateway, HLS, and ACSC. AES strives to maximize specialized skills within the civil service workforce, but it may also utilize a small amount of contractor effort in areas where NASA can leverage external skills and knowledge in a cost-efficient manner. AES will also use the Small Business Innovation Research (SBIR) program to engage small businesses for risk reduction and technology maturation. AES continues the use of competitively-selected external awards and public-private partnerships. Upgrades to existing ISS life support systems will use existing contracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Habitation Systems: Brine Water Processor	Paragon	Tucson, AZ; MSFC
Habitation Systems: Thermal Amine CO2 Scrubber	Collins Aerospace	Windsor Locks, CT
Habitation Systems: Oxygen Generation Assembly	Collins Aerospace	Windsor Locks, CT
Habitation Systems: Water Processor Assembly	Collins Aerospace	Windsor Locks, CT
NextSTEP Broad Agency Announcement Awards	Boeing, Bigelow Aerospace, Lockheed Martin, Orbital ATK, Dynetics	JSC; MSFC; KSC

INDEPENDENT REVIEWS

AES undergoes quarterly Directorate Program Management Council reviews, and periodically, representatives from the Office of Chief Engineer, the Office of Safety and Mission Assurance, and the Office of Chief Financial Officer will assess AES performance during Agency-level Baseline Performance Reviews (BPR). In addition, AES provides briefing reports to, and seeks feedback on planning and development activities from, the NASA Advisory Council Human Exploration and Operation Committee and the Technology Committee.

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**38.0**	**54.5**	**91.5**	**217.9**	**360.2**	**627.9**	**1,088.6**
Change from FY 2021			**37.0**				
Percentage change from FY 2021			**67.9%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Through the Advanced Cislunar and Surface Capabilities Program, NASA will develop an unpressurized Lunar Terrain Vehicle for lunar surface missions. An artist's rendition of surface activities is presented here.

The Advanced Cislunar and Surface Capabilities (ACSC) program is formulating the systems that NASA will use to explore the surface of the Moon. These surface systems, including surface mobility, logistics, and habitation, will provide capabilities and result in lessons learned and expertise that will support future Mars missions. ACSC will utilize initial studies and pre-formulation activities for future surface systems and the elements required for lunar sustainability. As these lunar-related technologies and systems mature, they will be the building blocks for the capability to extend stays on the Moon. In addition to systems specific to the lunar surface, ACSC will work with the Gateway program to provide lunar surface cargo transportation services for these systems and other required materials through the Deep Space Logistics services activity.

In the near term, ACSC is conducting risk-reduction studies to identify required lunar surface technologies to be utilized on the lunar surface and act as precursor systems for potential future missions. These surface systems include the Lunar Terrain Vehicle (LTV), the Habitable Mobility Platform (HMP), and the Foundation Surface Habitat (FSH).

LTV is an unpressurized surface transportation system concept that would significantly extend the range of crew excursions and enable more scientific research, resource prospecting, and exploration activities to be conducted. The LTV would also be tele-operated to perform scientific activities during the non-crewed lunar periods and transport small deployable assets to desirable locations.

The HMP is a pressurized surface transportation system concept that would be used on the Moon to expand the range of excursions even further, allowing crews to perform longer-duration research and exploration activities. FSH would provide a continuous long-term outpost for crew to visit for up to 60 days. The habitat would be delivered through commercial / international partnerships and will provide the support necessary for extended human occupation of the Moon. In addition, this capability would allow NASA to conduct analogs of Mars surface activities to reduce risk and optimize operational concepts.

EXPLANATION OF MAJOR CHANGES IN FY 2022

ACSC will fund Human Exploration and Operations Mission Directorate (HEOMD)-wide System Engineering and Integration activities with a focus on the larger Artemis mission plan, emphasizing capability integration strategies and science/technology utilization across the mission directorate.

ACHIEVEMENTS IN FY 2020

The Moon and Mars Architecture (M&MA) activity initiated studies to provide context for how near-term lunar activities can be "Mars forward." M&MA identified potential lunar surface systems, operations, and technology which will help NASA gain experience on and around the Moon that could evolve into the necessary components for eventual Mars missions. Through the M&MA activity, NASA released a LTV Request For Information in order to evaluate potential industry partnerships.

ACSC completed Appendix E: Human Landing System Studies, Risk Reduction, Development, and Demonstration under the NextSTEP Phase 2 Broad Agency Announcement (BAA). Through these awards, NASA solicited lander risk-reduction activities and concepts which lead towards sending humans to the surface of the Moon and bringing them home safely as part of a sustainable campaign of exploration.

As astronauts prepare for missions to the lunar surface, they will need deliveries of pressurized and unpressurized cargo, science experiments, supplies, and sample collection materials. In March 2020, NASA awarded SpaceX as the first U.S. commercial provider under the Deep Space Logistics (DSL) services contract to deliver cargo and other supplies to the lunar outpost.

In partnership with the Human Landing System (HLS) program, ACSC provided support for HLS related risk reduction activities such as the Navigation Doppler Lidar. This activity provides accurate, surface-relative altitude and vector velocity data to ensure HLS can land spacecraft safely on the Moon.

ACSC provided funding for the Solar Systems Trek software application, which combines images and other science data to simulate exploration of the solar system, including the Moon, Mars, and small-bodies (e.g., asteroids). This application can be used to inform future missions including the return to the lunar surface through HLS.

WORK IN PROGRESS IN FY 2021

The Surface Systems activity will conduct risk-reduction activities and evaluate potential commercial and international partnerships to take the next step in developing the systems and technologies identified in the M&MA activity. Through Surface Systems, NASA will seek to identify specific system architecture and begin formulation activities on key elements of NASA's Artemis plan.

Through a partnership with the Korea Aerospace Research Institute (KARI), ACSC will deliver the ShadowCam flight instrument for launch on the Korea Pathfinder Lunar Orbiter (KPLO) in June 2021. NASA will provide Deep Space Network lunar navigation and trajectory assistance in return for accommodating ShadowCam, an instrument developed by Arizona State University in collaboration with

NASA, which will image the shadowed regions at the Moon's poles to detect the presence of ice and potentially help to identify future sites for human lunar landings and surface operations.

DSL services are required for future human lunar landing missions. NASA has selected SpaceX to deliver logistics to the Gateway in support of lunar surface operations. ACSC is funding the first two DSL missions. The project is managed by the Gateway Program.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

M&MA and Surface Systems will continue conducting risk-reduction activities to further develop key elements of the Artemis plan for the lunar surface. This will include identifying and executing commercial and international partnerships to begin development of systems based on the LTV, HMP, and FSH concepts.

ACSC will advance technologies to prevent the accumulation of lunar dust on surface systems and protect the crew from the hazardous effects of dust upon the return of humans to the lunar surface and subsequent long duration missions.

Program Elements

HEO SYSTEM ENGINEERING AND INTEGRATION

The HEO Deputy Associate Administrator for Systems Engineering and Integration and supporting staff are responsible for ensuring the overall HEO strategy is reflected in program requirements. The office also leads architecture, formulation mission planning, and provides technical direction for HEO activities (Moon, Mars, and other human missions).

MOON AND MARS ARCHITECTURE

M&MA activities are focused on developing the future exploration architecture to take humans from the initial lunar landing to a Mars landing. This architecture will identify needed capabilities and technologies, as well as define operational concepts that will guide the development of flight systems.

Concepts for crewed lunar surface systems such as habitats, rovers, and a robotic precursor to support human exploration will be defined through these studies before being further pursued under Surface Systems.

SURFACE LOGISTICS

Through the DSL Request for Proposal, ACSC will use commercial partnerships to examine potential solutions for lunar surface logistics through systems development and delivery, in addition to the Gateway logistics services already under contract.

ADVANCED CISLUNAR AND SURFACE CAPABILITIES

SURFACE SYSTEMS

The Surface Systems group conducts activities leading directly to development of capabilities based on the LTV, HMP, and FSH concepts, as well as other systems required for NASA to continue to advance human exploration.

Program Schedule

The specific schedule for ACSC is still in the formulation phase and needs to be informed primarily by commercial responses to planned industry engagements. During FY 2021, NASA will make significant progress on establishing milestones, program implementation assignments, and acquisition strategy beyond the initial engagements.

Date	Significant Event
TBD	Launch of Lunar Terrain Vehicle
TBD	Launch of Habitable Mobility Platform
TBD	Launch of Foundation Surface Habitat

Program Management & Commitments

HEOMD manages the ACSC activities.

Program Element	Provider
ACSC Core	Provider: NASA Centers Lead Center: NASA Headquarters (HQ) Performing Center(s): Marshall Space Flight Center (MSFC), Langley Research Center (LaRC), Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), Johnson Space Center (JSC), Jet Propulsion Laboratory (JPL), Kennedy Space Center (KSC), Ames Research Center (ARC), Armstrong Flight Research Center (AFRC) Cost Share Partner(s): N/A
Moon & Mars Architecture	Provider: NASA Centers Lead Center: HQ Performing Center(s): MSFC, LaRC, GRC, GSFC, JSC, KSC, ARC Cost Share Partner(s): N/A
Surface Logistics	Provider: TBD Lead Center: KSC Performing Center(s): JSC, JPL, KSC, ARC Cost Share Partner(s): TBD

Acquisition Strategy

Acquisition plans for all functions/elements of ACSC will be varied and depend upon specific activities as this effort is comprised of risk-reduction activities, studies, and pre-formulation work.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

ACSC will undergo quarterly Directorate Program Management Council reviews, and periodically, representatives from the Office of Chief Engineer, the Office of Safety and Mission Assurance, and the Office of Chief Financial Officer will assess ACSC performance during Agency-level Baseline Performance Reviews (BPR). In addition, ACSC provides briefing reports to, and seeks feedback on planning and development activities from, the NASA Advisory Council Human Exploration and Operation Committee and the Technology Committee.

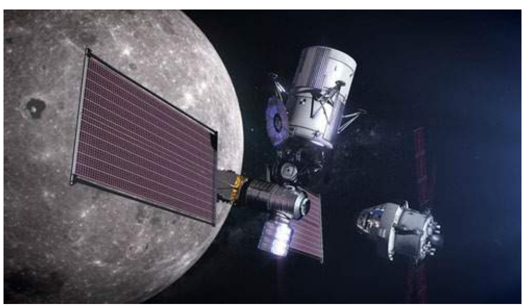
GATEWAY

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**421.0**	**698.8**	**785.0**	**810.5**	**765.0**	**670.0**	**670.0**
Change from FY 2021			**86.2**				
Percentage change from FY 2021			**12.3%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Shown here is an artist's rendition of the Gateway Initial Capability, which will support the initial Artemis missions.

The Gateway, an integral part of the Artemis Program, will be an outpost orbiting the Moon that provides support for a sustainable, long-term human return to the lunar surface. The initial Gateway capability will provide systems to support human lunar landings while serving as an aggregation point for future lunar missions. This approach enables a flexible human exploration architecture and will allow future collaboration with private sector companies and international partners to conduct long-term lunar missions and prepare for the exploration of Mars. The initial Gateway architecture is focused on two functional elements for sustaining lunar operations on the Moon. Those elements are the Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO). The Gateway program also manages the Deep Space Logistics Project and the Exploration Extravehicular Activity (xEVA) lunar surface efforts. Orion is designed to dock with Gateway, and Gateway will provide communications and support for lunar surface missions. In addition, NASA has signed Memorandums of Understanding (MOU) with the European Space Agency (ESA), Japanese Space Agency (JAXA), and Canadian Space Agency (CSA) for these international partners to provide future robotics and habitation contributions to the Gateway. The Gateway will enable science utilization, exploration technology demonstrations, and potential commercial utilization.

NASA selected Maxar Technologies for the development of the PPE. Maxar is currently targeting delivery of the element for integration in 2024. Working in partnership with the Space Technology Mission Directorate, PPE will demonstrate advanced high-power Solar Electric Propulsion (SEP) systems that will support future NASA and commercial applications. The PPE will generate and store a minimum of 50 kilowatts (kW), transfer power to the Gateway elements, and provide attitude control. Additionally, the PPE will provide accommodations for science and technology demonstration payloads.

Northrop Grumman has been selected for the development of the HALO. HALO is designed as a pressurized module with the same 10-foot diameter as the Cygnus cargo compartment and is being built based on this heritage design. PPE and HALO are targeted to be integrated and tested on the ground in 2024. HALO will provide habitable space for the astronauts, stowage volume, and an Environmental Control and Life Support System (ECLSS) that will work with the Orion capsule's ECLSS for crew stays in lunar orbit. HALO will also provide thermal control, allow power to pass through to other Gateway elements, provide communications with visiting vehicles and the lunar surface, and support external robotics and payloads.

Deep Space Logistics Services (DSL) will deliver supplies and hardware in support of Gateway's sustained lunar orbit operations and lunar landing missions. SpaceX has been selected for an initial contract to develop a logistic service. The DSL contracting mechanism allows for additional commercial logistics opportunities, if NASA determines them to be necessary.

The xEVA System, which is required for astronauts to conduct "Moonwalks" on the lunar surface, includes the Exploration Extravehicular Mobility Unit (xEMU) spacesuit development, vehicle interfaces to suit equipment (VISE), system servicing equipment, and specialized tools for these "Moonwalks." The xEMU is designed to provide astronauts with enhanced mobility to accomplish their exploration tasks on the lunar surface. It is also designed to be more comfortable when worn by astronauts with a wider range of physiological characteristics.

On the Gateway, the U.S. and its partners will test new technologies and systems that will support the infrastructure being built on the surface of the Moon for lunar exploration and will support preparation for future missions to Mars. NASA will also study the effects of the deep space environment, learning how living organisms react to the radiation of a deep space environment over long periods.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

The Gateway Program implemented the decision to launch PPE and HALO as a single integrated co-manifested vehicle (CMV), reallocated the functionalities of various habitable modules, and updated the PPE requirements to reflect its mission as a cornerstone of the Gateway. This included refinement of requirements across the Gateway and culminated in an initial capability-focused Systems Definition Review (SDR) synchronization review. The Gateway Program initiated the procurement activity for the CMV launch vehicle. The Program initiated manufacturing of key PPE and HALO components, and started design, development, test, and evaluation (DDT&E) of the Vehicle Systems Manager (VSM), one of the Gateway/Lander backbone systems.

The PPE Project completed initial Safety Reviews and the System Requirements Review (SRR).

NASA awarded a contract to Northrop Grumman for development and delivery of the HALO through the Preliminary Design Review (PDR).

Gateway evaluated Deep Space Logistics proposals received in October 2019 and awarded a firm fixed-price contract to SpaceX.

The xEMU Project completed a Delta PDR focused on lunar surface requirements and began assembly of the design verification test unit that will be tested in FY 2021. The Spacesuit Evaporation Rejection Flight

Experiment (SERFE) was delivered to ISS on Cygnus commercial cargo launch (NG-14) and will be operated remotely for over 12 months to validate the design of the xEMU thermal loop.

A request for information was issued in early 2020 that sought industry input on transitioning the xEVA production line to private industry for missions beyond 2024.

WORK IN PROGRESS IN FY 2021

Agreements have been signed with International Partners that define their collaboration with Gateway. MOUs have been signed with ESA, JAXA, and CSA. NASA reached an agreement with ESA to provide habitation and refueling modules, as well as enhanced lunar communications, for Gateway. ESA will provide the International Habitat (I-Hab) module and the European System Providing Refueling, Infrastructure, and Telecommunications (ESPRIT) module. The I-Hab module will provide additional crew habitation and workspace, as well as additional environmental control and life support systems capability. This module will also provide additional docking ports and accommodations for internal and external science experiments. The ESPRIT module will provide refueling to the PPE and additional communications capabilities for Gateway. The ESPRIT module will also feature a series of observation ports, with 360-degree views of the Moon and spacecraft as they approach and dock to the Gateway.

SpaceX was selected to provide launch services for the Gateway's PPE and HALO CMV. Originally, PPE and HALO were planned to be launched on separate launch vehicles and autonomously dock in orbit around the Moon. PPE and HALO will now be launched together as an integrated unit, effectively designated as a CMV.

PPE and HALO teams completed a CMV Sync Point.

Northrop Grumman initiated their HALO PDR process. The HALO team is planning to complete the preliminary design process and closeout the PDR in May 2021.

The International Habitat (I-Hab) team completed a Primary Structures PDR and began a full I-Hab System PDR process. The team is planning to have the PDR closeout board in June 2021.

Gateway Program completed a Delta SDR Sync Review and achieved Agency-level approval at their Key Decision Point (KDP)-0 to proceed with the formulation phase of the Program.

NASA will continue working with Maxar Technologies on PPE to enable successful delivery of the development and flight hardware schedule. Existing contracts are being modified to include the requirement changes associated with the CMV configuration. NASA is also working with Aerojet Rocketdyne to enable successful delivery of the development and flight hardware for the Solar Electric Propulsion System required for the PPE. Additional expected milestones for this FY will include a two-part PPE PDR, manufacturing readiness reviews, and hardware development testing.

NASA will continue working with Northrop Grumman on HALO to enable successful delivery of the development and flight hardware schedule. Existing contracts are being modified to include the requirement changes associated with the CMV configuration and provide a firm-fixed-price contract structure through HALO delivery and on-orbit checkout. The HALO PDR closeout will occur in the June 2021 timeframe.

xEVA will release a request for proposals for the xEVA production and services contract and will complete the assembly and testing of the integrated xEMU design verification test unit. Additionally, Gateway and the International Space Station programs together will conduct simulated EVAs with SERFE on ISS.

GATEWAY

KEY ACHIEVEMENTS PLANNED FOR FY 2022

A Gateway Program PDR Sync Review is planned for Q2 of FY 2022 in preparation for KDP-I. An Agency Baseline Commitment (ABC) and a Program Commitment Agreement (PCA) will be established at this KDP.

The HALO and PPE elements will conduct their Critical Design Reviews in Q2 of FY 2022.

A CMV launch vehicle Mission-Specific Preliminary Design Review is targeted for Q3 of FY 2022.

Thales Alenia Space Italy will be delivering the habitable element for HALO in Q4 of FY 2022, which will enable the start of the Assembly, Integration, and Testing cycle for HALO.

A CMV (PPE & HALO) Sync Point #2 is targeted for Q4 of FY 2022.

Program Projects

POWER AND PROPULSION ELEMENT (PPE)

The PPE project will provide electrical power and propulsion, orbital station keeping, orbital translation, and communication for the Gateway. It is being developed partially through a public-private partnership so that the capability is directly applicable to a wide range of NASA, commercial, robotic, and human spaceflight missions. PPE will leverage U.S. commercially available space system development and launch capabilities and align with anticipated industry needs, in particular with respect to power generation. It will provide transportation for the Gateway from Earth-orbit to cislunar orbit and between cislunar orbits, as well as perform needed orbital maintenance. PPE will provide altitude control for the Gateway in multiple configurations, accommodations for external research payloads, communication to and from Earth, and space-to-lunar communication. PPE will incorporate refueling capabilities. At the end of the Gateway's operational life, PPE will move the integrated Gateway stack to a disposal orbit.

The PPE project works with U.S. industry while leveraging Exploration Technology investments in Advanced Electric Propulsion Systems. PPE will demonstrate an advanced 50 kW-class SEP system, which combines an assortment of 12kW and 6kW SEP thrusters. PPE has a targeted delivery for launch integration in 2024.

HABITATION AND LOGISTICS OUTPOST (HALO)

The Gateway HALO project provides a livable section and short-duration life support functions for the crew in cislunar space. The docking ports allow for attachment to other elements and visiting vehicles. The HALO also provides attach points for external robotics, external payloads, and/or rendezvous sensors; thermal radiators that provide heat rejection and micro-meteoroid protection; and additional habitat systems that provide accommodations for crew exercise, science/utilization, and stowage. Some functions may be outfitted via future logistics flights. HALO is designed based on Northrup Grumman’s Cygnus spacecraft, which is used for ISS cargo missions. HALO will have an extra section, or bay, compared to the current three-bay Cygnus used on cargo missions. This stretched version will provide more volume and ensure adequate clearance for spacecraft to use its docking ports. HALO will have one axial and two radial docking ports, power distribution systems, and command and control systems. Under an agreement with Northrop Grumman, JAXA will provide batteries for HALO. HALO will be launched with PPE as an integrated vehicle on a SpaceX Falcon Heavy commercial rocket.

Deep Space Logistics (DSL) Services

The functional reality of human habitation in any location on Earth or in space is that it involves the consumption of resources and the generation of waste. The Deep Space Logistics Services project handles transportation of cargo to and from the Gateway. The orbit of the Gateway is optimized to enable Orion access and commercial logistics delivery for ongoing resupply of the Gateway.

Logistics flights are being considered for cargo delivery to the Gateway to support potential lunar surface operations, if needed. A logistics flight will also deliver the Canadian robotics arm.

The Logistics spacecraft will have their own power, propulsion, and navigation systems to rendezvous autonomously with the Gateway in cislunar orbit and dock at a radial port. The Logistics spacecraft will provide consumable resupply, outfitting equipment, and cargo delivery and disposal, including utilization and spares.

A Gateway Logistics Services contract was awarded to SpaceX in March 2020. Authority To Proceed has not yet been provided for this contract award.

Exploration Extravehicular Activity (xEVA)

NASA is developing the xEVA System to enable crewed exploration of the lunar surface and provide updated EVA systems for all future human space flight missions. The xEVA System encompasses the complete suite of hardware required to conduct spacewalks on the lunar surface and the associated vehicle interfaces for servicing, recharge, and consumables exchange. The largest element of the xEVA System is the xEMU, NASA’s next generation spacesuit. It is designed to enable surface and microgravity EVA from an airlock and requires minimal in-flight maintenance.

The xEMU is optimized for lunar surface missions and addresses the most challenging requirements for mobility, environmental protection, and spacewalk durations. The xEMU will tolerate the lunar thermal and dust environment and will incorporate features to minimize dust migration into the habitable environment. The xEMU baseline design has been formulated using lessons learned from NASA's experience on ISS and will form the foundation for the upcoming request for proposals for the xEVA production and services contract.

International Habitat (I-Hab)

The I-Hab module is a contribution from ESA and will provide additional crew habitation and workspace, as well as additional environmental systems capability. This module will also provide additional docking ports and accommodations for internal and external science experiments. I-Hab's environmental control and life support systems will augment the life support system capabilities provided by HALO and the docked Orion, enabling longer durations at the Gateway and supporting more robust Artemis missions to the lunar surface. JAXA will provide environmental control and life support systems, batteries, thermal control systems, and imagery systems for the I-Hab. Delivery of I-Hab to the Gateway will be via the SLS Block 1B launch vehicle with Orion providing orbital insertion and docking.

EUROPEAN SYSTEMS PROVIDING REFUELING, INFRASTRUCTURE, AND TELECOMMUNICATIONS (ESPRIT)

The ESPRIT module will provide refueling and additional capability for Gateway. The ESPRIT module will also offer a small pressurized workspace for the crew equipped with large windows offering 360-degree views of the Moon and spacecraft as they approach and dock to the Gateway.

GATEWAY EXTERNAL ROBOTICS SYSTEMS (GERS)

NASA and CSA reached an agreement for CSA to provide the Gateway's external robotics system, including a next-generation robotic arm, known as Canadarm3. Canadarm3 will move end-over-end to reach many parts of the Gateway's exterior. CSA also will provide robotic interfaces for Gateway modules, which will enable crew and ground control for payload/experiment installation and manipulation. This robotics capability could also provide support for future Gateway EVA considerations. Delivery of the Canadarm3 to Gateway will be via a commercial logistics supply flight.

GATEWAY AIRLOCK

A Gateway Airlock module could be used to perform Extra-Vehicular Activities (EVA) outside the orbiting platform. An airlock could be a part of a future Gateway evolution to enable EVAs and Extravehicular Robotics (EVR) transfer for utilization and equipment between internal and external volumes. Originally planned to be provided by an International Partner, there is not a current designated provider for this capability. NASA will continue to discuss Airlock options with the International Partner community.

Program Schedule

The Gateway elements and final configuration are in the formulation phase. During FY 2021, NASA will make significant progress on updating the PPE and HALO contracts with final requirements, completing preliminary design reviews, and ramping up manufacturing operations.

Date	Significant Event
Q2 FY 2021	Gateway Delta System Definition Review (SDR)-informed Sync Review (Completed)
Q3 FY 2021	Gateway KDP-0 (Completed)
Q2 FY 2022	Gateway PDR-informed Sync Review
Q3 FY 2022	Gateway KDP-I

Program Management & Commitments

The Human Exploration and Operations Mission Directorate (HEOMD) Associate Administrator (AA) assigned authority for the Gateway Program to Johnson Space Center (JSC). The Program Manager reports to the Deputy Associate Administrator (DAA) for Advanced Exploration Systems (AES) in coordination with the HEOMD AA. The Gateway program will make an Agency Baseline Commitment (ABC) for the initial capability spacecraft following the PDR-informed Sync Review at KDP-I. xEVA will make an ABC following its system-level PDR and KDP-C.

Program Element	Provider
Power and Propulsion Element	Provider: Maxar Technologies Lead Center: Glenn Research Center (GRC) Performing Center(s): GRC and JSC
HALO	Provider: Northrop Grumman Lead Center: JSC Performing Center(s): JSC and Marshall Space Flight Center (MSFC)
Logistics	Provider: SpaceX Lead Center: Kennedy Space Center (KSC) Performing Center(s): KSC
xEVA	Provider: TBD Lead Center: JSC Performing Center(s): TBD

Acquisition Strategy

The acquisition of the Gateway incorporates a hybrid mix of contracted development, international and domestic partnerships, in-house expertise, and potentially other initiatives that have not yet been identified. All approaches that improve NASA's acquisition agility and responsiveness to an evolutionary mission will be considered. The comprehensive attribute that binds the Gateway acquisition strategy is adherence to NASA's strategic principles for sustainable exploration.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
PPE (May 2019)	Maxar Technologies	Westminster, CO
HALO (Jun 2020)	Northrop Grumman	Dulles, VA
Gateway Logistic Services (Mar 2020)	SpaceX	Hawthorne, CA
CMV Launch Vehicle Provider (Feb 2021)	SpaceX	Hawthorne, CA

GATEWAY

INDEPENDENT REVIEWS

*Independent review of PPE will be in conjunction with the Baseline Completion Review.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PPE Authorization Review	Independent Review Team (IRT) Goddard Space Flight Center (GSFC) chaired; NASA members	Jul 2017	Independent review to support HEOMD Directorate Program Management Council (DPMC) decision to proceed with PPE	Passed	PPE Baseline Completion Review
Gateway Formulation Synchronization Review (FSR)	Independent Review Team	Feb 2019	Equivalent to an SRR, the FSR evaluated the program's functional and performance requirements, ensuring proper formulation and correlation with Agency and HEOMD strategic objectives	Program cleared to proceed to next phase	Gateway SDR
Gateway Program Systems Design Review (SDR)	Standing Review Board (SRB)	Jun 2020 Delta - Mar 2021	To evaluate the completeness/ consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and determine if the project is sufficiently mature for Gateway Program KDP-0	Passed	Gateway PDR-informed Sync Review
Gateway Program PDR	SRB	2022	To evaluate the completeness/ consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and determine if the project is sufficiently mature for Gateway Program KDP-1	TBD	KDP-I

HUMAN LANDING SYSTEM

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**654.1**	**928.3**	**1,195.0**	**1,266.7**	**1,579.5**	**1,989.0**	**1,807.2**
Change from FY 2021			**266.7**				
Percentage change from FY 2021			**28.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Shown here is an artist's rendition of the SpaceX's Starship Human Landing System (HLS), which NASA has selected to return humans to the lunar surface.

The Human Landing System (HLS) program is an integral part of achieving NASA's Artemis goals through landing U.S. astronauts, including the first woman and first person of color, on the Moon as part of a sustained exploration program.

Utilizing partnerships and competition to ensure affordability, the program will support industry development of an integrated landing system. Under the selected proposal for the initial lunar landing demonstration, two crew members will travel to lunar orbit in the Orion spacecraft and board the HLS for the final leg of their journey to the surface of the Moon. After approximately a week exploring the surface, crew will board the HLS for their trip back to lunar orbit where they will return to Orion before heading back to Earth.

NASA teams will be embedded with U.S. industry to provide insight and expertise to ensure it meets NASA's performance requirements and human spaceflight standards. These agreed-upon standards, which range from the technical areas of engineering, safety, health, and medical, are a key tenet of safe systems.

On April 16, 2021, NASA announced the selection of SpaceX to deliver the next American astronauts from lunar orbit to the surface of the Moon aboard the company's Starship Human Landing System. At the time of publication, protests have been filed with Government Accountability Office (GAO) concerning the HLS selection. NASA is awaiting resolution of the GAO process before proceeding with contract award. NASA will release an updated schedule for Artemis missions after the GAO process is resolved.

In addition, NASA intends to contract for sustainable transportation services to and from the lunar surface for long-term exploration of the Moon staged from the Gateway. The Agency has announced plans regarding NASA’s Lunar Exploration Transportation Services (LETS) to achieve service missions for the late 2020’s and is reaching out to all potential industry providers for input. NASA intends to support the development and use of multiple landing systems through various contractual mechanisms both leading up to and subsequent to the initial crewed demonstration to maintain competition in the HLS program.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

NASA selected three U.S. companies to design and develop HLS for the Agency's Artemis Program. The human landing system awards under the Next Space Technologies for Exploration Partnerships (NextSTEP-2) Appendix H Broad Agency Announcement (BAA) were firm-fixed price, milestone-based contracts. The total combined value awarded for the contracts was $856 million for the base period.

The following companies were selected to design human landing systems during the base period:

Blue Origin of Kent, Washington, is developing the Integrated Lander Vehicle (ILV) – a three-stage lander to be launched on its own New Glenn Rocket System and the United Launch Alliance's (ULA) Vulcan launch system.

Dynetics (a Leidos company) of Huntsville, Alabama, is developing the Dynetics Human Landing System (DHLS) – a single structure providing the ascent and descent capabilities that will launch on the ULA Vulcan launch system.

SpaceX of Hawthorne, California, is developing the Starship – a fully integrated lander that will use the SpaceX Super Heavy rocket.

These companies offered three distinct lander and mission designs, offering dissimilar redundancy, driving a broad range of technology development and, ultimately, more sustainability for lunar surface access.

WORK IN PROGRESS IN FY 2021

Through early FY 2021, NASA and its three industry partners advanced the partner designs to Preliminary Design Review (PDR) maturity culminating in a continuation review in December 2020 and in partner proposals for the continued development and demonstration of the lunar lander. NASA evaluated the proposals received and, on April 16, 2021, NASA announced the selection of SpaceX to deliver the next American astronauts from lunar orbit to the surface of the Moon aboard the company's Starship Human Landing System. At the time of publication, protests have been lodged with GAO concerning the HLS selection and the selection is under GAO review. NASA is awaiting resolution of the GAO process before proceeding with contract award.

In addition to the crewed demonstration mission to the Moon, NASA intends to contract for sustainable surface transportation services for long-term exploration of the Moon staged from the Gateway. The Agency is developing the structure of the procurement for the service of providing future lunar crewed missions and is reaching out to all potential industry providers for input. NASA has also announced plans for the NextSTEP-2 BAA Appendix N, which will used to fund continued development of other landing systems in the runup to the competition for the lunar crewed transportation services procurement.

HUMAN LANDING SYSTEM

KEY ACHIEVEMENTS PLANNED FOR FY 2022

HLS, with industry, will continue to design and develop lander systems for the initial return of American astronauts to the lunar surface.

NASA will continue to engage with industry as it develops a path forward for the procurement of sustainable lunar surface transportation services.

Program Elements

HLS PROGRAM MANAGEMENT

Human Landing System Program Management is responsible for executing programmatic roles assigned to Marshall Space Flight Center (MSFC) by the Human Exploration and Operations Mission Directorate (HEOMD). The HLS Program Office will oversee all HLS verification, validation and certification to ensure requirements for flight readiness and satisfy NASA's standards for crew safety and human rating.

HLS is responsible for the insight and oversight activities in collaboration with commercial partners associated with human landing system hardware development, integration, and flight demonstration, leading to services for NASA. HLS performs risk reduction activities and identifies and prioritizes upgrades to the human landing systems so it can support sustainable future exploration missions. HLS will include a lander ground operations office at Kennedy Space Center (KSC), and both a crew compartment office and a lander flight operations office at Johnson Space Center (JSC). HLS will also prioritize and coordinate collaboration resources across multiple NASA centers and manage major integrated system test activities (as applicable).

HUMAN LANDING SYSTEMS

HLS will provide the landing system that will carry astronauts to and from the lunar surface. The selected design will complete an uncrewed landing demonstration followed by a crewed landing demonstration that includes astronaut exploration of the surface.

HLS will establish a plan for the procurement of sustainable transportation services to and from the lunar surface for the long-term exploration of the Moon staged at the Gateway.

Program Schedule

Date	Significant Event
Mar 2020	Selected and awarded multiple industry partners for base contract period
Apr 2021	Selected SpaceX for initial HLS demonstration mission (selection under protest)
TBD	Uncrewed HLS demonstration

HUMAN LANDING SYSTEM

Date	Significant Event
TBD	Crewed HLS demonstration
TBD	First mission utilizing sustainable transportation services to and from the lunar surface

Program Management & Commitments

Program Element	Provider
HLS Program Management	Lead Center: MSFC Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), Goddard Space Flight Center (GSFC), Stennis Space Center (SSC), JSC, KSC Cost Share Partner(s): TBD
Integrated Lander Partner(s)	Provider: TBD Lead Center: MSFC Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

The HLS program utilizes the NextSTEP BAA contract vehicle. Through this approach, NASA awards firm-fixed-price, milestone-based proposals to enable rapid development of a crewed flight demonstration of the human landing system. NASA has structured the solicitation to award contracts with the following contract line item numbers (CLINs):

Base CLIN - contract award through 10 months - only long-lead items supporting the first mission and various design activities are allowed during this base period.

- Option A CLIN - flight and landing demonstrations of human landing systems.

The HLS program is currently evaluating acquisition vehicles for sustainable transportation services to and from the lunar surface for long-term exploration of the Moon staged from the Gateway. The Agency has announced the intent to procure future crewed Moon missions through NASA's Lunar Exploration Transportation Services (LETS).

MAJOR CONTRACTS/AWARDS

Next Space Technologies for Exploration Partnerships (NextSTEP-2) Appendix H Broad Agency Announcement (BAA) Option A: Selected SpaceX of Hawthorne, California. SpaceX is developing the Starship – a fully integrated lander that will use the SpaceX Super Heavy rocket.

HUMAN LANDING SYSTEM

At the time of publication, protests have been lodged with GAO concerning the HLS selection and the selection is under GAO review. NASA is awaiting resolution of the GAO process before proceeding with contract award.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Human Landing Systems Program	Standing Review Board (SRB)	Spring 2022	To evaluate the completeness/ consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and determine if the project is sufficiently mature for HLS Program Key Decision Point (KDP)-C	TBD	KDP-C

Historical Performance

The human landing system awards under the Next Space Technologies for Exploration Partnerships (NextSTEP-2) Appendix H Broad Agency Announcement (BAA) advanced the HLS designs to maturity. The next phase of the program will be determined after resolution of the GAO process.

HUMAN RESEARCH PROGRAM

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**125.0**	**115.0**	**130.2**	**140.0**	**145.0**	**145.0**	**145.0**
Change from FY 2021			**15.2**				
Percentage change from FY 2021			**13.2%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

NASA astronaut Victor Glover is shown here installing gear for MVP Cell-06, an investigation developing a biological model to study the effects of spaceflight on musculoskeletal disease.

Sending astronauts into space involves a multitude of complicated systems, but perhaps the most complex is the human system – human health, human factors (i.e., how crews interact with their environment, including the spacecraft, habitat, and systems during missions), and the crew interactions. While NASA has more than 50 years of crew experience in low-Earth orbit (LEO), researchers are continuing to unravel the mysteries of how the human body responds to the harsh environment of space. The Human Research Program (HRP) is responsible for understanding and mitigating the highest risks to astronaut health and performance to ensure crews remain healthy and productive during long-duration missions beyond LEO.

As NASA prepares to conduct crewed missions via the Artemis Program to cislunar space and the lunar surface, HRP is developing the scientific and technological capabilities to support these exploration missions. In support of the risk reduction strategy for human space exploration contained in the human research roadmap, HRP is coordinating with the National Academies, the National Council on Radiation Protection and Measurements (NCRP), and other domestic and international partners to deliver products and strategies to protect crew health and performance during and after exploration spaceflight missions. Current research on the International Space Station (ISS) in LEO and in ground-based analog laboratories is expanding our capabilities to enhance crew performance and protect the health and safety of astronauts. Investigations regarding space radiation protection, deep space habitat systems, behavioral health, innovative medical technologies, advanced food and pharmaceutical systems, space suit requirements, and validated countermeasures are evolving to ensure crew health. HRP also collaborates with NASA's Office of Chief Health and Medical Officer (OCHMO) and the Crew Health and Safety (CHS) and Spaceflight Crew Operations (SFCO) offices to research these issues and answer other questions to ensure crew health, safety, and mission success. SFCO and CHS are responsible for astronaut training, readiness, and health, while HRP funds research development on human health and performance countermeasures, knowledge, and technologies that enable safe, reliable, and productive human space exploration.

Space poses significant health risks for crewmembers, including the possibility of long-term health effects manifesting later in life from space radiation exposure, health and performance decrements developing during the mission, and decrements in capabilities immediately upon return to Earth. HRP is working with the Advanced Exploration Systems (AES), CHS, and Orion teams on both in-mission and post-mission countermeasures, medical treatment capabilities to maximize crew health and performance, and rehabilitation protocols to minimize residual impacts on the crew, to minimize exposures, and to provide radiation protection. The collaborative efforts involve defining permissible exposure limits, requirements for real-time medical response, optimized mission architectures, biomedical monitoring, and potential drug or nutritional countermeasures, as well as incorporating post-mission health surveillance to ensure that crewmembers can safely live and work in space without exceeding acceptable health risks.

In collaboration with other Federal agencies, such as the Department of Defense (DoD), the Department of Energy (DOE), the National Science Foundation (NSF), the Department of Health and Human Services (HHS), and the National Institutes of Health (NIH), HRP supports human research to increase our understanding of the effects of spaceflight on human physiological systems, behavioral responses to isolation and confinement, and space radiation health effects. This knowledge enables NASA's plans for long-duration human space missions beyond LEO. In addition, as is the case with many space-based medical investigations, this research may lead to significant advancements in treating patients on Earth.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

HRP researchers conducted 16 ISS biomedical research investigations across ISS Expeditions 61/62/63, completed three flight investigations, and initiated one flight research investigation with the start of pre-flight baseline data collection or in-flight data collection. ISS studies to mitigate the risk of long-duration spaceflight included the following: 1) standardized behavioral measures; 2) exploration food technology assessments; 3) core measurements on human spaceflight risks from astronauts before, during, and after long-duration missions; 4) human factors assessments on operational tasks and team effectiveness; 5) exploration of fresh-food production system; and 6) assessment of dynamic vertebral strength and injury risk following long-duration spaceflight.

HRP researchers for Fluid Shifts completed post-flight data collection of the 13th and final subject. Fluid Shifts began with the first One-Year Mission crew of Scott Kelly and Mikhail Kornienko and enrolled five Russian cosmonauts and eight U.S. Orbital Segment astronauts over the course of five years to investigate the effects of spaceflight-induced head-ward fluid shift on vascular, ocular, and central nervous system structure and function. The team, which included researchers from NASA, the European Space Agency (ESA), the Institute of BioMedical Problems (IBMP), and multiple universities, investigated one of HRP's highest exploration risks, the Spaceflight Associated Neuro-ocular Syndrome (SANS). The team demonstrated the efficacy of the Russian Chibis, a lower body negative pressure device, as a potential SANS countermeasure, and identified the first in-flight venous thromboembolism, which is currently being reviewed to determine if there is a possible relationship to SANS.

HRP researchers also began in-flight data collection for the new Food Physiology study. The primary purpose of this joint HRP/Space Biology study is to determine effects of diet quality on immune regulation, the taxonomic and metatranscriptomic profile of the gut microbiota, and nutritional biomarkers and metabolites at selected intervals. The start of the study represented the culmination of a multitude of coordination efforts across HRP, the Food Lab, and ISS to implement a comprehensive modification to the subject's diet and perform the first fecal processing operations on ISS to stabilize RNA for later analysis on the ground.

HRP continued to implement the ISS Spaceflight Standard Measures project that collects a set of core measurements from astronauts important for understanding many of the human spaceflight risks before, during, and after long-duration ISS missions. The project is designed to acquire a consistent set of validated, measured parameters that document the spaceflight normal response, as well as variations in the astronaut population in response to diverse duration exposures to spaceflight. The results will function as a data repository for investigators to develop hypotheses, provide supporting experimental data, or be used in astronaut and Earth-based epidemiology assessments.

HRP continued working with the Translational Research Institute for Space Health (TRISH) to solicit research and educate the next generation of space life scientists. TRISH focuses on rapidly translating fundamental research concepts into practice and thereby generating tangible health outcomes—in this case, for astronauts. During FY 2020, TRISH had 77 active projects in its Science and Technology pipeline and released five research announcements: 1) Biomedical Research Advances for Space Health; 2) an industry solicitation of proposals from small U.S.-based companies for technologies that would be essential for self-reliant healthcare in deep space; 3) a solicitation to issue transition awards to early career scientists; 4) a solicitation seeking to manipulate human metabolism and homeostasis at the cellular or whole organism level; and 5) a solicitation for postdoctoral fellowships.

In the area of behavioral health and performance and the effects of isolation, HRP relies on ground analogs to support risk mitigation. In FY 2020, HRP completed the final mission of the fifth Human Exploration Research Analog (HERA) campaign, with each campaign consisting of four 45-day isolation missions using the HERA facility located at Johnson Space Center (JSC). Each HERA mission uses crews of four supported by a mission control team and includes a portfolio of research and operational tests to be conducted during the simulated exploration mission. Additionally, HRP commenced preparation for the next in a series of long-duration isolation and confinement studies at the Nezemnyy Eksperimental'nyy Kompleks (NEK) facility in Moscow, Russia, in collaboration with the Russian Institute for Biomedical Problems. HRP also undertook joint NASA/NSF Antarctic analog studies to support behavioral health and performance and immune research. During FY 2020, the 2019 Antarctic winter-over campaign concluded with HRP completing two research studies focused on crew composition and teamwork using U.S. Antarctic program volunteers at the McMurdo and Amundsen-Scott South Pole Stations. The 2020 Antarctic winter-over campaign was also started with two studies focused on immune response at the McMurdo, Amundsen-Scott, and Palmer Stations.

HRP conducted joint NASA/ESA/German Aerospace Center (DLR) analog studies to support human health countermeasures, exploration medical, and behavioral health and performance research at the DLR Institute of Aerospace Medicine facility in Cologne, Germany. The final campaign of the Artificial Gravity Bed Rest with the European Space Agency (AGBRESA) study was completed in FY 2020 following post-bed rest Baseline Data Collection. The study involved a total of 24 test subjects across two bed rest campaigns, each of whom spent 60 days in a strict six-degree head down tilt bed rest, to examine the effects of centrifugation as a potential countermeasure to some of the physiological effects of space flight.

HUMAN RESEARCH PROGRAM

In support of future human exploration missions, HRP research resulted in recommended updates to physiological medical standards to better protect muscle and aerobic capacity and better methods to maintain team function and performance. HRP also continued space radiation research in support of human exploration at the NASA Space Radiation Laboratory using the galactic cosmic ray simulator for a more realistic simulation of the actual radiation environment found in space.

WORK IN PROGRESS IN FY 2021

HRP will continue to work on the highest human health and performance risk areas associated with human space exploration missions. To support this work, HRP will release NASA research solicitations to the national biomedical research community to better address the exploration spaceflight health, performance, and space radiation risks.

HRP will continue to implement a research plan that fully utilizes the ISS biomedical research capabilities to collect a set of core measurements related to many human spaceflight risks, study the effects of diet quality on immune regulation, and assess the performance capabilities of deconditioned crew, collaborate with CHS on ISS studies related to visual impairment, carbon dioxide analysis, and exercise systems; leverage resources and expertise through collaborative research with other NASA programs, international partners, and other U.S. agencies (e.g., DoD, DOE, NSF, HHS, NIH).

HRP will implement an ISS research plan that fully utilizes the ISS biomedical research capabilities to test mitigation approaches and validate countermeasures including the following: 1) technology demonstration of hardware to differentiate and count white blood cells in microgravity; 2) assessment of astronauts' post-landing functional capacity; 3) researching the effects of diet quality on immune regulation, profile of the gut microbiota, and nutritional biomarkers and metabolites; and 4) HRP-sponsored rodent study to determine whether microgravity alters the structure and function of the ocular vasculature in mice.

In support of exploration medical capability, HRP will develop an improved trade study evaluation and research prioritization tool suite to provide a data-driven means to inform human health and performance risk mitigation interests during resource-constrained exploration mission development. HRP will be evaluating a commercial-off-the-shelf flow cytometer device on ISS to determine whether the spaceflight environment affects its operation. HRP is also developing requirements for a clinical decision support system, which will help crews assess and diagnose conditions, determine appropriate responses, and guide treatment.

HRP and DLR will implement a study to assess the effectiveness of different countermeasures to mitigate the SANS symptoms observed in prior bedrest studies using the DLR: envihab facility. During the new campaign, the subjects will be assigned to one of six groups: 1) will experience lower body negative pressure (LBNP) for 6 hours each day; 2) will serve as a control for the LBNP condition and be seated upright for 6 hours each day; 3) will conduct prescribed exercises for 45 minutes per day six days out of each week; 4) will receive a daily B-vitamin complex supplement; 5) will serve as a seated control and sit upright for 16 hours per day and supine at night; and 6) will serve as a control and will be at six-degree head-down tilt only. Investigators will compare subjects with head-down bedrest or seated only to subjects experiencing head-down bedrest in combination with countermeasures on aspects such as ocular measures, cerebral measures, cognition, neuroimaging, and structural and functional Magnetic Resonance Imaging (MRI). Subjects in all groups except the 16-hour seated condition will adhere to strict six-degree head-down tilt bedrest for the 30-day duration of each bedrest campaign.

HUMAN RESEARCH PROGRAM

In understanding the behavioral and physiological health challenges associated with isolation and confinement, HRP will continue implementing collaborative NASA/NSF human health and performance studies on the effects of remote location, extreme isolation, and confinement during winter-over missions in Antarctica using the NSF polar stations. HRP will also undertake a mission on long-duration isolation and confinement studies in collaboration with Russia and it will continue the 45-day HERA studies at JSC In the Scientific International Research in Unique Terrestrial Station (SIRIUS) 21 mission, crew members will conduct experiments on behalf of nearly 70 different researchers from around the world, including eight studies funded by HRP over the course of an 8 month mission spent isolated in the NEK facility

In support of Artemis and future exploration missions, HRP continues to support Gateway Crew Health and Performance System requirements definition, deliver habitat standards and evaluation tools, evaluate exploration habitats, and deliver food system requirements and nutritional recommendations. HRP has proposed Phase I Artemis payloads to support HRP science goals. HRP will work to transition payload proposals to implementation. HRP is currently engaged in defining science objectives for Gateway experiments, as well as providing science objective recommendations for extended Artemis missions.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

HRP will implement an ISS flight research plan critical to mitigating crew health and performance risks for Artemis missions that includes the following: ISS Standard Measures Project to capture a core set of physiological and performance measures from crew members to accurately characterize the adaptive responses to long-duration spaceflight and monitor the effectiveness of countermeasures; a microbial risk assessment study to ensure crew safety and allow increased dependence on bioregenerative food systems; and a study on detecting individual performance susceptibilities to sleep loss and circadian desynchronization to optimize individualized countermeasures during spaceflight. HRP also plans to implement an ISS research project to characterize the time courses of physiological and psychological measures on missions up to one year in duration to understand the impact to human health and performance during future long-duration planetary missions. This project will be known as CIPHER - Complement of Integrated Protocols for Human Exploration Research.

HRP will leverage resources through multiple research partnerships, including advanced food and nutrition studies with DOD, behavioral and physiological studies during winter over campaign at NSF polar facilities, isolation and confinement studies with Russia, bed rest studies at the DLR :envihab facility, and develop joint flight research and data sharing with international partners.

In support of Artemis missions, HRP will also develop space habitat standards and evaluation tools for use in designing and evaluating spacecraft volume and layout to optimize crew performance and develop research and technical flight objectives for Gateway experiments and lunar surface missions.

Program Elements

EXPLORATION MEDICAL CAPABILITY

As NASA makes plans to extend human exploration beyond LEO, identifying and testing next generation medical care and crew health maintenance technologies is vital. Healthcare options evolve based on experience, anticipated needs, and input from flight surgeons and crew offices. During future Mars missions, crews will not be able to rely on real-time conversations with Earth-based medical experts in the future due to communication lag-time associated with the distance between Earth and deep space. Therefore, crew and relevant systems will have to be able to facilitate autonomous medical care operations. Teams in this area draft requirements for medical equipment and clinical care, develop remote medical technologies, and assess medical requirements unique to long-duration space missions.

HUMAN HEALTH COUNTERMEASURES

Countermeasures are the procedures, medications, devices, and other strategies that offset the impacts of spaceflight stressors (e.g., low-gravity, closed environment) and help keep astronauts healthy and productive during space travel and after their return to Earth. Researchers are responsible for understanding the normal physiologic effects of spaceflight and provide biomedical expertise and develop countermeasures to harmful effects on human health and performance. These experts define health and medical standards; validate human health prescriptions and exercise system requirements; develop injury and sickness prevention standards; integrate and validate physiological countermeasures; and establish criteria for NASA fitness for duty, as well as crew selection and performance standards.

HUMAN FACTORS AND BEHAVIORAL PERFORMANCE

Just as the space environment poses physical risks to crewmembers, the unique stresses and challenges of spaceflight, as well as the vehicle design, can affect cognitive and mental performance. Considering external factors is essential when designing a spacecraft, habitat, or spacesuit. Human factors experts develop new equipment, procedures, and technologies designed to make the space environment more livable. Behavioral health researchers assess the impact of space travel on human behavioral health and develop interventions and countermeasures to ensure optimal health and performance. Experts in this area make extensive use of analogs, which are experimental environments created to simulate certain aspects of space travel. By duplicating space conditions, such as altered day and night cycles, heavy workloads, social isolation, and close living quarters, scientists gain insight into the impact of these circumstances on human behavior and performance. Scientists then work to develop countermeasures, equipment, and other interventions to minimize these risks.

SPACE RADIATION

As NASA expands human presence beyond the Earth's protective magnetic field, it is critical that astronauts be able to safely live and work in a space radiation environment without exceeding exposure limits. Space radiation researchers develop the knowledge base necessary to determine the biological effects of space radiation. This information can then be used for standards for health and habitability and the requirements for radiation protection. They also develop tools to assess and predict risks due to space radiation exposure and strategies to mitigate exposure effects. The deep space radiation environment is far different from that on Earth or in LEO. NASA and the DOE have partnered on a facility at Brookhaven National Laboratory in Upton, NY to simulate the deep space radiation environment, which researchers use to help understand its biological effects.

RESEARCH OPERATIONS AND INTEGRATION

The ISS provides a unique testbed for HRP activities. The Research Operations and Integration (ROI) element plans, integrates, and implements HRP-approved biomedical flight experiments on the ISS, as well as research studies that use ground-based spaceflight analog facilities to accomplish program objectives. These experiments and studies pertain to pre- and post-flight activities, and the program objectives include coordinating flight or ground resources with our international partners, maintaining the Human Research Facility (HRF) biomedical research racks on ISS and flight hardware, and developing crew training for both flight and ground investigations. Teams also operate a Telescience Support Center (TSC), which provides real-time support and data services to all HRP flight experiments. Strong interfaces with external implementing organizations, such as the ISS Research Integration office, analog coordination offices, and international partners, are critical to maintaining a robust research program. This group is also responsible for operating the HERA facility and for arranging access to other analog facilities required by HRP researchers, including NSF Antarctic facilities and international partner facilities in Germany and Russia.

Program Schedule

Date	Significant Event
May 2021	2020 Human Exploration Research Opportunity (HERO) NASA Research Announcement Selections
Jun 2021	Deliver Inputs to Vehicle and Medical Standards for Lighting
Jun 2021	Deliver Validated Key Indicators of Team Functioning and Performance
Aug 2021	Release 2021 HERO NASA Research Announcement
Sep 2021	Characterize SANS Fluid Shift Hypothesis

HUMAN RESEARCH PROGRAM

Program Management & Commitments

The program office is located at JSC with support from Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), and Kennedy Space Center (KSC).

The Human Exploration and Operations Mission Directorate (HEOMD) Associate Administrator delegated the authority, responsibility, and accountability of HRP management to the Human Spaceflight Capabilities Division at NASA Headquarters. Working closely with the Office of the Chief Scientist and the OCHMO, the Division establishes the overall direction, scope, budget, and resource allocation for the program, which the NASA centers then implement.

Program Element	Provider
Exploration Medical Capability	Provider: JSC Lead Center: JSC Performing Center(s): GRC, ARC, and LaRC Cost Share Partner(s): N/A
Human Health Countermeasures	Provider: JSC Lead Center: JSC Performing Center(s): ARC and GRC Cost Share Partner(s): N/A
Human Factors and Behavioral Performance	Provider: JSC Lead Center: JSC Performing Center(s): ARC, GRC, and KSC Cost Share Partner(s): N/A
Space Radiation	Provider: JSC Lead Center: JSC Performing Center(s): LaRC Cost Share Partner(s): N/A
Research Operations and Integration	Provider: JSC Lead Center: JSC Performing Center(s): N/A Cost Share Partner(s): N/A

Acquisition Strategy

Based upon National Academies' recommendations, external peer reviews, and Agency human exploration plans, NASA HRP awards contracts and grants to further efforts in mitigating risks to crew health and performance by providing essential biomedical research and technologies for human space exploration. HRP uses a peer review process that engages leading members of the research community to competitively assess the merits of submitted proposals to assure a high-quality research program.

HUMAN RESEARCH PROGRAM

HRP plans to release the HERO umbrella NASA Research Announcement (NRA) that will request research proposals across all its research elements throughout the year. This NRA provides opportunities for universities, other Government agencies, and industry researchers from across the Nation to develop high NASA priority ground and spaceflight experiments, which directly contribute to NASA's exploration mission.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Program Management	Translational Research Institute for Space Health	Baylor College of Medicine

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Peer Review Panel	Feb 2020	Peer review of NRA	Selected grantees	Feb 2021
Quality	National Council on Radiation Protection and Measurements (NCRP)	Sep 2020 - April 2021	Sex-differences in Lung Cancer Radiation Risks for use in Project Models	Reduced uncertainties and improved information for cancer risk projections	TBD
Quality	Independent Program Assessment	Jun 2019	Review of program management policies and practices	Verify adherence to NASA program management policies	Jun 2022

SPACE TECHNOLOGY

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Early Stage Innovation and Partnerships	119.8	117.5	**145.0**	147.9	150.8	153.9	157.0
Technology Maturation	179.2	227.1	**491.2**	501.0	511.1	521.3	531.7
Technology Demonstration	575.5	528.4	**501.8**	512.9	525.9	539.4	553.5
SBIR and STTR	225.5	227.0	**287.0**	292.7	298.6	304.6	310.7
Total Budget	**1,100.0**	**1,100.0**	**1,425.0**	**1,454.5**	**1,486.4**	**1,519.2**	**1,552.9**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Pursuant to P.L. 115-10 Title VII Sec 702(e), this budget is formulated in such a manner to avoid duplication of projects, programs, or missions conducted by other projects, programs, or missions conducted by another office or directorate of the Administration.

SPACE TECHNOLOGY

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Early Stage Innovation and Partnerships	119.8	117.5	**145.0**	147.9	150.8	153.9	157.0
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SBIR and STTR	225.5	227.0	**287.0**	292.7	298.6	304.6	310.7
Total Budget	**1,100.0**	**1,100.0**	**1,425.0**	**1,454.5**	**1,486.4**	**1,519.2**	**1,552.9**
Change from FY 2021			**325.0**				
Percentage change from FY 2021			**29.5%**				

On January 22, 2020, the Laser Communications Relay Demonstration (LCRD) flight payload was delivered to Northrop Grumman's facility in Sterling, Virginia. There the payload will be integrated onto the U.S. Air Force's Space Test Program Satellite 6 (STPSat-6) and prepared for launch. LCRD will be NASA's first end-to-end optical relay, sending and receiving data from missions in space to mission control on Earth. This image shows the LCRD space switching unit, which will enable digital communications from space to ground.

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The Space Technology Mission Directorate (STMD) is dedicated to developing transformative, cross-cutting technologies that enable NASA's missions while also supporting commercial and other government agencies' needs where appropriate. The Space Technology account supports the Administration's priorities of developing new technologies to enable human and robotic exploration of the Moon, Mars, and beyond and enhancing research and development to contribute to U.S. leadership in space technology. Through STMD, NASA invests in high-risk, high-reward activities across the technology development spectrum through partnerships with academia, entrepreneurs, and small and large businesses.

STMD actively engages its many stakeholders to identify opportunities of common interest to better leverage government investments. Through its Public-Private Partnerships, STMD invests in industry-developed space technologies that can advance the commercial space sector and benefit future NASA missions. STMD also promotes equity supporting underserved communities through its programs by increasing participation of women and socially or economically disadvantaged businesses, historically black colleges (HBCU), and minority serving institutions (MSI).

Space Technology investments keep NASA's technology pipeline growing with emerging, innovative technologies that benefits a wide range of users, ensuring the nation realizes the full economic value and societal benefit of these innovations. STMD's technology portfolio includes broad technology applications addressing multiple stakeholder needs. Technologies such as autonomous landing and hazard avoidance, advanced cryogenic fluid management, rapid and efficient transit propulsion, advanced materials, and in-space manufacturing and assembly technologies benefit both human and robotic exploration and spur economic growth in the space industry. Robotics, On-orbit Servicing, Assembly, and Manufacturing (OSAM), Small Spacecraft technologies, and Flight Opportunities are specific examples of technologies that support industry needs, thereby enhancing U.S. competitiveness for R&D, innovation, and technology advancement.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Space Technology portfolio is broadened to develop technologies that can benefit other NASA Directorates, the commercial space sector and other government agencies, as appropriate. As such, the FY 2022 budget request includes a new Industry & Commerce Innovation Opportunity which will utilize existing acquisition vehicles (such as Announcement of Collaborative Opportunity [ACO]/Tipping Points, Small Business Innovation Research [SBIR]) to pursue technologies needed by commercial space stakeholders. It also includes funding to enhance R&D investments to colleges and universities to enable breakthrough technology R&D in support of U.S. competitiveness and job creation.

ACHIEVEMENTS IN FY 2020

GO: RAPID, SAFE, AND EFFICIENT SPACE TRANSPORTATION

STMD's "Go" Thrust is focused on providing technologies that support rapid and efficient in-space transportation that reduce transit times to distant destinations. During FY 2020, STMD invested in key cryogenic fluid management and advanced propulsion technologies that directly contribute to enabling advanced space transportation capabilities.

- The Green Propellant Infusion Mission (GPIM) completed one year of on-orbit operations in September 2020, and successfully demonstrated a safer propellant alternative while providing 40 percent higher performance by volume. The results will help lower the cost of fueling spacecraft before launch and provide efficient propulsion solutions for small and large satellites.
- The Thruster Advancement for Low-temperature Operation in Space (TALOS) thrusters successfully developed and hot-fire tested two 150-pound-force (lbf) thrusters and two 10-lbf thrusters designed for low temperature operation in space in March 2020. The TALOS Project matures propulsion technology specifically designed for extreme cold tolerance as encountered during the long lunar nights without needing thermal management subsystems to prevent propellant freezing. The technology also features significant reductions in size, mass, complexity, and cost in comparison to state-of-the-art bipropellant thrusters of the same thrust class.
- The Composite Technology for Exploration (CTE) project developed and demonstrated critical composites technologies that provide weight-saving, performance-enhancing bonded joint technology

to be used on future NASA missions. The CTE Project completed longitudinal joint testing and associated non-destructive evaluation methods. NASA's Space Launch System (SLS) used the CTE longitudinal bonded joints as the baseline design for the SLS Payload adapter, which is the adapter used on the larger SLS Block 1B configuration for attaching co-manifested payloads. The technology was demonstrated on a manufacturing demonstration article. The project hopes to extend this to the Universal Stage Adapter as well as incorporate circumferential bonded joints in future structures.

- The Space Nuclear Propulsion (SNP) project continued testing fuel forms for low and moderate temperature thermo-chemical stability, evaluated fuel element design, and completed the feasibility assessment. NASA initiated studies in collaboration with several Government agencies and industry partners to develop candidate flight demonstration concepts. NASA revised a fuel and reactor development plan in March 2020, completed a Flight Demonstration Study in June 2020, and finished a nuclear thermal transient testing of fuel in September 2020. The test results will help inform potential future nuclear propulsion efforts.

LAND: EXPANDED ACCESS TO DIVERSE SURFACE DESTINATIONS

NASA human exploration and science missions are dependent on the capability to land large payloads on the surface of Mars while also avoiding landing in hazardous locations, such as on the steep slope of a crater or in a boulder field. STMD's "Land" thrust area focuses on Entry, Descent, and Landing (EDL) capabilities, including precision landing, which are critical to helping ensure a safe touch down for surface exploration of other worlds.

- The Safe and Precise Landing – Integrated Capabilities Evolution (SPLICE) technology suite, which includes precision landing sensor systems, advanced algorithms, and new software, flew on the Blue Origin New Shepard launch vehicle to 100 km altitude and successfully demonstrated precision propulsive landing.
- The Mars Entry, Descent and Landing Instrumentation-2 (MEDLI2) and the Terrain Relative Navigation (TRN) are technologies that were incorporated as part of the Mars 2020 Perseverance mission. Both MEDLI2 and TRN were successfully integrated into the Mars Perseverance spacecraft and the mission was successfully launched in July 2020.

LIVE: SUSTAINABLE LIVING AND WORKING FARTHER FROM EARTH

Sending human and robotic explorers to the Moon, Mars, and other planetary bodies requires technology investments beyond the current state of the art. Enabling sustainable operations for these human and robotic explorers requires efficient life support systems to enable long-duration missions without resupply from Earth and autonomous systems that augment operations during crewed and un-crewed mission segments. To reduce reliance on resource resupply from Earth, the capability of producing critical consumables and propellant from the local resources is needed. In FY 2020, STMD's "Live" thrust area made progress in the areas of In-Situ Resource Utilization (ISRU), autonomous robotic systems, and low-TRL life support systems technologies as well as other technologies required for long-duration spaceflight.

- Mars Oxygen In-Situ Resources Utilization Experiment (MOXIE) and Mars Environmental Dynamics Analyzer (MEDA) successfully launched in July 2020 as part of the Mars 2020 Perseverance mission. MOXIE successfully demonstrated the first oxygen production from the Martian atmosphere meeting its expected production rate and purity. This technology, when scaled, could be used for producing the necessary consumable for propellent and for breathing. MEDA is a Mars weather station, whose objective is to provide measurements of temperature, wind speed and direction, pressure, relative humidity, radiation, and dust size and particulate distribution in the Martian atmosphere.

- Lunar Surface Innovation Initiative (LSII) got underway in FY 2020, aiming to spur the creation of novel technologies needed for lunar surface exploration and accelerate the technology readiness of key systems and components. LSII activities are implemented through a combination of unique in-house activities, competitive programs, and public-private partnerships.
- In February 2020, STMD kicked off its Lunar Surface Innovation Consortium with the Johns Hopkins Applied Physics Laboratory which will team experts from academia, industry, and government to shape the technologies and systems needed to explore the surface of the Moon in new ways.
- In July 2020, NASA announced its new lunar surface technology research (LuSTR) opportunity, seeking U.S. universities' ideas to advance technologies needed for sustainable operations on the Moon.
- The Polar Resources Ice Mining Experiment (PRIME) project continued to make progress and completed the Preliminary and Critical Design Reviews in FY 2020 for two of its key instruments: Mass Spectrometer observing lunar operations (MSolo) and the Regolith and Ice Drill for Exploring New Terrain (TRIDENT). PRIME is a critical instrument suite that will be integrated on the Intuitive Machines commercial lunar lander that will land at the lunar South Pole to assess the volatiles and determine water content. PRIME will help provide the knowledge necessary to find critical resources to produce propellant, water, and oxygen for lunar missions.
- The Space Synthetic Biology (SSB) project demonstrated its second bionutrients flight experiment on the International Space Station (ISS). The five-year investigation of the long-term stability of a nutrient production system in space will continue to determine the effects of the space environment on survival and growth of engineered yeast and other biomanufacturing organisms.
- The Regenerative Fuel Cell (RFC) project is developing energy storage system technology to provide sustained and reliable electrical power for surface and near-surface missions where photovoltaic, battery or nuclear options are not feasible and will provide the capability to survive the Lunar night (14 days). In FY 2020, the RFC Project completed Conceptual Design Review, awarded multiple SBIR contracts for fuel cell and electrolyzer stacks, and successfully completed Preliminary Design Review of those subsystems.

EXPLORE: TRANSFORMATIVE MISSIONS AND DISCOVERIES

The STMD "Explore" thrust area focuses on technology developments that enable transformative missions and discoveries with high-performance computing, communications and navigation, autonomy technologies, and new vehicle platforms for science missions. The "Explore" thrust area also addresses challenges facing NASA and emerging space industries by developing capabilities such as satellite servicing and assembly, and in-space manufacturing. During FY 2020, STMD made progress in multiple areas, including advanced avionics, advanced communications and navigation, on-orbit servicing, assembly and manufacturing, small spacecraft technologies, and autonomous systems and robotics.

- The Deep Space Atomic Clock (DSAC), launched in 2019, successfully completed its first year of operations, and will continue into FY 2021. This mission successfully demonstrated a low-mass atomic clock based on mercury-ion trap technology, providing unprecedented stability needed for next-generation deep space navigation and radio science. The atomic clock on this mission offers 50 times greater accuracy than today's best space navigation clocks which will improve the navigation accuracy and allow for gravity science measurements to measure how well the clock keeps time down to the nanosecond. In controlled tests on Earth, demonstrations showed DSAC only losing one second every 10 million years.

- The Bulk Metallic Glass Gears (BMGG) project made progress towards demonstrating the capability of gearboxes to operate in extreme cold environments where temperatures are below -238 degrees Fahrenheit. In September 2020, BMGG successfully completed the cold life test of the planetary gears to test the survivability of the gears without heating and lubricant. These heater-free gearboxes could increase science return for in-space missions by reducing power consumption, mass, system complexity, and operational constraints.
- NASA performed swarm autonomous operations of multiple Autonomous Pop-Up Flat Folding Explorer Robot (A-PUFFER) robots navigating and exploring as a team on extreme terrain. The test successfully demonstrated autonomous capabilities of accurate instrument placement in extreme terrain with minimal operational intervention while coordinating with other mobile platforms. Further, NASA developed mission concepts to enlist these versatile robotic platforms for supporting Exploration and Science for reconnaissance of ISRU resources.
- Distributed Spacecraft Autonomy (DSA) Project completed a critical design assessment review in conjunction with the Small Spacecraft Technology Starling mission. DSA will be performing an in-space experiment demonstrating advance command and control methodologies for controlling a swarm of spacecraft as a single entity, demonstrate autonomous coordination between multiple spacecraft in the swarm, and demonstrate approaches for adaptive reconfiguration of the swarm's plan and distributed decision-making across the swarm.

LEAD: ENSURING AMERICAN GLOBAL LEADERSHIP IN SPACE TECHNOLOGY

NASA embraces competition and external partnerships by harnessing innovation and entrepreneurship through partnerships with universities, small businesses, emerging commercial entities and other government agencies to meet NASA exploration needs and support commercial expansion in space. During FY 2020, the STMD "Lead" thrust area contributed towards a robust national space technology engine to meet national needs, foster U.S. economic growth for the space industry, and expand the commercial enterprise in space.

- Through the Space Technology Research Grant Program, the Lunar Surface Technology Research (LuSTR) opportunity was announced to engage with talented teams at universities to develop technologies supporting NASA's Lunar Surface Innovation Initiative and the Artemis Program. LuSTR will enable lunar technology development and accelerate the readiness of systems and components needed for sustainable operations on the Moon. The inaugural solicitation focused on in-situ resource utilization and sustainable surface power.
- The Lunar Surface Innovation Initiative (LSII) established an agreement with the Department of Defense University Affiliated Research Center (UARC), the Johns Hopkins University Applied Physics Laboratory (APL), initiating the Lunar Surface Innovation Consortium (LSIC), which is comprised of experts from academia, non-profits, industry, and government to shape the technologies and systems needed to explore the surface of the Moon.
- Flight Opportunities flew 46 technology development payloads across 16 suborbital launch vehicles, high-altitude balloons, and aircraft parabolic flights.
- Through the ACO and Tipping Point acquisition mechanisms, STMD establishes partnerships focusing on advancing commercially developed space technologies that benefit both the commercial

and government use of space. In FY 2020, STMD awarded 17 ACO contracts for a total of $16 million and 15 Tipping Point fixed-price contract awards for a total of $372 million. NASA's support through partnerships with industry can accelerate the availability and reduce costs for the development and infusion of new emerging space capabilities.

- By FY 2020, the NASA Technology Transfer Program had over 1,545 New Technology Reports (i.e., Invention Disclosures) submitted, with more than 544 of these having at least one NASA inventor.
- In February 2020, the Breakthrough, Innovative and Game-changing (BIG) Idea Challenge, in partnership with the Space Grant project, announced nearly $1 million in awards to eight university teams to build sample lunar payloads and demonstrate new ways to study the Moon's polar regions.

WORK IN PROGRESS IN FY 2021

GO: RAPID, SAFE, AND EFFICIENT SPACE TRANSPORTATION

Making critical advancements in propulsion system technologies is one strategic objective of the STMD "Go" thrust area to enable transformative exploration missions. In FY 2021, STMD continued to invest in propulsion technologies focused on higher performance and efficiency, including alternatives to traditional chemical propulsion systems for deep space exploration spacecraft systems and advancement of additive manufacturing techniques.

- In FY 2021 through Public Private Partnership arrangements, NASA selected Eta Space, Lockheed Martin, SpaceX, and United Launch Alliance to develop and test technologies that enable long-term cryogenic fluid storage and management. These cryogenic fluid management technologies are essential for establishing a sustainable presence on the Moon, enabling crewed missions to Mars, and providing enhanced in-space transportation capabilities for commercial and government needs.
- The Solar Electric Propulsion (SEP) is developing and qualifying for flight the xenon thrusters for the Gateway Power and Propulsion Element (PPE). Once qualification is complete, the thrusters will be transferred to HEOMD and integrated onto the Gateway PPE for demonstration and mission use. The xenon thrusters will provide more efficient propulsion capability compared to conventional chemical propulsion systems. The SEP project is pursuing completing Critical Design Review (CDR) for the xenon thrusters by end of CY 2021. The team will conduct Laser Induced Fluorescence testing on a thruster engineering unit at Glenn Research Center and thermal vacuum chamber testing on a second thruster engineering unit at Jet Propulsion Laboratory. Other tests will focus on development of the thruster cathodes at wear/cycling conditions. The Plasma Diagnostics Package (PDP) Thruster Probe Assembly (TPA) engineering development unit will be assembled and placed through shock, vibration, and thermal vacuum test conditions.
- Thruster for Advancement of Low-temperature Operation in Space (TALOS) is successfully progressing towards a delivery of the Axial Thrusters to Dynetics for final vehicle integration in Summer 2021. TALOS is developing and qualifying a high-performance, lightweight, and compact axial, and Attitude Control System (ACS) thruster engines to operate in extreme environments and will fly on the first Commercial Lunar Payload Services (CLPS) flight on the Astrobotic Peregrine lander.
- Nuclear thermal propulsion efforts in FY 2021 included the technology maturation of high-temperature fuels and reactor materials. Fuel element fabrication trials and performance tests were also performed to demonstrate the durability of the block reactor design approach and validate

thermal models. This project also completed the industry-led flight demonstration study and extended the study to include an examination of high-performance reactor systems. The project also formulated a procurement strategy and statement of work to solicit industry reactor designs. The first phase of this strategy was executed in February 2021 through a request for proposal process managed through the DOE Idaho National Laboratories.

LAND: EXPANDED ACCESS TO DIVERSE SURFACE DESTINATIONS

Progress continues in developing technologies to enable human and robotic exploration missions entering planetary atmospheres and landing on planetary bodies. In FY 2021, the STMD "Land" thrust area continues to develop technologies used to study plume impingement on the dusty lunar surface and understand the heat and pressure generated during atmospheric entry and through parachute deployment. Ultimately, the data obtained from these experiments and analyses will help improve designs of future entry and landing systems for robotic and crewed missions.

- On February 18, 2021, the Mars Entry Descent and Landing Instrumentation 2 (MEDLI2) and Terrain Relative Navigation (TRN) experiments successfully performed during the Mars 2020 Perseverance Mission entry into the Martian atmosphere and collected data during the descent. The MEDLI2 researchers have begun comparisons between analytical models and experimental data. Using TRN, the Mars 2020 powered descent vehicle estimated its location while descending through the Martian atmosphere. This allowed the vehicle to determine its position relative to the ground with an accuracy of approximately 5-meters, required performance was 200-feet (60-meters or less). Through these experiments, NASA will reduce landing ellipse uncertainties to improve landing accuracies and improve thermal protection system designs for future robotic and crewed Mars missions.
- The Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) Project continues to make progress towards its flight test in FY 2022 demonstrating an inflatable aeroshell using a Hypersonic Inflatable Aerodynamic Decelerator (HIAD) technique. Because current rigid aeroshells are constrained by a rocket’s shroud size, the inflatable LOFTID aeroshell provides a mass-efficient method that can be deployed to a scale much larger than the shroud. The LOFTID Project is completing hardware build and will initiate integration and test phase. Ultimately, the LOFTID Project will enable atmospheric re-entry and landing of heavier cargos than ever before for a variety of proposed NASA missions.
- In FY 2021, the Plume Surface Interaction (PSI) Project will be conducting ground tests for validation of analysis codes used to determine and predict lunar dust dispersion. This technology will help identify how rocket plumes interact with lunar and other planetary regolith upon touchdown. The information obtained by PSI will be used by multiple Commercial Lunar Payload Services (CLPS) and Human Lunar Lander companies to ensure safe landings as well as provide information for placement of lunar infrastructure.
- Stereo CAmeras for Lunar Plume Surface Studies (SCALPSS 1.1), a new FY 2021 Project, will complete design and fabrication of flight hardware and perform a system level functional test. SCALPSS 1.1 is scheduled to fly on Firefly Blue Ghost Lander CLPS mission and will capture video and still images of the area under the lander from when the engine plume first disturbs the lunar surface through engine shutdown.
- The SPLICE project will demonstrate subsystems of the Navigation Doppler LIDAR (NDL), Descent Landing Computer, and Terrain Relative Navigation on Blue Origin's New Shepard suborbital flight test vehicle. Post-flight data performance analysis of the associated subsystems will inform design changes and modifications for the upcoming lunar flight units. Further, the NDL will be delivered to

Astrobotic's and Intuitive Machine's Lunar Lander for demonstration and infusion for lunar precision landing capability.

LIVE: SUSTAINABLE LIVING AND WORKING FARTHER FROM EARTH

A key component of the overall STMD technology investment strategy is collecting data from precursor missions and demonstrations in relevant environments. STMD's "Live" thrust area has several demonstrations planned for delivery to the lunar surface under the Commercial Lunar Payload Services (CLPS) Program. The knowledge gained from these precursors and demonstrations will inform the development of core capabilities and subsystems required to work on the surface of the Moon.

- During FY 2021, the Fission Surface Power (FSP) project formulated a procurement strategy for an industry design of a fission surface power system that can be demonstrated on the lunar surface. The Phase I procurement strategy will provide NASA insight to innovations potentially proposed by industry. In order to keep the design trade space open for industry, FSP has defined a limited set of high-level requirements that are key to meeting NASA mission goals (e.g., mass, volume, power output, and design life). FSP released the draft Request for Proposal (RFP) for Phase I in December 2020 and received comments back from industry in early February 2021. The final release of the solicitation is planned for early FY 2022. FSP also refined the government reference design which is being used to identify key subsystem requirements for a low-enriched uranium reactor and guide high-risk technology maturation investments.
- In February 2021, Mars Oxygen In-Situ Resources Utilization Experiment (MOXIE) and Mars Environmental Dynamics Analyzer (MEDA) landed on the Martian surface aboard the Mars 2020 Perseverance rover. MEDA began taking weather measurements the day after the rover touched down on Mars and continues to collect and transmit data. On April 20, 2021, MOXIE converted some of Mars' thin, carbon dioxide-rich atmosphere into oxygen and is continuing to conduct testing.
- The Polar Resources Ice Mining Experiment (PRIME) project continued to make progress and completed the Payload Integration Review in FY 2021 for two of its key instruments: Mass Spectrometer observing lunar operations (MSolo) and The Regolith and Ice Drill for Exploring New Terrain (TRIDENT). PRIME will help identify and assess the abundance and quality of water in an area expected to contain ice. This information will inform future missions and sustainable operations, including in-situ resource utilization, on the Moon.
- Lunar Dust Mitigation projects which incorporate active, passive, and operational approaches, are in development and will be demonstrated as payloads on CLPS missions in the early 2020s. Specifically, in FY 2021, the Electrodynamic Dust Shield (EDS) Project will complete its Preliminary Design Review (PDR) in designing approaches for applying dielectrophoretic and electrostatic forces capable of lifting, transporting, and removing dust from surfaces such as solar panels or optical systems. Also, the Regolith Adherence Characterization (RAC) Project continues performing materials and coatings samples experiments design reviews preparing for a CLPS experiment. RAC will determine how lunar regolith sticks to a range of materials exposed to the Moon’s environment at different phases of flight.
- In FY 2021, the In-Space Manufacturing (ISM) Project is manifested on ISS to conduct the first in-space manufacturing of metals. Techshot is developing a novel power system to meet stringent requirements in space or in the field with limited power availability.
- STMD's Prizes, Challenges, and Crowdsourcing conducted the second phase of the Space Robotics competition, which seeks to advance robotic software and autonomous capabilities for space

exploration missions on the surface of extraterrestrial objects, such as distant planets or moons. The challenge requires competitors to develop software that allows a virtual robotic team to operate autonomously to successfully achieve these tasks.

EXPLORE: TRANSFORMATIVE MISSIONS AND DISCOVERIES

STMD's progress with "Explore" thrust area projects continues with demonstrations of next generation communication, navigation, and small spacecraft technologies and continues to make advancements in on-orbit servicing, assembly and manufacturing (OSAM) and vehicle platform technologies. "Explore" projects enable science and crewed missions more affordable and capable than ever before using technologies that augment the robotic and crews on science and human missions, respectively.

- In FY 2021, the Laser Communications Relay Demonstration (LCRD) will be delivered, integrated, and final system tested in preparation for launch in June 2021. The mission will use lasers to encode and transmit data at rates 10 to 100 times better than radio systems, using significantly less mass and power.
- Deep Space Optical Communication (DSOC) completed Flight Model Optical Transceiver Assembly (OTA) and the remainder of the hardware built and is on-target for delivery for integration to the Psyche mission in June 2021. DSOC will deliver a flight-ready, deep space optical platform assembly and ground data system comprised of a ground laser receiver and transmitter that use existing ground assets.
- On-orbit Servicing, Assembly, and Manufacturing (OSAM) projects OSAM-1 (Restore/SPIDER) and OSAM-2 (Archinaut) are on track for completing Mission Critical Design Review (CDR) in FY 2021. These projects are key in demonstrating the foundational capabilities for servicing, assembly, and manufacturing in space that will extend the lifespan of satellites, assemble large telescopes in space, and refueling and repairing of spacecraft.
- Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE), a microwave oven-sized CubeSat that will serve as the first spacecraft to test a unique, elliptical lunar orbit, is expected to launch in Fall 2021. As a precursor for Gateway, a Moon-orbiting outpost that is part of NASA’s Artemis Program, CAPSTONE will help reduce risk for future spacecraft by validating innovative navigation technologies and verifying the dynamics of this halo-shaped orbit.
- Lunar Flashlight, an innovative, low-cost secondary payload concept aboard Artemis I mission, will map the lunar South Pole for volatiles in late 2021. Lunar Flashlight will use lasers to help determine the presence and nature of water ice at the bottom of some of the Moon's craters. The demonstration includes several technological firsts, including being the first CubeSat to reach the Moon, the first planetary CubeSat mission to use green propulsion, and the first mission to use lasers to look for water ice.
- The Cooperative Autonomous Distributed Robotic Explores (CADRE) project is developing a network of shoe-box-sized mobile robots that explore as a group and collect data in hard-to-reach places such as craters and caves on the Moon. In FY 2021, the project is scheduled to complete a Mission Design Review and provide an autonomy testbed demonstration in FY 2021. These low-mass, low-volume, low-cost autonomous rover scouts will enable exploring high-risk environments without endangering primary assets.

SPACE TECHNOLOGY

LEAD: ENSURING AMERICAN GLOBAL LEADERSHIP IN SPACE TECHNOLOGY

In FY 2021, STMD's "Lead" thrust area continues to pursue cutting edge R&D investments reaching a wide space of researchers and small businesses developing technologies for the future that could lead to spinoff companies, thereby creating jobs. Focus areas under consideration include engaging with Space Technology Research Grant (STRG) researchers to encourage increased lab to market opportunities and spinoff company creation; involving underrepresented students and expanding planning grants to strengthen and develop MSI/HBCU research capacity and infrastructure; continuing a robust Technology Transfer program to increase NASA’s activation of regional economic hubs; and expanding opportunities for interchange between NASA, universities, industry and local economic development organizations. Investment in these areas will have an economic impact in industries of the future and contribute towards building stronger and equitable communities and maintaining U.S. leadership in space technology.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

NASA will continue to partner with researchers across academia and industry and explore transformative technologies and approaches. Upcoming Early Stage Innovation portfolio activities will investigate areas such as breakthrough propulsion, challenges in deep space human habitation, space-optimized energy systems, radiation protection, advanced materials, and climate and clean energy-related challenges. These areas are part of a comprehensive approach to efficiently support innovative discovery, progress toward important goals, and the development of transformative new capabilities.

NASA will release the Industry & Commerce Innovation Opportunity announcement which will be an open topic call for proposals utilizing existing acquisition vehicles (e.g., ACO/Tipping Points, SBIR) to pursue technologies needed by commercial space stakeholders.

NASA will continue to invest in key cryogenic fluid management technologies for effective and efficient storage, transfer, and utilization for cryogenic propellants and reactants in space enable capabilities including high performance chemical propulsion, electric propulsion and nuclear propulsion. STMD will also continue advancing manufacturing methods that will improve the performance and reduce the production costs of rocket engine parts.

- Solar Electric Propulsion: The Plasma Diagnostic Package (PDP) will be delivered to the Gateway Power Propulsion Element (PPE) by summer 2022. The PDP will fly on the Power and Propulsion Element for NASA's Gateway lunar orbital platform and collect flight data related to the plasma environment produced by high-power solar electric propulsion (SEP) during operation. Also, in FY 2022, assembly of the qualification Xenon thrusters will begin and will undergo rigorous testing for compliance with space flight requirements, regulations, and conformity with standards followed by acceptance testing at the end of FY 2022 that will evaluate system configuration and performance to determine if test objectives have been met.
- The Rapid Analysis and Manufacturing Propulsion Technology (RAMPT) project is maturing novel design and manufacturing technologies to increase scale, significantly reduce cost, and improve performance for regeneratively cooled thrust-chamber assemblies, specifically the combustion chamber and nozzle for Government and industry programs. This project will conduct a hot fire test of a large-scale composite overwrapped Thrust Chamber Assembly (TCA) with a directed energy dispositioned (additive manufactured) nozzle. This development will address the longest lead, highest cost, and heaviest component in the rocket propulsion engine system. The project will complete vendor trials and lab testing in FY 2022.

- The Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) Project, in partnership with United Launch Alliance, will complete fabrication of a flight-ready, inflatable aerodynamic decelerator technology in preparation for an FY 2022 flight test in the Earth's atmosphere to determine the feasibility of this technology in supporting high-mass entry descent and landing.
- The Plume-Surface Interaction (PSI) Project will continue advancing both modeling and testing capabilities to understand exactly how rocket exhaust plumes affect a planetary landing site. In FY 2022, PSI will continue with its Science Scale Ground Test (SSGT) campaign and collect data relevant to support mission design for a science class mission, which will support computational code validation, future engineering model development, and mature PSI-dedicated instrumentation.
- SCALPSS 1.1 project will complete environmental testing on hardware and deliver flight hardware to lunar lander provider for integration and preparation for flight.
- SPLICE project will incorporate design changes based on Blue Origin's New Shepard flight tests and complete development and assembly of the Descent and Landing Computer and Navigation Doppler Lidar (NDL) flight units for CLPS technology demonstration. Further, the NDL will be delivered to Astrobotic's and Intuitive Machine's Lunar Lander for demonstration and infusion for lunar precision landing capability.
- In FY 2022, the Fission Surface Power Project will award up to three industry contracts for preliminary designs of a 10 kilowatt-electric class fission power system. The industry awards will have a one-year performance period, and the results will inform NASA design and performance requirements for a second solicitation which will generate a complete design of a lunar demonstration system. Additionally, FY 2022 investments will advance space-rated power conversion systems, and mature high-risk reactor technologies on low-enriched moderator materials and lighter weight radiation shielding.
- In FY 2022, the Regenerative Fuel Cell (RFC) Project is planning to hold its Critical Design Review (CDR) in preparation for a fuel cell subsystem test in FY 2023. Ultimately, the RFC project will deliver a regenerative fuel cell that would be capable of producing electricity from hydrogen and water while also performing the reverse function — using water and electricity generated by solar panels or other sources to produce hydrogen and oxygen.
- Vertical Solar Array Technology (VSAT) project aims to develop lightweight solar arrays capable of autonomous 10-meter vertical deployment on uneven terrain. This technology will enable near continuous capture of sun light by the solar arrays at the lunar South Pole region.
- STMD has two Dust Mitigation experiments manifested on the sixth Commercial Lunar Payload Service (CLPS) awarded to Firefly Aerospace of Cedar Park, Texas. The Electrodynamic Dust Shield (EDS) will generate a non-uniform electric field using varying high-voltage on multiple electrodes. This traveling field, in turn, carries away the particles and has potential applications in thermal radiators, spacesuit fabrics, visors, camera lenses, solar panels, and many other technologies. The second demonstration is the Regolith Adherence Characterization (RAC), which will determine how lunar regolith sticks to a range of materials exposed to the Moon's environment during landing and lander operations. Components will be derived from the Materials International Space Station Experiment (MISSE) facility currently on ISS.
- In-Space Manufacturing (ISM) will deliver flight hardware of first-in-space metallic fabrication laboratory for ISS demonstration in FY 2023. ISM is developing technologies and processes which will enable on-demand manufacturing capability during long-duration space missions and leveraging

the highly disruptive technologies being developed terrestrially and adapting them for operations in the space environment such as ISS.

- Prizes and Challenges will launch competitions to address lunar power (Watts on the Moon) requirements as well as lunar excavation (Break the Ice), manufacturing, and construction to support in-situ resource utilization applications. Additionally, NASA will host a competition to support nutrition needs of astronauts on the lunar surface (Deep Space Food), an essential aspect of sustainable human presence on the Moon.
- Polar Resources Ice Mining Experiment (PRIME) project will be delivered to the Moon by December 2022 by Intuitive Machines of Houston under the Commercial Lunar Payload Services Contract. PRIME1 will land on the Moon and drill up to three feet below the surface. It will measure, using a mass spectrometer, how much ice in the sample is lost to sublimation as the ice turns from a solid to a vapor in the vacuum of the lunar environment. Honeybee Robotics of Pasadena, California, is developing the ice-mining drill. NASA's Kennedy Space Center in Florida, in partnership with INFICON of Syracuse, New York, is developing the mass spectrometer.
- The "Honey I Shrunk the NASA Payload Challenge, The Sequel" will provide the 14 winning teams the opportunity to further develop their payload concepts for small lunar rovers. NASA's Lunar Surface Innovation Initiative will award prizes to 4 teams to develop working prototypes at a technology readiness level (TRL) of 5 or greater by January 2022. NASA will test one to two prototypes to failure and to reserve the remaining one(s) for possible deployment on the lunar surface aboard a rover. These miniature payloads will enable lunar science, demonstrate new technologies, and advance the use of resources found on the moon (in-situ resource utilization, ISRU).
- On-orbit Servicing, Assembly, and Manufacturing-1 (OSAM-1Restore/SPIDER) is planning to conduct a major project lifecycle review where the Decision Authority determines whether the project is on track. OSAM-1's Key Decision Point-D will officially approve initiating the project's integration and test phase.
- On-orbit Servicing, Assembly, and Manufacturing-2 (OSAM-2 Archinaut) is planning to launch in late 2022 and demonstrate its capability on orbit. The OSAM-2 demonstration will build, assemble, and deploy its own operational solar arrays in space. The small spacecraft will 3D print two beams. The first beam will extend nearly 33-feet from one side of the spacecraft while deploying a solar array surrogate. The second beam will extend nearly 20 feet from the opposite side of the spacecraft. As it continues to manufacture the hardware, these beams will unfurl solar arrays that can generate up to five times more power than traditional solar panels on similar-sized spacecraft.
- Deep Space Optical Communications (DSOC) is preparing for a launch in August 2022 on the Psyche mission where it will demonstrate and validate laser communications that improves performance 10 to 100 times over the current state of the art without incurring increases in mass, volume, or power. Communications between space and ground will employ novel, advanced lasers in the near-infrared region of the electromagnetic spectrum and will provide the fastest, most efficient means of communicating with mission managers on Earth.
- As part of NASA's Lunar Surface Innovation Initiative and 2020 Tipping Point Awards, STMD will demonstrate two "Explore" projects that will accelerate technology readiness for key lunar infrastructure capabilities.
    - The Deployable Hopper Project will deliver and integrate flight hardware on Intuitive Machines Nova-C Lander for integration into SpaceX Falcon 9 launch vehicle. The project

will demonstrate a small, deployable hopper lander capable of carrying a 2.2-pound (1-kilogram) payload more than 1.5 miles (2.5 kilometers). This hopper could access lunar craters and enable high-resolution surveying of the lunar surface over a short distance.
    - In partnership with NASA, Nokia will deploy the first LTE/4G communications system on the surface of the Moon. The system will support lunar surface communications at greater distances, increased speeds, and provide more reliability than current radio standards. Nokia's data transmission communications would help that effort, including control of lunar rovers, real-time navigation of the Moon's geography and stream high-definition video.
- The Cubesat Laser Intersatellite Crosslink (CLICK) will advance state of the art communications between small spacecraft as well as the capability to gauge their relative distance and location. CLICK is comprised of two sequential missions with CLICK A launching launch in 2021 and CLICK B/C planned to launch in 2022. CLICK B/C will demonstrate full-duplex (send and receive) optical communication crosslink between two 3U small spacecraft, in low-Earth-orbit, at distances between 15 and 360 miles apart at data rates greater than 20 Mbps.
- The Cooperative Autonomous Distributed Robotic Exploration (CADRE) project, which is a low-mass, low-volume, low-cost autonomous rover scout for collaboratively exploring high-risk environments without endangering primary assets, will complete a Flight Readiness Review and deliver flight hardware in FY 2022 in preparation for its launch in 2023.

Programs

EARLY STAGE INNOVATION AND PARTNERSHIPS

Early Stage Innovation and Partnerships spur collaboration with innovators across the Nation to capitalize on the ideas, talent, and experience of a diverse set of contributors to achieve NASA's Agency objectives. STMD funds early stage research and development (TRL 1-3) sourced from academia, industry, entrepreneurs, and from the NASA workforce to generate pioneering approaches to the Agency's difficult and far reaching exploration challenges. It also puts emphasis on increasing participation by women and socially or economically disadvantaged businesses and historically black colleges (HBCU) and minority serving institutions (MSI). NASA sustains these Early Stage investments at seven to eight percent of the overall Exploration Technology budget which includes Space Technology Research Grants (STRG), NASA Innovative Advanced Concepts (NIAC), Center Innovation Fund (CIF), and Early Career Initiative (ECI). In addition, NASA funds STMD partnership activities including technology transfer and technology commercialization activities, and the Agency's Prizes and Challenges activities (including Centennial Challenges and the NASA Tournament Lab). NASA's Technology Transfer Program ensures NASA's inventions can be utilized to provide U.S. commercial benefit by tracking, analyzing, and reporting investments and progress, as well as managing patent licenses and software releases.

TECHNOLOGY MATURATION

STMD is advancing revolutionary space technologies from proof of concept to demonstration, maturing transformational, and foundational technologies across the critical gap that resides between early stage concepts and flight demonstration (TRL 3-6). The Technology Maturation portfolio, which includes the

Game Changing Development (GCD) Program, develops and demonstrates technologies needed to support other NASA Directorates, the commercial space sector and other government agencies, as appropriate. The portfolio emphasizes technologies that address technical challenges faced by robotics and human explorers and is aligned with the STMD Technology Thrusts. A portion of the Technology Maturation portfolio is dedicated to the Lunar Surface Innovation Initiative (LSII), targeting critical technologies needed for surface activities. In addition, Technology Maturation includes strategic technology investments that are critical for to industry and other Government agency stakeholders.

TECHNOLOGY DEMONSTRATION

The Technology Demonstration portfolio supports ground-based testing to determine feasibility and technology flight demonstrations in relevant environments to effectively transition technologies for NASA missions and for use by other Government agencies and industry. Through the Technology Demonstration Missions (TDM), Small Spacecraft Technologies (SST) and Flight Opportunities (FO) Programs, ground, and flight demonstrations (TRL 5-7) are prioritized to complete multiple projects nearing completion, while demonstrating cross-cutting applications applicable to multiple stakeholders.

SMALL BUSINESS INNOVATION RESEARCH (SBIR) AND SMALL BUSINESS TECHNOLOGY TRANSFER (STTR)

The SBIR/STTR programs leverage the Nation's innovative small business community to support research and development efforts that enable NASA's mission in human exploration, science, and aeronautics. SBIR/STTR supports early-stage research and mid-Technology Readiness Level (TRL) development, performed by small businesses through competitively awarded contracts. These programs provide the small business sector with an opportunity to develop technology for NASA and to commercialize that technology to spur economic growth and potentially address national needs in the aerospace industry and other sectors. These programs produce innovations for both Government and commercial applications. Annual solicitations maintain commitment to an integrated Agency-wide SBIR/STTR program that supports both commercial interests and NASA mission needs, while addressing innovation initiative that aligned with Administration priorities (e.g., climate science); and increase participation by women and socially or economically disadvantaged businesses, historically black colleges (HBCU), and minority serving institutions (MSI).

EARLY STAGE INNOVATION AND PARTNERSHIPS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Agency Technology and Innovation	9.4	8.4	**9.4**	9.6	9.8	10.0	10.2
Early Stage Innovation	90.8	89.2	**115.6**	117.9	120.2	122.7	125.2
Technology Transfer	19.6	19.9	**20.0**	20.4	20.8	21.2	21.6
Total Budget	**119.8**	**117.5**	**145.0**	**147.9**	**150.8**	**153.9**	**157.0**
Change from FY 2021			**27.5**				
Percentage change from FY 2021			**23.4%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

NASA Innovative Advanced Concepts grantee facilitated a citizen science, public competition to seek ideas for a mechanical obstacle avoidance sensor that could be incorporated into a possible future Venus rover. The winners of the "Exploring Hell: Avoiding Obstacles on a Clockwork Rover" included three novel designs (one of which is pictured above) and a number of honorable mentions, with ideas that ranged from systems of rollers to detect hazards to oversized fenders that would snap the rover in reverse should it hit a boulder.

Early Stage Innovations and Partnerships spur collaboration with innovators across the Nation to capitalize on the ideas, talent, and experience of a diverse set of contributors to achieve commercialization of aerospace technologies, economic impact, and contributions to NASA's Artemis objectives. There is also an expanded focus beyond Moon to Mars, including other Mission Directorates, the commercial space sector, and other Government agencies.

Early Stage Innovation supports concept studies, applied research, and early technology development that germinate revolutionary ideas, expand innovation, and transform future capabilities. Emphasis is placed on identifying emerging concepts and technologies that support objectives such as long-term Lunar surface requirements and climate challenges. Open innovation capabilities also support NASA's R&D objectives and leverages the Agency's connection with the American and global public to support NASA's objectives. By leveraging the technical capabilities of experts across the Nation from academia, established industry, new businesses, NASA Centers, and individual members of the public, the Agency gains new ideas and alternative approaches to solving NASA's difficult and far reaching exploration challenges.

Within Technology Transfer, NASA responds to Administration priorities and legislative requirements to promote technology transfer, including commercialization of technologies that emerge from NASA's

EARLY STAGE INNOVATION AND PARTNERSHIPS

research and development activities to support commercial expansion in space, economic development, and tangible Earth applications.

Agency Technology and Innovation funds the operations of the Office of the Chief Technologist (OCT), which performs Agency outreach, and promotes innovative culture and partnerships internally and externally.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Budget provides a $27.5 million increase to Early Stage Innovation and Partnerships; at least $10 million will support climate research and clean energy economy investments. This Budget also moves the Prizes, Challenges and Crowdsourcing Program to the Early Stage Innovation budget line.

ACHIEVEMENTS IN FY 2020

Agency Technology and Innovation:

- OCT demonstrated the effectiveness of the Strategic Technology Integration Framework by working with directorates to incorporate mission data into models for analysis, while also executing collaborative innovation experiments at each NASA Center and across the Agency.
- The 2020 NASA Technology Taxonomy was successfully completed and released. The Taxonomy includes a discipline-based realignment of technology areas and leveraged the knowledge of recognized experts during development of the update. The Taxonomy is one of NASA's key contributions to the international technology community, as it greatly assists the community in managing and communicating relevant technologies while also serving NASA's needs.
- OCT hosted a regular cadence of virtual interagency Science and Technology Forum technical interchange meetings, helping to coordinate technology needs across several agencies related to trusted autonomous systems and cybersecurity mission assurance. In FY 2020, OCT executed an interagency pilot program with the National Reconnaissance Office, resulting in technology projects of mutual interest in several early stage technology areas related to remote sensing, autonomous systems, and space-based communications.

Early Stage Innovation:

- NASA Innovative Advanced Concepts awarded an additional Phase III study to complement its portfolio of Phase I and Phase II concepts. The Phase III selection will explore direct multipixel imaging and spectroscopy of an exoplanet with a solar gravitational lens, which could potentially enable viewing a habitable exoplanet in detail. Previous Phase III selections continue to progress with work on robotic technologies enabling the exploration of lunar pits and optical mining technology.
- Space Technology Research Grants (STRG) released the inaugural Lunar Surface Technology Research (LuSTR) Opportunities solicitation featuring six topics in two LSII focus areas: In-Situ Resource Utilization and Sustainable Power. As part of the LSII portfolio, LuSTR solicits ideas from university researchers for the creation of new, enabling technologies that will be needed for lunar surface exploration and to accelerate the technology readiness of key lunar surface exploration systems and components.

EARLY STAGE INNOVATION AND PARTNERSHIPS

- STRG released its biennial Space Technology Research Institutes solicitation with two topics: High-Power Electric Propulsion Ground Testing and Modeling Extensible to In-Space Operation and Revolutionary Advancements in Multidisciplinary Modeling and Simulation of Entry Systems.
- Five new Early Career Initiative (ECI) awards were selected in September 2020, with NASA Centers partnering with industry and/or academia to rapidly develop technologies supporting Artemis and next generation robotic Mars exploration. These projects provide NASA's early career employees with direct, hands-on leadership experience, including applying innovative project management techniques with public-private partnerships.
- The Center Innovation Fund (CIF) selected 137 new projects in September 2020, representing advanced technology investments across a broad spectrum of NASA Taxonomy areas. NASA Centers collaborated with 23 industry partners, 57 academic institutions, and 12 other Government agencies to develop these new National aerospace capabilities.

Partnerships & Technology Transfer:

- NASA formulated and developed three Centennial Challenges focused on human lunar exploration needs: Watts on the Moon (power storage and distribution), Break the Ice Lunar (excavation, manufacturing, and construction); and Deep Space Food (astronaut nutrition).
- NASA Technology Transfer played a pivotal role in licensing NASA technologies that supported COVID-19. JPL developed a ventilator that can be built faster and maintained more easily than a traditional ventilator and is composed of far fewer parts. NASA received more than 100 license applications and nine U.S. and 19 international manufacturers were selected to produce the Ventilator Intervention Technology Accessible Locally (VITAL Ventilators), making it the most-licensed NASA invention of all time. Additionally, Technology Transfer is providing royalty payment relief and new opportunities under StartUp NASA to encourage entrepreneurship and support small business impacted by COVID-19.
- NASA Technology Transfer partnered with FedTech to bring teams of entrepreneurs together to conduct commercial assessments of select NASA technologies, leading to the creation of new companies using NASA technologies. Additionally, the NASA Entrepreneurial Workforce Initiative continues to introduce NASA innovators to entrepreneurial-focused thinking to maximize the commercial potential of their inventions.

WORK IN PROGRESS IN FY 2021

Agency Technology and Innovation:

- OCT will continue to serve as the NASA champion for innovation and will oversee collaborative experiments that foster an innovative culture at the Agency. The office will complete the NASA Innovation Portal, which utilizes an intelligent search engine to link NASA employees to people, tools, and information that facilitate innovation.
- The Strategic Technology Integration Framework effort will continue to develop guidelines for synthesizing the state of NASA's technology investment portfolio. As the guidelines are refined, inputs from the Mission Directorates will help identify potential technology gaps.
- The Science and Technology Partnership Forum will continue to engage with interagency partners on joint technology assessments, particularly in low technology readiness areas.

EARLY STAGE INNOVATION AND PARTNERSHIPS

Early Stage Innovation:

- NASA will continue to partner with researchers across academia and industry to explore transformative technologies and approaches. Upcoming Early Stage Innovation activities will investigate areas that contribute to NASA STMD's strategic framework and other areas such as High-Fidelity Emulation of Full-Physics Models in Earth Science. These areas are part of a comprehensive approach to efficiently support innovative discovery, progress toward important goals, and the development of transformative new capabilities.
- Sixteen Phase I NIAC studies were announced in March 2021, which offer a range of inventions and applications including a lunar levitation track system, a light bending lunar power system, and a method for making soil from asteroid material.
- In October 2020, STRG awarded 14 Early Career Faculty grants sponsoring cutting edge research by exceptional university faculty who are still early in their careers. Research topics include coordination of teams of robots, in-space food production, and advanced, multi-layer spacecraft insulation.
- STRG awarded 14 Early Stage Innovations grants in January 2021. The university-led teams will investigate challenging aspects of space exploration ranging from cryogenic refrigeration technologies to modeling parachute inflation and descent to additive manufacturing of high temperature materials.
- STRG announced its inaugural Lunar Surface Technology Research (LuSTR) selections in March 2021. NASA selected six new projects in two LSII focus areas: In Situ Resource Utilization and Sustainable Power. The awards, set to commence in May 2021, emphasize near-term infusion and are up to $2 million in value. Three university-led efforts will research innovative ways to identify resources (such as water on the Moon) and inventive architectures for their extraction, processing, and utilization. The Sustainable Power related projects will mature next-generation power distribution technologies and aim to facilitate the robust operation of infrastructure on the Moon.
- The biennial Space Technology Research Institutes solicitation selections were announced in March 2021. The new STRIs will bring together researchers from different disciplines and organizations to tackle challenges associated with electric propulsion ground testing and atmospheric entry systems modeling. The new STRIs aim to advance these game-changing technologies for exploring the Moon, Mars, and beyond.
- STRG released its 11th annual call for proposals from graduate student researchers. Students were notified on April 2, 2021, and the awards (which span the technology taxonomy space) will commence in August 2021. The Early Career Faculty solicitation was released in February 2021 and an early May 2021 release of the Early Stage Innovations solicitation is planned with awards scheduled for late FY 2021 and early FY 2022, respectively.
- The annual Early Career Innovations program, which engages NASA early career researchers with world class partners to develop the innovative leaders and technologies of the future, released the annual solicitation to the NASA centers in March 2021 with selections planned for September 2021. The Center Innovation Fund will also plan to make selections in September 2021.

EARLY STAGE INNOVATION AND PARTNERSHIPS

Partnerships & Technology Transfer:

NASA will conclude the following Centennial Challenges:

- Vascular Tissue Challenge: Create viable, thick metabolically functional human vascularized organ tissue that can be used to advance research and medicine in space and on Earth; awards will be made to teams in summer 2021.
- CO2 Conversion Challenge Phase II: Using carbon dioxide (CO2) to generate substrates that feed microbial bioreactors to generate essential products for long duration missions; Phase II seeks to award up to $750,000 to the top three teams that demonstrate operational systems in FY 2021.

NASA launched or continued the following Centennial Challenges:

- CubeQuest Challenge, which offers a total of $5 million to teams that meet the challenge objectives of designing, building, and delivering flight-qualified small satellites capable of advanced operations near and beyond the Moon.
- Space Robotics Challenge Phase II, a virtual competition to advance robotic software and autonomous capabilities for space exploration missions on the surface of extraterrestrial objects, such as distant planets or moons.
- Phase I of Watts on the Moon, Break the Ice Lunar, and Deep Space Food challenges.
- NASA continues to leverage challenge and crowdsourcing platforms to run innovative competitions through the NASA Tournament Lab that support a diverse set of problem areas across NASA. Several Artemis focused competitions based on identified technology needs were launched or concluded, including: Lunar Deep Freeze Challenge, Lunar Delivery Challenge, and Honey I Shrunk the NASA Payload, the Sequel.
- NASA Technology Transfer will continue to expand Technology Transfer Expansion (T2X) activities, which include entrepreneurship initiatives, innovative ecosystem engagement, and partnerships for bringing new products and services to market. The goal of these activities is to increase licensing and commercialization successes and increase novel public-private partnerships.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

Agency Technology and Innovation:

- OCT will build on the success of the Science and Technology Partnership Forum, identifying additional areas of mutual interest and technology gaps that may be filled through cooperative interagency efforts.
- A revision of the NASA Strategic Technology Investment Plan will be produced to provide an Agency-level assessment on the balance of technology investments across technical areas as well as across near, mid, and long-term needs. The office will continue ongoing horizon-scanning studies to assess emerging technology development practices within industry that may provide value to NASA.

Early Stage Innovation:

NASA will expand Early Stage capabilities and impact by implementing the following:

- Efforts to increase the number of projects transitioning from early stage innovations to higher technology readiness levels to increase their impact;

EARLY STAGE INNOVATION AND PARTNERSHIPS

- Expanding the number of NASA Innovative Advanced Concepts awards;
- Expanding the Lunar Surface Technology Research portfolio with awards in other LSII focus areas;
- Exploring innovation pilots to enable breakthrough technology R&D in support of U.S. competitiveness;
- Emphasizing increased participation in underserved communities, as well as individuals from those communities;
- Building evidence to determine what works to advance early-stage innovations and partnerships through STMD's portion of the Learning Agenda consistent with the Evidence-based Policy Making Act of 2018;
- Efforts include the potential for Space Technology Research Grants to address climate challenges and/or clean energy economy;
- NASA will expand engagement with the Nation's innovators through the Phase 2 continuation of three lunar-focused Centennial Challenges: Watts on the Moon, Break the Ice Lunar, and Deep Space Food. There is also potential development of new prize concepts to address climate challenges and/or clean energy economy. Several additional smaller challenges to support NASA technology needs will be conducted.
- Bridging early career opportunities between NASA Mission Directorates to enhance the technical and project management skills of NASA's early career workforce.

Technology Transfer:

- NASA will continue efforts described below in the Technology Transfer Section.

Program Elements

AGENCY TECHNOLOGY AND INNOVATION

Agency Technology and Innovation funds the operations of the OCT and Agency activities for promoting innovative culture and partnerships within and outside of NASA.

The NASA Chief Technologist serves as the Agency's principal advisor and advocate on matters concerning Agency-wide technology policy to internal and external stakeholders. The office also communicates and helps strategically integrate technology efforts within the Agency. The office conducts regular reviews and assessment of technology investments across NASA, including the mission-focused investments made by the Agency's Mission Directorates. The organization also assesses and communicates the societal and economic impact of technology investments at NASA and outside the Agency.

OCT hosts several technical interchange meetings in support of NASA's participation in the interagency Science and Technology Partnership Forum activity, an ongoing activity that brings leaders in Government aerospace, defense, and national security communities together to better coordinate Federal investments and activities based on mutual critical needs and future plans. These exchanges are working to identify partnership opportunities that reduce duplication of effort and investment across Government while advancing the TRLs and infusion paths that will benefit Agency missions.

OCT is finalizing a Strategic Technology Integration Framework to more efficiently identify and connect technology investments to needs across the Agency. This initiative will inform the next version of NASA's Strategic Technology Investment Plan.

OCT continues to work closely with internal and external stakeholders to develop strategies to expand NASA’s innovation ecosystem and the development of an Agency innovation framework.

For more information, go to: http://www.nasa.gov/oct

EARLY STAGE INNOVATION

NASA's Early Stage Innovation activities employ various approaches to engage subject matter experts at universities, companies, independent labs, NASA Centers, and other Government agencies. Through a steady cadence of competitive solicitations, NASA continuously develops new and innovative high-risk/high-payoff technologies. Early Stage studies cultivate new ideas and alternative approaches and leverage the technical capabilities of the experts across the Nation that can fuel economic growth. Technologies are often developed with support and coordination among NASA and various external partners and primarily focus on innovative ways to further humankind’s exploration from conception to testing to spaceflight. NASA awards early stage efforts through Space Technology Research Grants, NASA Innovative Advanced Concepts, the Center Innovation Fund, and the Early Career Initiative and innovation efforts through the Prizes, Challenges and Crowdsourcing Program. Open innovation capabilities support NASA’s R&D objectives and leverages the Agency’s connection with the American and global public to support NASA's objectives. By leveraging the technical capabilities of experts across the Nation from academia, established industry, new businesses, NASA Centers, and individual members of the public, the Agency gains new ideas and alternative approaches to solving NASA’s difficult and far reaching exploration challenges.

It is not always clear which efforts will result in breakthroughs, effective improvements, or exciting new approaches. The technology innovation process is nonlinear and takes time. Therefore, a balance of early stage, mid-Technology Readiness Level (TRL), and technology demonstration investment is critical for an effective technology development portfolio.

Space Technology Research Grants

STRG conducts a series of annual and biennial competitive solicitations targeting high-priority technologies that engage the entire spectrum of academic researchers from graduate students to early career and senior faculty members. STRG emphasizes technology areas that can make space activities more effective, affordable, and sustainable. In the process, close collaborations between U.S. universities and NASA are established and nurtured. The NASA Space Technology Graduate Research Opportunities solicitation seeks to sponsor graduate researchers who show significant potential to contribute to NASA’s goal of creating innovative new space technologies for our Nation’s exploration, science, and economic future. The topics featured in the Early Career Faculty, Early Stage Innovations, Lunar Surface Technology Research, and Space Technology Research Institutes solicitations are of high priority to NASA and the aerospace community in areas where it is anticipated that academia is ideally suited to provide significant innovations.

STRG funds innovative space technology research and currently features more than 300 active grants to U.S. universities. In FY 2020, NASA made 14 Early Stage Innovations awards, nine Early Career Faculty awards, and 63 NASA Space Technology Graduate Research Opportunities awards. The program has supported research projects at 116 universities across 44 States since its inception in 2011.

STRG awards result in numerous technology transition successes and contributions to NASA's mission:

- Heisenberg vortex for Light-Weight Refrigeration of Liquid Hydrogen: Carl Bunge, a NASA Space Technology Graduate Researcher from Washington State University developed a new type of refrigeration system for liquid hydrogen rocket propellant to decrease hydrogen boiloff and enable its use on longer duration missions, resulting in over five times more cooling power. National Science Foundation is now funding further development of this technology.
- Heterogeneous Laser Transmitter Integration for Low SWaP: Jonathan Klamkin, an Early Career Faculty Principal Investigator from University of California, Santa Barbara assembled a photonic integrated circuit which combines several components on a single chip to reduce size, weight, and power requirements for optical communications devices. The technology can enable higher bandwidth communications and is currently being developed for commercial applications by a private company.
- Material Characterization while Drilling on Lunar/Martian Surface: Jamal Rostami, an Early Stage Innovations Principal Investigator from the Colorado School of Mines uses in-process data from an instrumented drill in order to characterize the material being drilled through. The technique can be used to adjust drilling parameters to prevent damage to equipment and can also be used to discover valuable materials underneath the surface. The technology was recently able to determine water content in lunar regolith simulant samples to within 0.25 percent.
- Center For The Utilization of Biological Engineering in Space: Multi-university Space Technology Research Institute (led by University of California, Berkeley and awarded in 2017) has had numerous breakthroughs in biomanufacturing including 85 percent power efficiency for a lighting system required to grow plants, bioengineered rice which is more suitable to farming in indoor habitats, and biomanufacturing biopolymers for use as structural materials. Each of these are key technologies which will be needed for long term space missions away from Earth.

NASA Innovative Advanced Concepts

NASA Innovative Advanced Concepts (NIAC) executes annual solicitations seeking exciting, unexplored, and technically credible new concepts that could one day "change the possible" in space and aeronautics. These efforts improve the Nation's leadership in key research areas, enable long-term capabilities, and spawn disruptive innovations that make space exploration more effective, affordable, and sustainable.

Phase I and continuation Phase II solicitations are open to NASA Centers, other Government agencies, universities, industry, and individual entrepreneurs. NASA implemented Phase III studies to complement its portfolio of Phase I and Phase II concepts for the first time in FY 2019. Phase III studies are designed to continue maturation of Phase II transformative ideas allowing NASA to strategically transition the most promising NIAC concepts to other NASA programs, other Government agencies, or commercial partners. In 2020, NIAC made 16 Phase I, six Phase II, and one Phase III awards across industry, academia, and NASA Centers. NIAC has been a regular source of transformative aerospace concepts and innovative approaches. Dr. Jonathan Sauder ran a very successful Mechanical Maker Challenge, leveraging crowdsourcing to further his NIAC study "Exploring Hell: Avoiding Obstacles on a Clockwork Rover." The challenge sought an innovative obstacle avoidance sensor for a mechanical clockwork rover, receiving 572 submissions.

EARLY STAGE INNOVATION AND PARTNERSHIPS

Center Innovation Fund

CIF provides annual seed funding to each NASA Center and NASA's Jet Propulsion Laboratory to stimulate aerospace creativity and grassroots innovation to transform future missions and advance the Nation's capabilities. CIF activities are competitively selected to explore alternative approaches or develop enhanced capabilities that will feed into NASA's objectives. Partnerships with academia, private industry, individual innovators, as well as among NASA Centers and Government agencies, are highly encouraged.

An integrated review of all CIF candidates is conducted to ensure a strategic and coordinated portfolio. These investments have led to multiple successful NASA and commercial applications. For example, a Drill-Integrated Gamma Ray/Neutron Detector for Solar System Exploration transitioned to Rapid Reaction Development and Demonstration (R2D2) Program, funded by the Small Spacecraft Technology Program (SSTP). This tool will enable the real time assessment of subsurface environments on the Moon, Mars, asteroids, and other bodies to better understand and characterize their composition for future resource utilization. In addition, CIF projects have led to some well-known applications, such as the Woven Thermal Protection System (Woven TPS) used on Orion.

Since its inception in 2011, the CIF Program has transitioned 227 projects to other NASA programs, industry partners, academia, and other Government agencies. CIF has resulted in more than 250 New Technology Reports, 300 publications and conference papers, 85 patent applications, and over a dozen commercial licenses. In addition, two spin-off companies are directly attributable to the CIF Program: Nirvana Energy Systems, formed to manufacture and sell energy systems and technology for homes (a Stirling Engine with no hot moving parts developed at Glenn Research Center) and Amorphology, LLC, formed to commercialize the Jet Propulsion Laboratory invention of Harmonic Drives Utilizing Bulk Metallic Glasses.

Early Career Initiative

As an element of the Center Innovation Fund, the ECI provides the opportunity for NASA early career civil servants to propose and work on two-year technology projects with industry and academic partners, engage in hands-on technology development opportunities, and learn different approaches to project management. To maximize the effectiveness of the early career projects, each team is mentored by more senior Center personnel and NASA STMD subject matter experts. Several ECI projects have targeted technology demonstrations or flight opportunities that support lunar surface operations, providing NASA civil servant innovators the opportunity to have their technologies demonstrated on the lunar surface. Designed to invigorate NASA's technology base and champion innovative management processes, ECI successfully partners NASA early career leaders with external world-class innovators to deliver transformative national space capabilities.

Prizes, Challenges, and Crowdsourcing

NASA recognizes the value of incentivizing new technology advancement and problem solving through open innovation approaches, including the use of prize competitions and challenges open to the public. Government and non-Government organizations have demonstrated the value of prize competitions for their ability to tap into new sources of talent they have not typically reached. Prize competitions also reduce risk to the buyer because payments only occur after receipt of satisfactory solutions.

STMD's Prizes, Challenges, and Crowdsourcing Program utilizes the NASA Tournament Lab to enlist crowdsourcing to tackle challenges faced in its space and aeronautics research and development programs. The NASA Tournament Lab, which is managed by the Center of Excellence for Collaborative Innovation (CoECI), offers a wide variety of open innovation platforms that engage the crowdsourcing community in challenges to create the most innovative, efficient, and optimized solutions. When challenge owners were surveyed, NASA users of these tools have found them useful for meeting their needs in 94 percent of cases. Other Federal agencies use the NASA platform on a reimbursable basis. The NASA Tournament Lab also supports NASA@Work, an internal crowdsourcing and challenge platform designed to improve the ability of NASA employees to connect with others within the Agency to solve technical and non-technical problems. This platform played a vital role for the Agency in canvassing the workforce in the spring of 2020 for ideas to mitigate the impacts of the COVID-19 pandemic.

Centennial Challenges offers incentive prizes to generate revolutionary solutions to support advanced NASA technology needs and, where appropriate, partners with other organizations to maximize return on investment. NASA has launched three challenges that will address lunar excavation, manufacturing, and construction, lunar power needs, and nutrition needs of astronauts.

- Watts on the Moon Challenge: The purpose of this challenge is to identify flexible, robust energy distribution, management, and storage solutions to power upcoming Moon missions. Phase 1 has a $500,000 prize purse and is accepting conceptual studies for unique solutions to this challenge.
- Break the Ice Lunar Challenge: NASA launched Phase 1 of this competition in November 2020. Phase 1 has a $500,000 prize purse and the goal of finding solutions to autonomous icy regolith excavation technologies for near-term lunar missions that address key operational elements and environmental constraints.
- Deep Space Food Challenge: This competition launched Phase 1 in January 2021 with a $500,000 prize purse, and seeks input on the demonstration of novel technologies, systems, and/or approaches for nutritious food production to support long duration space exploration missions. This competition is running in coordination with the Canadian Space Agency, which is running a parallel competition and will judge and award Canadian citizen competitors with a separate prize purse.

In FY 2021, NASA plans to formulate new competitions to focus on advancing long-lead technologies that support NASA priorities. The FY 2022 budget request proposes approximately $8 million in new prize authority (no-year funding) to support multi-year challenges. This will continue the Phase 2 prizes for Break the Ice Lunar Challenge and the Deep Space Food Challenge in addition to new prizes, challenges and crowdsourcing activities related to climate and clean energy economy. In addition, active Centennial Challenges in progress include: Cube Quest Challenge, Vascular Tissue Challenge, CO2 Conversion Challenge, and Space Robotics Challenge.

TECHNOLOGY TRANSFER

Technology Transfer provides Agency-level management and oversight of NASA-developed and NASA-owned intellectual property and manages the transfer of these technologies to external entities. Activities include active collection and assessment of all NASA inventions, strategic management and marketing of intellectual property, negotiation and management of licenses, software release, development of technology transfer-focused partnerships, and the tracking and reporting of metrics related to these activities (e.g., numbers of new inventions, patents, licenses, cooperative research and development agreements, or software use agreements). NASA Technology Transfer ensures that innovations developed for exploration and discovery are broadly available to the public, maximizing the benefit to the Nation.

EARLY STAGE INNOVATION AND PARTNERSHIPS

NASA's Technology Transfer System (NTTS) platform provides Technology Transfer personnel with tools to facilitate the entire technology transfer process, and it enables NASA to track activities in fine-grained, quantifiable detail.

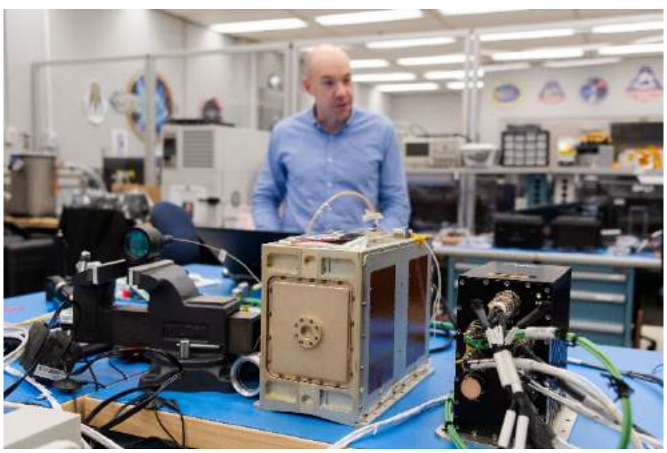
TECHNOLOGY MATURATION

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**179.2**	**227.1**	**491.2**	**501.0**	**511.1**	**521.3**	**531.7**
Change from FY 2021			**264.1**				
Percentage change from FY 2021			**116.3%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



SPLICE Project Manager Ron Sostaric checks out SPLICE technology (including the descent and landing computer, navigation doppler lidar, terrain relative navigation camera, and inertial measurement unit) at NASA's Johnson Space Center in Houston.

NASA is advancing revolutionary space technologies from proof-of-concept to demonstration, maturing transformational and foundational technologies that primarily reside between early stage research and flight demonstration. The Technology Maturation investment portfolio provides transformative and crosscutting technologies that contribute to U.S. leadership in space technology and support NASA missions, including human and robotic exploration of the Moon, Mars, and beyond. Technology Maturation is also committed to supporting advancement in clean energy by collaborating with industry in research and development projects for fuel cells and solar technology.

Technology Maturation includes a broad array of cross-cutting technology applications that fulfill multiple stakeholder needs, including NASA's Human Exploration and Science Mission Directorates, commercial, and other government agencies. Example technologies include autonomous landing and hazard avoidance, advanced materials, and in-space manufacturing and assembly technologies, which benefit both human and robotic exploration, as well as science technologies that can spur economic growth in the space industry. In addition, NASA is introducing the new Industry & Commerce Innovation Opportunity which will expand upon the utilization of existing STMD acquisition vehicles (i.e., Announcement of Collaborative Opportunity [ACO], Tipping Point [TP]). This Opportunity will provide open topic calls for industry to identify and propose activities that will further enable commercial development of key technologies that will support creating good jobs in a growing U.S. space industry.

TECHNOLOGY MATURATION

Public-private partnerships are an important mechanism used by NASA for Technology Maturation projects, such agreements enable NASA and private sector industry to share in the risk and benefit of common technology development interests and investments. These shared risks and benefits include incentivizing technical performance, building future commercial markets, and sharing financial interest in the development of capabilities that support both NASA and other stakeholder needs. NASA will execute a technology portfolio that includes enabling human and robotics exploration and bringing new knowledge and opportunities to Earth through the high-priority technology focus areas described in further detail below. These public-private partnerships are developed through NASA's Tipping Point (TP) Solicitation and Announcement of Collaborative Opportunities (ACO). In FY 2021, NASA is implementing 22 TPs and 28 ACOs.

The Lunar Surface Innovation Initiative (LSII) is also a component under Technology Maturation. Through LSII, NASA STMD collaborates and partners with industry, academia, and other government agencies to develop crosscutting technologies that provide key lunar surface capabilities and feed forward to Mars and beyond. Since its inception in 2019, LSII has engaged ~400 organizations across 48 states and Puerto Rico to advance the technologies needed to explore the lunar surface and stimulate economic development.

Elements of LSII include:

- In-Situ Resource Utilization (ISRU) with an emphasis on collecting, processing, storing, and using material found or manufactured on other astronomical objects;
- Sustainable Surface Power, enabling continuous power throughout lunar day and night;
- Surface Excavation/Construction to enable affordable, autonomous manufacturing and construction;
- Dust Mitigation Technologies to address lunar dust hazards; and
- Extreme Environments and Extreme Access capabilities to operate through the full range of surface and subsurface conditions.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Space Technology portfolio is broadening to develop technologies that can benefit other NASA Directorates, the commercial space sector and other government agencies, as appropriate. The FY 2022 budget request includes funding for Industry & Commerce Innovation Opportunity which will utilize existing acquisition vehicles (such as ACO/Tipping Points, etc.) to pursue technologies needed by commercial space stakeholders. It also includes funding to enhance R&D investments to colleges and universities to enable breakthrough technology R&D in support of U.S. competitiveness.

TECHNOLOGY MATURATION

PROGRAM ELEMENTS

Technology Maturation Budget Estimated by Focus Area[1]

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Rapid, Safe & Efficient Space Transport	18.8	11.0	44.0	33.8	26.6	12.0	12.0
Expanded Access to Diverse Surface Dest	38.1	43.9	43.8	43.2	45.8	26.0	25.7
Sustainable Living & Work Far From Earth	71.3	110.3	199.5	187.8	188.3	237.1	250.0
Transformative Missions and Discoveries	24.9	36.7	85.3	60.2	67.9	49.0	28.0
Industry & Commerce Inn Oppt (ACO/TP)	2.0	0.0	85.6	142.4	148.4	162.7	180.9
Space Tech Management and Integration	24.1	25.1	33.1	33.6	34.1	34.6	35.1
Total Budget	179.2	227.1	491.2	501.0	511.1	521.3	531.7

[1]Technology Maturation categories are under review for revision and are anticipated to change going forward.

**Sums may not add to Total Budget due to rounding.*

PROJECT OVERVIEWS

GCD has a broad portfolio of more than 120 projects, with more than 70 percent of the project including partnerships and collaborations with industry, academia, and/or other government agencies. The portfolio includes a combination of mid-TRL ground-based and flight demonstration development. Below are highlights for some of the key projects.

NASA is making progress in advancing technologies that support rapid and efficient in-space transportation that reduce transit times. Propulsion investments focus on higher thrust and efficiency, including alternatives to traditional chemical propulsion systems for deep space exploration spacecraft systems, and advancement of additive manufacturing techniques. Specific investments include:

- The Thruster for the Advancement of Low-temperature Operation in Space (TALOS) is a new class of thruster to the aerospace community for deep space missions that will provide superior thermal performance due to lower freezing points and mass savings over other thrusters with comparable performance. Through public-private partnership with Frontier Aerospace, NASA is building upon the TALOS effort, providing the first flight set of axial thrusters for the Astrobotic mission for integration on the Peregrine Lander.
- Rapid Analysis Manufacturing Propulsion Technology (RAMPT) and Long-Life Additive Manufacturing Assembly (LLAMA) are advancing the state-of-the-art for additive manufacturing techniques that will reduce lifecycle development time and costs, along with reducing system weight and improving performance, to fabricate liquid rocket engine components. Specifically, RAMPT is advancing large-scale, light-weight manufacturing techniques and analysis capabilities required to reduce design and fabrication cycles (by 60 percent) for regenerative-cooled liquid rocket engine

components. A partnership with Auburn University provides a 25 percent cost share with the technology manufacturing vendors and will strengthen the U.S. supply chain in these manufacturing areas. This project will culminate in a large-scale Thrust Chamber Assembly hot-fire test.

- LLAMA is advancing fabrication of liquid rocket engine components using state-of-the art additive manufacturing techniques. These processes will enable 3D printed parts for use on future lunar landers.
- NASA currently is funding 22 active public and private partnerships (ACO and TP) projects in collaboration with a broad range of industry partners. These ACO and TP projects are advancing rapid and efficient in-space transportation technologies that include additive manufacturing, propellant development from ISRU, new material systems, and engine subcomponents.

For NASA to more accurately land more mass on planetary bodies, as well as improve capabilities to return spacecraft from low-Earth orbit and deep space, the Agency has been working to develop capable Entry Descent and Landing (EDL) systems, materials, and computer modeling capabilities. NASA investments have focused on precision landing and hazard avoidance; design, analysis, and testing of advanced materials for thermal protection; and EDL architectures - for future exploration vehicles and planetary entry missions. Key projects within EDL include:

- Safe and Precise Landing – Integrated Capabilities Evolution (SPLICE) will enable safer and more accurate lunar landings than ever before. Upcoming Moon missions will use SPLICE's advanced algorithms and sensors to target landing sites not possible during the Apollo missions, such as regions with hazardous boulders and nearby shadowed craters.
- Mars Entry Descent and Landing Instrument 2 (MEDLI2) project is a second-generation sensor suite that is incorporated into the Mars 2020 heat shield. This effort improved our understanding of entry system performance by acquiring flight data from an actual Mars mission, informing NASA designs for future exploration missions.
- Mars Environmental Dynamics Analyzer (MEDA) is a suite of environmental sensors aboard the NASA Mars 2020 Perseverance rover that characterizes the climate, including wind speed, near the Martian surface. These sensors include dust, optical, radiation, and temperature, as well as a camera for remote observation.
- The Plume-Surface Interaction (PSI) Project is advancing both modeling and testing capabilities to understand how rocket exhaust plumes affect a planetary landing site. PSI will be improving and validating relevant models with high-fidelity that will provide industry with an in-depth understanding and tools for lunar lander vehicle designs and provide information to mitigate lunar dust impacts.
- Stereo Camera for Lunar Plume-Surface Studies (SCALPSS) is composed of tiny cameras placed around the base of the commercial lunar lander that monitor crater formation from the precise moment a lander's hot engine plume begins to interact with the Moon's surface. This data coupled with the PSI project will be used by future lunar lander vehicle designs. SCALPSS is a collaboration with SMD.

NASA is also working on capabilities for sustainable living and working farther from earth to support routine crewed operations beyond low-Earth orbit. Technologies demonstrated will enable humans to live and operate on the Moon and, eventually, Mars. Additionally, these capabilities provide the ability to reach challenging sites and resources on the Moon and Mars to survive and operate through the lunar night. Descriptions of these capabilities are listed below.

TECHNOLOGY MATURATION

Environmental Control and Life Support Systems (ECLSS), Synthetic Biology, Intra-Vehicle Robotics (IVR), and In Space Manufacturing (ISM)

NASA will advance synthetic biology, in space manufacturing, and IVR in order to enable and sustain human presence in space. Key projects within this portfolio include the following:

- Spacecraft Oxygen Recovery will advance atmospheric capture and conversion aspects of closed-loop life support systems. These technologies will be used by the International Space Station (ISS) as a proving ground to retire risk and gain experience with capabilities needed for deep-space exploration.
- Synthetic Biology will demonstrate producing high-value bio-nutrients on demand, minimizing the need for launched resources. This capability allows biomanufacturing systems to scale to viable production systems for mission products, such as food components, pharmaceuticals, polymers, fuels, and a range of valuable chemicals. This technology will enable the availability of nutrient-rich foods to maintain astronaut health for long duration missions.
- The Integrated System for Autonomous and Adaptive Caretaking (ISAAC) is developing technology for autonomous caretaking of spacecraft, primarily during uncrewed mission phases. The focus is on integrating autonomous IVRs with spacecraft infrastructure (power, life support, etc.) and ground control. ISAAC will provide new capabilities for in-space operations and adaptive vehicle caretaking.
- ISM provides a solution towards sustainable, flexible missions (both in-transit and on-surface) through on-demand fabrication, repair, and recycling capabilities for critical systems, habitats, and mission logistics and maintenance. These additive manufacturing capabilities provide tangible cost savings due to reducing launch mass, as well as significant risk reduction due to decreasing dependence on spares and/or over-designing systems for reliability. This technology will continue to be demonstrated on the ISS.

LUNAR SURFACE INNOVATION INITIATIVE (LSII)

Through the LSII, NASA, in collaboration with industry, academia, and other government agencies, will develop the essential capabilities required for humans and systems to successfully live and operate on the lunar and other planetary body surfaces. These novel technologies will operate through a broad range of lunar environments and will result in the capability to extract and utilize local resources, generate surface power and store energy, access and navigate a variety of terrains, autonomously excavate lunar surface materials for manufacturing and construction, and mitigate lunar dust. Key activities and elements of this initiative are described below.

In-Situ Resource Utilization

ISRU will develop and demonstrate technologies to use the Moon's resources to produce water, fuel, and other supplies. These activities will validate high-fidelity ISRU systems' mass, power, and volume data for incorporation into large-scale flight projects. Following development and maturation of ISRU technologies at the component, subsystem, and scaled system levels, this effort will demonstrate the ability to produce propellants, other mission consumables, products, and infrastructure from regolith and atmospheric resources from a variety of destinations.

- Polar Resources Ice Mining Experiment-1 (PRIME-1) will be the first ISRU demonstration on the Moon. The project includes a flight-ready instrumentation package that will robotically sample and analyze for ice from below the surface. PRIME is a critical instrument suite that will be integrated on the Intuitive Machines commercial lunar lander to land at the lunar South Pole to assess the volatiles and determine water content. PRIME will help provide the knowledge necessary to find critical resources to produce propellant, water, and oxygen for lunar missions.

- The ISRU subscale demonstrates critical technologies on CLPS landers (e.g., mining and processing of oxygen and water, excavation, mineral beneficiation, and regolith processing).

Sustainable Surface Power

NASA is making critical advancements in power generation and energy storage technologies for exploration missions. These technology advancements will provide the capability for continuous power throughout day and night operations on the lunar surface. Solar array technology under development can generate energy in extreme environments, including low-light intensity and low temperature. In addition, NASA is developing and demonstrating a primary fuel cell system to support operations with long discharge times, including applications on rovers, powering of habitats, powering in-situ resource utilization systems, and for general energy storage.

- Vertical Solar Array Technology (VSAT) project aims to develop lightweight solar arrays capable of autonomous ten-meter vertical deployment on uneven terrain through the release of multiple contracts with industry. This technology will enable near continuous capture of sunlight by the solar arrays at the lunar South Pole region.
- Chemical Heat Integrated Power Source (CHIPS) project will demonstrate a combined electrical and thermal power source for lunar night survival and surface operations on the Moon.
- Breakthrough Distributed Power Architecture (BDPA) will develop a highly efficient (greater than 95 percent), low-mass, distributed power subsystem for in-situ platforms on the Moon and beyond.
- Through TP Awards, NASA is working with industry partners to develop and test surface power generation and energy storage technologies. Masten Space Systems will develop a universal chemical heat and electrical power source attachment that lets payloads survive the extreme environments encountered during the lunar night and in craters. pH Matter will develop a reversible, regenerative fuel cell capable of producing power and storing energy on the lunar surface. Precision Combustion will develop a solid-oxide fuel cell stack that generates power directly from methane and oxygen propellants and other in-situ resources.

Dust Mitigation

Lunar dust is one of the principal issues that NASA must address before returning to the surface of the Moon. It has the potential to affect every lunar architecture system. NASA will develop and demonstrate technologies and concepts to mitigate lunar dust hazards; enabling affordable, sustained operations both on the lunar surface and with transfers to and from the Lunar Gateway or other orbital platforms.

- Electrodynamic Dust Shield (EDS) is an active dust mitigation technology demonstration that has potential implications for thermal radiators, spacesuit fabrics, visors, camera lenses, solar panels, and many other technologies. An EDS flight demonstration is scheduled for a CLPS mission in 2023.
- Lunar Occupancy Dust-Surface Separation Technologies project is a passive mitigation strategy that involves applying robust ceramic coatings to the surface of metal-based components susceptible to lunar dust abrasion. This extends the lifetime of parts while decreasing overall component weight. As part of the Dust Mitigation Standards project, NASA is developing Classifications and Standards for Testing with Dust that will identify sources of lunar dust, both natural and induced, particulate size range, surface loading, volumetric loading, and dust velocity. It will define testing types, simulants,

facilities, and include detailed test plans (e.g., protocols for abrasion testing). The integrated test plans will span surface operations, landing vehicles, and orbital assets.

Excavation and Construction

NASA will develop and demonstrate technologies that enable affordable, autonomous manufacturing and construction (e.g., of a landing pad, berm, or shielding) using lunar surface materials. Critical to NASA's ISRU Sub-Scale Demo Plant is the ability to excavate regolith under lunar environmental condition which include lunar dust, extreme temperatures, and minimal gravity.

- The Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) project that will utilize lunar in-situ materials for the on-demand construction of large-scale infrastructure elements such as habitats, berms, landing pads, and blast shields. These structures will provide protection of crewmembers, hardware, and electronics while on the surface of an extraterrestrial body to enable sustained surface exploration. Partners include ICON, Space Exploration Architecture (SEArch+), Department of Defense (DoD) Innovation Unit and the United States Air Force.
- ISRU Pilot Excavator will demonstrate a 30-kilogram Regolith Advanced Surface Systems Operations Robot excavator capable of supplying the full feedstock to an ISRU pilot plant, first in a ground demonstration followed by a lunar surface demonstration. It will incorporate an Astrobotic CubeRover avionics and software developed under Small Business Innovation Research (SBIR) and TP contracts.

Extreme Environments

NASA is advancing rovers, manipulators, and other systems that can operate throughout the full range of lunar surface conditions, including lunar noon (up to 150 degrees Celsius), lunar night (down to -180 degrees Celsius), multiple day/night cycles, and permanently shadowed regions (down to -240 degrees Celsius). Key technologies include:

- Bulk Metallic Glass Gears (BMGG) will improve rover mobility performance at low temperatures by creating alloys made of "metallic glass" eliminating the need for gear lubricant and associated heaters. This project will deliver planetary gears and strain wave gears that will enable surface missions where temperatures drop below the freezing point of typical lubricants.
- Cold Operable Lunar Deployable Arm (COLDArm) payload will significantly improve the utility for lunar landers by providing autonomous manipulation capabilities during the lunar night. It will expand the science capabilities of lunar robotic missions, including deploying instruments/payloads and sampling.

Extreme Access

STMD demonstrates technologies enabling humans or robotic systems, particularly autonomous systems, to efficiently access, navigate, and explore previously inaccessible lunar or planetary surface or subsurface areas.

- Autonomous Pop Up Flat Folding Exploration Robot (A-PUFFER) project develops autonomous navigation, map generation and exploration capabilities for accessing new, high-interest, extreme terrains.
- Cooperative Autonomous Distributed Robotic Exploration (CADRE) project will incorporate technology developed by PUFFER and demonstrate collaborative autonomous exploration on the

lunar surface by navigating, communicating, computing, perceiving, and decision-making without human interaction.

- CubeRover TP project, a public-private partnership with Astrobotic and Carnegie Mellon University, will develop a small rover platform that complements lunar payload delivery services by providing a low-cost mobility platform with small payload capability for lunar science and exploration.
- Inspired by terrestrial technology, Nokia, through a TP contract, will deploy the first LTE/4G communication system on the lunar surface. The system could support lunar surface communications at greater distances, increased speeds, and provide more reliability than current standards.
- Intuitive Machines is developing a small, deployable hopper lander capable of carrying a 2.2-pound payload more than 1.5 miles. This hopper could access lunar craters and enable high-resolution surveying of the lunar surface over a short distance.
- The High Technology Readiness Level (TRL) Rover LIDAR project will develop a vision mapping system that will enable rovers to venture beyond benign planetary and lunar surfaces into dark, high-contrast, confined, or low-texture (i.e., extreme) environments.

NASA is developing and integrating a wide range of technologies that will enable or dramatically improve a multitude of future robotic and human exploration missions and lead to transformative missions and discoveries. These technologies are applicable to lunar exploration as well as many Earth, planetary, heliophysics and astrophysics science missions. Examples and descriptions of these technologies are listed below.

On-Orbit Servicing, Assembly, and Manufacturing

Key projects within this portfolio include the following:

- The Super-lightweight Aerospace Composites (SAC) project will scale up the manufacturing and use of high-strength carbon nanotube composite materials leading to significant mass savings in rocket and spacecraft structures.
- Precision Assembled Space Structure (PASS) will develop and validate critical technologies, such as autonomous assembled structures and high-precision joints for effective efficient on-orbit assembly of large structures, such as next generation science telescope. The project is collaborating with DoD and SMD.

Avionics, Communication, and Navigation

Key projects within this portfolio include the following:

- High Performance Spaceflight Computing (HPSC) will develop the next generation Application-Specific Integrated Circuit (ASIC) chip that will vastly improve in-space computing performance, energy management, and radiation fault tolerance.
- Distributed Spacecraft Autonomy (DSA) will develop technology demonstrating autonomous decision-making for multi-spacecraft missions and will significantly increase the effectiveness of missions and systems by operating them as a collective rather than individually.
- In-space Navigation Vision System Tipping Point (IViS-TP) project, a public-private partnership with Intuitive Machines, will develop a foundational vision processing hardware and software with a revolutionary commercialization model to reduce the cost and schedule required for deploying optical navigation capabilities on commercial and exploration space missions.

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ACHIEVEMENTS IN FY 2020

- TALOS completed design development hot-fire testing of both the axial and Attitude Control System workhorse thrusters at Moog Niagara Falls and Whittinghill Aerospace. These thrusters will be infused into the Astrobotic Peregrine lander.
- Busek conducted testing of a 600-Watt Hall Thruster. The thruster exceeded the baseline goal of 5,000 hours of operation in early FY 2020 and completed testing with over 7,000 hours of operation. This technology could be infused into sub-kilowatt power level electric propulsion systems to enable more affordable missions with smaller spacecraft.
- The Composite Technology for Exploration (CTE) Project developed and demonstrated critical composites technologies that provide weight-saving, performance-enhancing bonded joint technology to be used on future NASA missions. The CTE Project completed longitudinal joint testing and associated non-destructive evaluation methods. NASA's Space Launch System (SLS) used the CTE longitudinal bonded joints as the baseline design for the SLS Payload adapter, which is the adapter used on the larger SLS Block 1B configuration for attaching co-manifested payloads. In FY 2022 future work will include developing and maturing material systems, such as thermoplastic composites to improve efficient joining solutions for large scale space structures and applications. Technology developed and matured under CTE has potential for significant benefits to the Universal Stage Adapter as well as circumferential bonded joint applications for future spaceflight structures.
- The SPLICE project successfully delivered the descent landing computer for integration with Blue Origin's New Shepard launch vehicle for flight demonstration of deorbit, descent, and landing sensors. In addition, the project completed Hazard Detection Light Detection and Ranging (LIDAR) (HDL) prototype lab testing.
- Blue Origin Deorbit Descent and Landing (DDL), a public-private partnership project, successfully completed Critical Design and Integration reviews, and integrated SPLICE components that included Navigation Doppler LIDAR (NDL), and Descent Landing Computer (DLC) Engineering Development Unit along with onboard Guidance, Navigation and Control algorithms plus a camera and Inertial Measurement Unit.
- The MEDLI2 and MEDA projects completed environmental testing and hardware integration and testing of entry system sensor suite with the Mars 2020 Perseverance Mission, which was launched in July 2020.
- The PSI project evaluated and validated the results of initial comparisons of computational simulations to experimental test data.
- The Synthetic Biology project delivered the second bionutrients flight demonstration hardware to the ISS in January 2020. These first two demonstration samples were returned in April 2020 and are being assessed.
- The ISM project finished a 24-month Phase A activity with Techshot, Inc., for development of a multi-material manufacturing prototype for metal and polymer 3D printing using a titanium feedstock. Additionally, the project completed design and successful lab demonstration of the Vulcan Metal 3D printing system for ISS under development through a Phase II Extended and Phase III SBIR award. The project also developed an on-demand printed circuit cortisol sensor with Caltech.
- NASA established an agreement with the Department of Defense University Affiliated Research Center and the Johns Hopkins University Applied Physics Laboratory (APL), initiating the Lunar

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Surface Innovation Consortium (LSIC), which comprises experts from academia, industry and government to shape the technologies and systems needed to explore the surface of the Moon.

- The PRIME project successfully completed Critical Design Review (CDR) for the Mass Spectrometer observing lunar operations and the Regolith and Ice Drill for Exploring New Terrain drill being developed by Honeybee Robotics.
- The COLDArm project completed technology infusion workshop for potential future COLDArm payloads.
- A-PUFFER project completed the first phase of a field test demonstrating multiple robots in the JPL Mars Yard, where a PUFFER robot autonomously self-localized and traversed the area and shared grid maps with a base station. The robot was then able to merge the captured maps into a single map and issue commands for subsequent exploration goals.
- Cooperative Autonomous Distributive Robotic Explorer (CADRE) project completed multiple mission concepts and approaches for integrating industry and academia in providing collaborative robots and payload instruments in preparation for an early CLPS flight. The successful A-PUFFER technology development has informed the CADRE lunar demonstration.
- CubeRover TP project successfully completed Systems Requirements Review, developing the payload interface design and initiated environmental testing of subsystem components.
- SAC project through a SBIR Phase III contract with Nanocomp Technologies developed and brought online a high-capacity reactor that is demonstrating a tenfold increase in carbon nanotube production.
- HPSC Advanced Memory project in partnership with the Air Force Research Laboratory awarded volatile and non-volatile memory devices contract to support processor and digital devices. The industry partners in this activity have completed initial design concepts and reviews. The HPSC Chiplet project-initiated contract for radiation testing of 22 nanometer test chips and released Request for Information from industry on developing NASA ASIC Chip.
- DSA project completed a critical design assessment review in conjunction with the Small Spacecraft Technology STARLING mission. DSA will be performing an in-space experiment demonstrating multi-spacecraft autonomous communication and operation.
- IViS - TP project completed the Design Review for the Vision Processing Unit (VPU) for optical navigation.
- The integrated Radio Optical Communications (iROC) terminal concept provides a hybrid radio-frequency (RF) and optical approach to space communications technology. iROC project will complete design and prototype development of subsystems, including the teletenna and beaconless pointing system after leveraging previous SBIR awards.

WORK IN PROGRESS IN FY 2021

- NASA will complete the design and combustion testing of the TALOS, leading to qualification testing in FY 2021 that will validate the thruster's performance in a relevant environment.
- RAMPT will demonstrate a hot-fire test of a large-scale composite overwrapped thrust chamber assembly with an additively manufactured nozzle.

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- LLAMA will perform hot-fire tests, which will demonstrate two additively manufactured engine components, a copper alloy combustion chamber, and nozzle made of a high-strength hydrogen resistant alloy.
- Blue Origin Lunar Lander Advanced Nozzle will evaluate and mature high-temperature liquid rocket engine nozzle material technologies. This public-private partnership will leverage Blue Origin experience in propulsion and material development and NASA expertise on high-temperature materials and nozzle testing.
- The SPLICE project will demonstrate the sensors, software, and avionics hardware of the NDL, DLC, and Terrain Relative Navigation (TRN) on Blue Origin's New Shepard suborbital flight test vehicle. Post flight data performance analysis of the associated subsystems will inform design changes and modifications for the upcoming lunar flight units. Additionally, NDL will be delivered to Astrobotic's and Intuitive Machine's Lunar Lander for demonstration and infusion for lunar precision landing capability.
- Through public-private partnerships with Blue Origin, the DDL project successfully completed its first suborbital flight test and will perform a second suborbital flight test that will verify and validate the navigation system using the Jet Propulsion Laboratory's (JPL) terrain relative navigation.
- The MEDLI2 project successfully entered the Martian atmosphere on February 18, 2021 and is characterizing and measuring atmospheric pressures, temperatures, and heating rates. The project successfully performed post flight data analysis of the entry system, which will be used to improve the precision landing capability for future robotic missions.
- The MEDA project is providing weather measurements, including wind speed and direction, temperature, and humidity. The instrument will also measure the amount and size of dust particles in the Martian atmosphere.
- SCALPSS provides PSI data through development of a stereo camera and will be flown on Firefly Blue Ghost Lander CLPS mission. The project will complete design and fabrication of flight hardware and perform a system level functional test.
- SpaceCraft Oxygen Recovery will complete CDR of subscale oxygen recovery from carbon dioxide reactor.
- Synthetic Biology returned production packs and the bioreactors containing their cultures were frozen and returned on SpaceX-21 for analysis. The samples were hydrated by ISS crew where the nutritional engineered yeast grew for 48 hours.
- ISAAC will perform a demonstration on ISS to validate the initial IVR Technology architecture.
- ISM project is manifested on ISS to conduct the first in-space manufacturing of metals. Techshot is developing a novel power system to meet stringent requirements in space or in the field with limited power availability.
- NASA has entered into a contract with APL to serve as a system integrator for LSII and continuation of the LSIC with over 400 members across 44 states. In addition, APL has established monthly focus groups for each of the six LSII capability areas with active participation across LSIC community. APL is integrating these findings to better inform and guide STMD investments. The consortium conducted the first of several workshops with a focus on Dust Mitigation with 370 attendees (new and non-traditional stakeholders). The next workshop will focus on Lunar Mapping and Precision Landing.

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- PRIME-1 will complete interface CDR and deliver Mass Spectrometer observing lunar operations (MSolo) and The Regolith and Ice Drill for Exploring New Terrain (TRIDENT) drill to CLPS provider, Intuitive Machines. MMPACT project will complete the Concept Design Review (CoDR) in order to move forward with prototype hardware and work on collecting material characterization data to support construction efforts. Additionally, the ISRU Pilot Excavator project will complete its CoDR and Preliminary Design Review (PDR). In addition, NASA will be conducting ground tests using high-fidelity regolith simulant and testing designs of sample collection buckets developed via the crowdsourcing challenge through NASA Tournament Labs.
- VSAT project will award contracts to multiple vendors for the purpose of developing concept designs.
- The BDPA project will evaluate the proposed surface system development hardware for scalability to larger crewed systems. The project will deliver a Hardware Extensibility Report that determines concept extensibility and identify technology gaps to a higher power application.
- Lunar Dust Mitigation projects, which incorporate active, passive, and operational approaches, are in development and will be demonstrated as payloads on early CLPS missions. Specifically, the EDS project will complete PDR. Further materials and coatings samples experiments design reviews will be completed for the CLPS Regolith Adherence Characterization experiment.
- The COLDArm project will complete the final design review and will integrate BMGG technology into project actuators to enable lunar night operations.
- CADRE project will complete the System Requirements and Technology Demonstration review which will lead to a CLPS mission demonstrating cooperative autonomy between robotic platforms such as Astrobotic's CubeRover.
- CubeRover TP project will complete the build, assembly, and environmental testing of the engineering unit. The project will hold PDR and CDR leading to a finalized design of the flight unit.
- Deployable Hopper TP project, with Intuitive Machines (IM), will complete CDR.
- The High TRL LIDAR project will complete a complete risk reduction activities and formulation reviews.
- SAC project will further develop and test multiple manufacturing techniques with industry partner Nanocomp Technologies to increase production of high-strength carbon nanotubes to develop structures for extreme environments.
- PASS project will develop tri-truss modules and reversible joints that will enable robotic assembly of large space structures.
- HPSC project will release a Request for Proposal and award contracts to multiple companies for design studies and evaluate results of radiation testing 22 nanometer test chips.
- DSA project will complete validation and verification testing of processor-in-the-loop and hardware-in-the-loop of flight software as a final ground demonstration of multi-spacecraft autonomous communication and operation.

TECHNOLOGY MATURATION

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- RAMPT project will complete a manufacturing demonstration of a 35,000 pound of force composite overwrap combustion chamber. In addition, new project content for additive manufacturing technology materials will be pursued for high-temperature applications.
- The Small Spacecraft Electric Propulsion System ACO project will complete endurance testing and cycling of electric propulsion thruster in collaboration with Northrop Grumman.
- The Reactive Additive Manufacturing for Fourth Industrial Revolution Exploration Systems ACO project will perform a hot-fire demonstration of a nozzle using a newly patented additive manufacturing material developed by Elementum 3D in partnership with Marshall Space Flight Center, Aerojet Rocketdyne, and the Air Force Research Laboratory (AFRL).
- Frontier Aerospace will deliver qualified thrusters for flight qualification on Astrobotic's Peregrine Lander Commercial Lunar Payload Service (CLPS) mission to Lacus Mortis, a larger crater on the near side of the Moon.
- The SPLICE project will incorporate design changes based on Blue Origin's New Shepard flight tests and complete development and assembly DLC and NDL flight units for CLPS technology demonstration. The project will complete development of high-fidelity HDL for a terrestrial flight test.
- Through public and private partnership with Astrobotic, the TP project will deliver an operational Terrain Relative Navigation and Visual Velocimetry sensor product. This project will develop a commercial TRN system capability for lunar and planetary landers.
- The PSI project will incorporate results from Physics Focused Ground Test campaign experimental data to update and release PSI computational model software tool for CLPS and Human Lunar Lander companies.
- SCALPSS project will complete environmental testing on hardware and deliver flight hardware to lunar lander provider for integration and preparation for flight.
- Synthetic Biology will complete development of a prototype bioreactor that can convert locally-sourced carbon dioxide to organic compounds. Synthetic Biology will continue analysis of future returned BioNutrient packs and submit an initial report quantifying results of experiments completed to date.
- ISAAC project will complete autonomous operation demonstration on ISS using IVR for operations without human intervention.
- ISM will deliver flight hardware of first in space metallic fabrication laboratory for ISS demonstration in FY 2023.
- APL will provide iterative Technology Maturation Assessments for the six LSII capability areas as the LSII System Integrator. These assessments will incorporate key insights and feedback from the LSIC industry and university members. This ensures NASA's collaborative opportunities and solicitations result in accelerating the development of cutting-edge technologies, while providing the greatest value-proposition for commercial and academic partners across the United States.

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- NASA will complete integration of the PRIME-1 hardware to Intuitive Machine's Lunar Lander to be sent to the lunar surface for demonstration on an early CLPS mission in CY 2022. In addition, the ISRU Pilot Excavator plans to complete a full-system excavation ground demonstration.
- Under Sustainable Surface Power, the Regenerative Fuel Cell project will complete the CDR of the 100-Watt class autonomous engineering model for the fuel cell, targeting an integrated ground demonstration in FY 2024.
- CHIPS project will begin the assembly of the integrated system that includes the reaction control subsystem, the thermal control subsystem, and the thermoelectric converter subsystem, which once integrated with lunar landers will extend operational life. In addition, BDPA will perform a demonstration of a single flat satellite system integrated with a lander electrical power system in the Modular Power Testbed at Glenn Research Center. Demonstration will explore the ability to integrate with higher power systems and assess electrical power quality and stability of the distributed power system.
- NASA will deliver Dust Mitigation Payloads, the EDS, and materials for the Regolith Characterization Experiment for integration with Firefly Aerospace Blue Ghost lander mission, scheduled for launch in 2023.
- The MMPACT project will complete a prototype that demonstrates additive manufacturing using simulated regolith for large structures such as habitats. In addition, NASA Lunar Water Extraction Project will complete a PDR for an Automated Carbothermal Reactor Prototype Design leading to a ground demonstration in a relevant environment.
- CADRE project will perform ground-based autonomous operation of multiple robotic explorers, complete environmental tests, and hold final design review leading to a CLPS flight to the lunar surface in 2023.
- Deployable Hopper TP and Nokia 4G/wireless TP will deliver and integrate flight hardware on Intuitive Machines Nova-C Lander for integration into SpaceX Falcon 9 launch vehicle.
- The High Technology Readiness Level (TRL) LIDAR project will complete CDR.
- SAC project will develop and deliver scaled-up composite processes using carbon nanotubes that will yield panels demonstrating achievement of increased tensile, toughness, and extreme environmental properties above the current state-of-the-art composite materials. Those applications include entry, descent and landing systems, hypersonic vehicles, and propulsion systems.
- PASS Project will integrate tri-truss modules, data and electronic connector modules, and autonomous assembly techniques for a ground demonstration of an autonomous assembly of a large space structure.
- HPSC project will evaluate the results of the design studies and award contracts to the appropriate industry partners to develop radiation tolerant ASIC Chip.
- DSA project will demonstrate autonomous decision-making on multiple spacecraft as part of Small Spacecraft Technology STARLING mission. Further, the project will simulate a mission of 100 spacecraft in an autonomous multiple spacecraft operation.

TECHNOLOGY MATURATION

ACQUISITION STRATEGY

These critical technology projects are defined as part of the strategic framework and capabilities, through requirements determined by the Federated Team, and through selection by STMD's annual Strategic Technology Architecture Round-table (STAR) process. In addition, STMD embraces competition and external partnerships; as such, some of the technologies are selected through the annual TP, ACO, and other NASA solicitations.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Lunar Surface Innovation Initiative	Johns Hopkins Applied Physics Lab	Laurel, Maryland
LTE/4G communications	Nokia of America	Sunnyvale, California
Deployable Hopper	Intuitive Machines	Houston, Texas

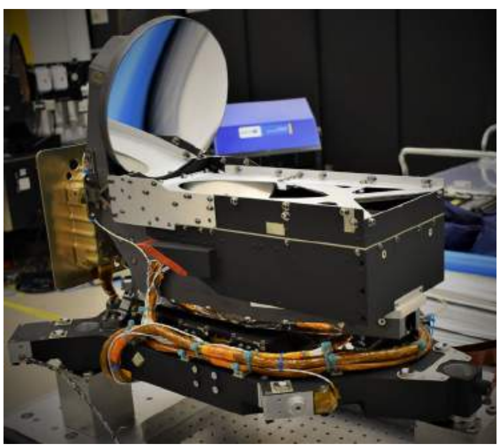
TECHNOLOGY DEMONSTRATION

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Laser Comm Relay Demo (LCRD)	28.5	15.1	**0.0**	0.0	0.0	0.0	0.0
Solar Electric Propulsion (SEP)	67.0	26.2	**24.2**	18.5	15.9	17.8	5.8
Restore & SPIDER (OSAM-1)	227.2	227.0	**227.0**	227.0	227.0	103.6	25.4
Small Spacecraft, Flight Opportunities & Other Tech Demo	252.9	260.1	**250.6**	267.4	283.0	418.0	522.3
Total Budget	**575.5**	**528.4**	**501.8**	**512.9**	**525.9**	**539.4**	**553.5**
Change from FY 2021			**-26.6**				
Percentage change from FY 2021			**-5.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



The Deep Space Optical Communications (DSOC) Flight Optical Transceiver Assembly was delivered on February 2021. DSOC is a one-year flight mission planned to fly on the Psyche mission to demonstrate optical communications from deep space.

The Technology Demonstration portfolio includes the Technology Demonstration Missions, Small Spacecraft Technology, and Flight Opportunities.

The Technology Demonstration Missions (TDM) Program conducts both ground-based testing and space flight demonstrations. Ground-based testing is performed to advance technologies from component validation in a relevant environment to system model or prototype demonstration in an operational environment. TDM also advances technologies through the completion of space flight demonstrations and transitions these new capabilities to NASA exploration missions and potentially to industry and other Government agencies.

Current and future projects in this portfolio include projects supporting Artemis, science missions, other NASA directorates, the commercial space sector, and other Government agencies. Technology investments include high-power solar electric propulsion for the Artemis Power and Propulsion Element, precision lunar landing and hazard avoidance, cryogenic fluid management, in-situ resource utilization and sustainable lunar surface power, advanced communications and navigation demonstrations, and in-space manufacturing and assembly.

Public-private partnerships continue to be used to enable NASA to share the risk and financial interest with private industry and better leverage Government investments. For example, through NASA's fifth Tipping Point Technologies solicitation and selection process, cryogenic fluid management technologies will be matured through in-space demonstrations and lead to the implementation of these technologies in operational missions. NASA and industry partners will develop and test numerous technologies to enable long-term cryogenic fluid management, which is essential for more efficient in-space transportation. In-space servicing, manufacturing, and assembly will enable transformative missions that cannot currently be performed and will diversify the existing Government and commercial spacecraft development options, which are currently limited by launch vehicle shape, size, and mass constraints. Additionally, entry, descent, and landing technologies will provide the capability to return large payloads to Earth, enabling the re-use of space systems and, potentially, the affordable return of objects manufactured in space to Earth.

This account also supports the Flight Opportunities and Small Spacecraft programs' rapid development and demonstration of technologies through partnership with U.S. industry for suborbital flight testing and small spacecraft missions. These programs leverage agile spacecraft platforms and responsive launch capabilities to increase the pace of space exploration, scientific discovery, and the expansion of space commerce. These emerging capabilities have the potential to enable new mission architectures, enhance conventional missions, and promote development and deployment on faster timelines. The programs partner with U.S. industry and academia to target technology gaps that market forces would not otherwise fill; specific emphasis is placed on National efforts in cislunar space, breakthrough observing capabilities for Earth and beyond, and capabilities that ensure National leadership in space and help the commercial space industry grow.

EXPLANATION OF MAJOR CHANGES IN FY 2022

NASA will fund the OSAM-1 mission consistent with its approved baseline, which will allow Space Technology Mission Directorate to advance servicing technologies to on-orbit demonstration. Details of the baseline are discussed as part of this congressional justification.

The Solar Electric Propulsion Budget reflects the changes approved at the Delta Key Decision Point-C, held in May 2021.

The FY 2022 budget submission does not support nuclear propulsion.

LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	169.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	169.5
Development/Implementation	93.3	28.1	7.2	**0.0**	0.0	0.0	0.0	0.0	0.0	128.6
Operations/Close-out	0.0	3.2	9.3	**0.0**	0.0	0.0	0.0	0.0	0.0	12.5
2021 MPAR LCC Estimate	**262.7**	**31.3**	**16.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**310.5**
Total STMD Budget	**222.0**	**28.5**	**15.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**265.5**
Change from FY 2021				**-15.1**						
Percentage change from FY 2021				**0.0%**						
Total NASA Budget	**262.7**	**31.3**	**16.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**310.5**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The Laser Communications Relay Demonstration (LCRD) flight payload (pictured above) was delivered to Northrop Grumman’s facility in Sterling, Virginia. There, the payload was integrated onto the U.S. Space Force’s Space Test Program Satellite 6 (STPSat-6) in preparation for launch. LCRD will be NASA’s first end-to-end optical relay, sending and receiving data from missions in space to mission control on Earth.

PROJECT PURPOSE

The goal of the Laser Communications Relay Demonstration (LCRD) project is to prove the utility of bi-directional optical communications relay services between geosynchronous orbit and Earth. The project supports the advanced communications, navigation, and avionics exploration key focus areas. This effort will prove optical communications technology in an operational setting, providing data rates up to 100 times faster than today’s radio frequency-based communication systems. The demonstration will measure and characterize the system performance over a variety of conditions, develop operational procedures, assess applicability for future missions, and provide an on-orbit capability for test and demonstration of standards for optical relay communications. This capability, if successfully demonstrated, could be quickly infused into NASA missions, other

LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

Federal agencies, and U.S. satellite manufacturers and operators given the rising demand for bandwidth. LCRD will fly as a hosted payload with the U.S. Space Force Space Test Program (STP-3 mission). NASA has a cost-sharing agreement with the U.S. Space Force related to the STPSat-6 spacecraft manifested on that mission. Upon a successful flight demonstration, NASA will provide the communications industry with access to the integrated system to test these new capabilities for commercial applications.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

PROJECT PARAMETERS

LCRD will conduct a minimum two-year flight demonstration to advance optical communications technology toward infusion into Near Earth operational systems while growing the capabilities of industry sources. Objectives include:

- Demonstrating bidirectional optical communications between geosynchronous Earth orbit and Earth;
- Measuring and characterizing the system performance over a variety of conditions;
- Developing operational procedures and assessing applicability for future missions; and
- Providing an on-orbit capability for test and demonstration of standards for optical relay communications.

ACHIEVEMENTS IN FY 2020

The project completed standalone testing of the LCRD flight payload and delivered the flight payload to the spacecraft integrator, as well as having supported flight payload integration and testing as a part of the STPSat-6 spacecraft manifested on the STP-3 mission. The project supported space vehicle integration and testing, including end-to-end testing with the LCRD Mission Operations Center. Additionally, the project certified the mission operations network that will be used to operate the payload on-orbit and completed their System Integration Review and KDP-D.

WORK IN PROGRESS IN FY 2021

The project continued to support space vehicle integration and testing, including vibration, thermal vacuum, and electromagnetic compatibility testing, as well as continued to support end-to-end testing with the LCRD Mission Operations Center and the optical ground stations. The STPSat-6 spacecraft will be delivered to the launch site and the project will complete an Operations Readiness Review (ORR) and KDP-E. Launch was scheduled for February 2021 but has been delayed to enable the host space vehicle to resolve spacecraft technical issues. Launch is now scheduled for June 2021. Project will begin on-orbit operations following two months of on-orbit checkout and an on-orbit acceptance review.

LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2022

Human Exploration Operation Mission Directorate's Space Communications and Navigation (SCaN) Program will operate and maintain the LCRD payload through the LCRD Mission Operations Center (LMOC) after the LCRD commissioning. SCaN will continue to support the LCRD mission demonstrations through the two-year prime demonstration operations period.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
CDR	Dec 2016	Dec 2016
KDP-C	Feb 2017	Feb 2017
System Integration Review	May 2018	Apr 2020
KDP-D	Feb 2020	Jul 2020
Operational Readiness Review	Oct 2020	May 2021
KDP-E	Dec 2020	Jun 2021
Launch Readiness Review	Dec 2020	Jun 2021
Launch (or equivalent)	Jan 2021	Jun 2021

LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

Development Cost and Schedule

The table below includes the base and current year development cost estimate for STMD ($95.7 million) as well as the NASA total, which also includes funding ($32.9 million) from SCaN. The baseline LCC is $310.5 million and the development cost is $128.6 million.

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2020	95.7 (STMD)	70%	2021	95.7 (STMD)	0%	Launch	Jan 2021	Jun 2021	5
2020	128.6 (NASA)	70%	2021	128.6 (NASA)	0%	Launch	Jan 2021	Jun 2021	5

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost. NASA originally baselined LCRD in 2017 and conducted a re-plan in 2019. JCL was not updated in re-plan.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**128.6**	**128.6**	**0**
Aircraft/Spacecraft	32.5	37.6	+5.1
Payloads	25.5	25.5	0
Systems I&T	15.6	16.7	+1.1
Launch Vehicle	0.0	0.0	0
Ground Systems	7.3	12.3	+5.0
Science/Technology	6.0	6.3	+0.3
Other Direct Project Costs	41.7	30.2	-11.5

LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Program Management	Project Management, LCRD Payload, LCRD Mission Operations Center	Goddard Space Flight Center	N/A
Optical Ground Station	Optical Ground Stations, RF Ground Station and STPSat-6 Mission Control Center	Human Exploration and Operations Mission Directorate (HEOMD)/SCaN	N/A
Technology Transfer	Technology Transfer for Payload	Massachusetts Institute of Technology: Lincoln Laboratory	N/A
Ground Station	Optical Ground Station 1	Jet Propulsion Laboratory	N/A
Spacecraft and Launch Vehicle	STPSat-6 Spacecraft and Launch Vehicle	U.S. Space Force and Northrop Grumman (Spacecraft vendor); ULA (Launch Vehicle)	N/A

Acquisition Strategy

All major acquisitions are in place.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Technology Transfer for Payload and Optical Ground Station	Massachusetts Institute of Technology: Lincoln Laboratory	Lexington, MA

LASER COMM RELAY DEMO (LCRD)

Formulation	Development	Operations

INDEPENDENT REVIEWS

Completed independent assessment prior to KDP-C.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Joint Confidence Level (CL)	Tecolote	Oct 2016	Determine realistic 50/70 percent CL budget and schedule in accordance with Agency requirements	70 percent CL used to define Program-held UFE above project for KDP-C	N/A
Standing Review Board / Independent Readiness Team	Various subject matter experts	Nov 21-22, 2019 (technical presentation); April 21, 2020 (Programmatic)	Provide STMD and GSFC Center Director project delivery readiness assessment	Project was approved to deliver flight payload	Operational Readiness Review currently scheduled for May 2021

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

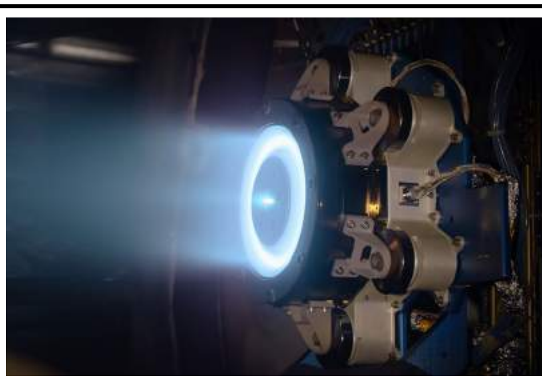
FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	179.2	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	179.2
Development/Implementation	0.0	67.0	49.2	**25.4**	9.0	5.8	0.0	0.0	0.0	156.4
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2021 MPAR LCC Estimate	**179.2**	**67.0**	**49.2**	**25.4**	**9.0**	**5.8**	**0.0**	**0.0**	**0.0**	**335.6**
Total Budget	**179.2**	**67.0**	**26.2**	**24.2**	**18.5**	**15.9**	**17.8**	**5.8**	**5.6**	**360.2**
Change from FY 2021				**-2.0**						
Percentage change from FY 2021				**-7.6%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The 2021 MPAR LCC Estimate reflects the Fiscal Year 2021 Quarter 2 Financial Report, which is current as of March 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since March 2021.



The Electric Propulsion thruster is shown here in testing. The project will be qualifying a 30-50 kilowatt (kW)-class solar electric propulsion system that will be demonstrated on the Lunar Gateway Power and Propulsion Element.

PROJECT PURPOSE

At the Glenn Research Center (GRC), NASA will continue the development of Solar Electric Propulsion (SEP) with higher-power, longer-life thrusters. The first demonstration of this 50-kilowatt (kW)-class thruster will be as the primary propulsion element to place the Lunar Gateway into the highly elliptical lunar orbit. This demonstration will provide NASA with experience in electric propulsion maneuvers in the family of orbits around the Moon and demonstrate operational approaches and interfaces with visiting crew and robotic vehicles. SEP will also enable more efficient orbit transfer of spacecraft and accommodate the increasing power demands for Government and commercial satellites.

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

The SEP thrusters will not only meet the objectives of future NASA exploration purposes, but also will support the growing demand for increased electric propulsion performance for commercial satellites. This development will be integrated with previous NASA advancements in deployable solar array structures. These arrays, with half of the mass and one-third of the packaging volume compared to state-of-the-art solar arrays, have already been incorporated into commercial satellite product lines enabling greater payload mass.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The SEP FY 2022 Budget reflects the changes approved at the Delta Key Decision Point (KDP)-C, which was held in May 2021. Details of this re-plan are provided below

PROJECT PARAMETERS

The goal of the project is to qualify a 30-50 kW-class solar electric propulsion thruster to be used as primary propulsion for a spaceflight demonstration. Objectives include:

- Develop instrumentation to characterize performance of an integrated system, including thrusters, arrays, bus, and payloads as they operate as an integrated system and as they respond to the in-space environment.
- Qualify high-power SEP thruster technology for use in relevant space environments through demonstration of continuous long-term operation of the system sufficient to characterize and predict the capability and lifetime of the system.
- Qualify electric propulsion thruster for extended operations in deep space.

ACHIEVEMENTS IN FY 2020

This project passed a Directorate Program Management Council (DPMC) for a Solar Electric Propulsion (SEP)/ Power and Propulsion Element (PPE) governance implementation approach. In addition, the project released a request for proposal (RFP) to Aerojet Rocketdyne for the thruster-only development and qualification that incorporates requirements changes baselined at PPE control board.

The Plasma Diagnostic Package (PDP) thruster probe assembly (TPA) and main electronics package (MEP) completed Preliminary Design Review (PDR). The SEP project completed steady state component thermal cycling tests to correlate thermal models. Test facilities at the Jet Propulsion Laboratory (JPL) and (GRC) completed checkout testing in preparation for engineering test campaigns and resolved test fixture/instrumentation anomalies.

WORK IN PROGRESS IN FY 2021

The SEP contract with Aerojet Rocketdyne was renegotiated, reflecting development of electric propulsion thrusters going through qualification only. A Delta KDP-C was held in May 2021 to update the project's Level 1 requirements to develop and qualify an advanced 12.5 kW electric propulsion thruster applicable to human/robotic exploration and commercial spaceflight missions including PPE. A

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

project re-plan was approved at the Delta KDP-C and addressed contractor performance, COVID-19 impacts, the PPE procurement strategy, schedule, and mission requirements. This re-plan reflects adjustments to the Gateway PPE requirements and is aligned to the Gateway PPE mission needs. Reviews are ongoing.

The team will conduct Laser Induced Fluorescence testing on a thruster engineering unit at GRC and thermal vacuum chamber testing of a second thruster engineering unit at JPL. Other tests will focus on development of the thruster cathodes at wear/cycling conditions. PDP TPA engineering development unit will be assembled and placed through shock, vibration, and thermal vacuum test conditions.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The SEP project is working toward completing the Critical Design Review (CDR) for the electric propulsion thrusters by the second quarter of FY 2022. PDP will be delivered to PPE by summer 2022.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
Formulation Authorization	Mar 2015 (as part of Asteroid Redirect Robotic Mission [ARRM])	Mar 2015 (as part of ARRM)
KDP-A	Mar 2015 (as part of ARRM)	Mar 2015 (as part of ARRM)
Preliminary Design Review	Aug 2017	Aug 2017
KDP-C	Jun 2019	Jun 2019
Delta KDP-C	-	May 2021
CDR	Sep 2020	TBD
Deliver Plasma Diagnostics Package for Lunar Gateway for Integration	Jul 2021	TBD
Advanced Electric Propulsion System Life Qualification Test Report	Dec 2024	TBD

Note: SEP cost and schedule milestones are currently under review; NASA will notify Congress on the results of these reviews.

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2020	155.9	70%	2021	156.4	0%	Electric Propulsion Thruster Life Qual Test Report	Dec 2024	Dec 2024	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**155.9**	**156.4**	**+0.5**
Science/Technology	124.9	127.9	+3.0
Other Direct Project Costs	31.0	28.5	-2.5

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Program Management	Manages Aerojet Rocketdyne contract, thruster development life testing and qualification testing, Plasma Diagnostics Package	Lead Center: GRC Performing Center(s): GRC Cost Share Partner(s): N/A	N/A

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Thruster Development	Thruster development and life qualification testing support	Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Flight Thruster Design	Flight thruster design and qualification	Provider: Aerojet Rocketdyne Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Acquisition Strategy

All major acquisitions are in place.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Advanced Electric Propulsion System Contract	Aerojet Rocketdyne	Redmond, WA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PDR	IRT	Aug 2017	Assess/approve preliminary design	Passed	CDR
CDR	SRB	Jan 2022	Assess/approve final design	TBD	N/A

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	585.8	154.9	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	740.7
Development/Implementation	0.0	72.3	227.0	**227.2**	227.2	177.4	43.2	0.0	0.0	974.3
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	39.6	25.4	0.0	65.0
2021 MPAR LCC Estimate	**585.8**	**227.2**	**227.0**	**227.2**	**227.2**	**177.4**	**82.8**	**25.4**	**0.0**	**1,780.0**
Total Budget	**585.8**	**227.2**	**227.0**	**227.0**	**227.0**	**227.0**	**103.6**	**25.4**	**0.0**	**1,849.9**
Change from FY 2021				**0.0**						
Percentage change from FY 2021				**0.0%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The 2021 MPAR LCC Estimate reflects the Fiscal Year 2021 Quarter 2 Financial Report, which is current as of March 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since March 2021.

The OSAM-1 spacecraft bus is under development in Maxar's Palo Alto facility. The 14-foot-tall bus (pictured) will provide OSAM-1 with power and the ability to maneuver in orbit. Credit: Maxar Technologies.

PROJECT PURPOSE

On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) is a full-scale technology demonstration mission to advance robotic on-orbit satellite servicing, assembly, and manufacturing technologies to operational status. This will be accomplished via the on-orbit refueling of a U.S. Government satellite in low-Earth orbit (LEO), followed by an assembly and manufacturing demonstration. The SPace Infrastructure DExterous Robot (SPIDER), which is a payload developed under a NASA Space Technology Mission Directorate (STMD) Tipping Point procurement to advance technologies needed for an in-space robotic manufacturing and assembly capability, is part of this mission and will robotically assemble a communications antenna and manufacture a spacecraft beam in orbit.

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

The technologies developed and demonstrated by OSAM-1 have direct applicability to future space endeavors by providing capture technologies for spacecraft, refueling and fluid transfer capabilities, the ability to conduct unplanned repairs and planned maintenance of client spacecraft, and the capability to assemble and manufacture structures. For instance, NASA will assemble multiple antenna elements into one large antenna reflector using SPIDER. This revolutionary process allows satellites, telescopes, and other systems to use larger and more powerful components that would not fit into a standard rocket fairing when assembled on the ground without complex folding mechanisms. The OSAM-1 technologies could enable entirely new architectures and space infrastructure for a wide range of Government and commercial missions. The project is actively transferring technologies to the U.S. commercial sector in an effort to jump-start new industries such as a robust satellite servicing market.

EXPLANATION OF MAJOR CHANGES IN FY 2022

NASA will fund the OSAM-1 mission consistent with its approved baseline, which will allow us to advance servicing technologies to on-orbit demonstration. Details of the baseline are discussed as part of this congressional justification.

PROJECT PARAMETERS

With application to both commercial and NASA operations, OSAM-1 will demonstrate satellite servicing capabilities and in-space assembly and manufacturing capabilities. Objectives include:

- Autonomous, real-time relative navigation system, including sensors, algorithms, and processors integrate together allowing the spacecraft to inspect and rendezvous safely with its client;
- Servicing Avionics control the spacecraft rendezvous and robotic tasks;
- Autonomous capture of client satellite;
- Dexterous Robotic Arms provide maneuverable arms for executing servicing assignments using telerobotics, including software;
- Advanced Tool Drive and Tools are multifunction tools for executing the servicing tasks;
- Propellant Transfer System delivers measured amounts of fuel to the client at the right temperature, pressure, and rate;
- Relocation of client satellite;
- On-orbit assembly of an antenna; and
- On-orbit manufacture of a beam.

ACHIEVEMENTS IN FY 2020

The project finalized the plan to incorporate the SPIDER payload and NASA finalized the SPIDER contract with Maxar in January 2020. Additionally, the project continued development of the servicing payload subsystems and completed design, engineering design unit test, validation, and risk mitigation activities, as well as ground subsystems Critical Design Reviews (CDR). Qualification began for the subsystems that have completed CDR. The project also completed a successful Key Decision Point (KDP)-C review in May 2020.

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2021

In FY 2021, the project will continue CDR for subsystems and continue qualification efforts that support commercial on-orbit servicing systems. OSAM-1 will proceed to an integrated flight demonstration mission CDR, which is currently planned for September 2021.

SPIDER held its CDR in February 2021 and will continue build and assembly and initiate payload and integration activities into FY 2021. The project will also continue the development of the spacecraft bus.

OSAM-1 will continue to leverage Technology Transfer mechanisms and pursue partnerships with interested U.S. companies through Space Act Agreements to transfer knowledge and capabilities to industry.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The spacecraft bus and the SPIDER pallet deliveries will be completed in FY 2022. The project will hold its Systems Integration Review (SIR) and the space vehicle Integration and Testing activities will commence at Goddard Space Flight Center (GSFC).

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
KDP-C	May 2020	May 2020
CDR	Sep 2021	Sep 2021
System Integration Review	Jul 2022	Jul 2022
KDP-D	Aug 2022	Aug 2022
Operational Readiness Review	Sep 2025	Sep 2025
KDP-E	Sep 2025	Sep 2025
Launch Readiness Review	Sep 2025	Sep 2025
Launch	Sep 2025	Sep 2025

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2021	974.4	>70%	2021	974.4	0%	Launch	Sep 2025	Sep 2025	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)*	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**974.4**	**974.4**	**0**
Aircraft/Spacecraft	53.1	53.9	+0.8
Payloads	338.5	340.5	+2.0
Systems I&T	70.9	70.9	0
Launch Vehicle	83.0	99.2	+16.2
Ground Systems	32.6	32.6	0
Science/Technology	0	0	0
Other Direct Project Costs	396.3	377.3	-19.0

** The Base Year Development Cost Estimate was established as part of KDP-C in FY 2020.*

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Propellant Transfer Subsystem (PTS)	Develop, test, and build of propellant transfer system.	Provider: N/A Lead Center: Kennedy Space Center (KSC) Performing Center(s): KSC, GSFC Cost Share Partner(s): N/A	N/A
Spacecraft Bus	Build and deliver a spacecraft bus to carry the payload.	Provider: Maxar Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Program Management	Project management, payload development and delivery, mission integration.	Provider: N/A Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
SPIDER	Build and deliver the SPIDER payload.	Provider: Maxar Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): Langley Research Center (LARC)	N/A

Acquisition Strategy

Element/Component	Acquisition Method	Developer
Robot Arm	In-house development	GSFC with MacDonald, Dettwiler and Associates (MDA) as major sub
Rendezvous and Proximity Ops Cameras	NASA Competition	Neptec Design Group
LIDAR	In-house development	N/A
Vision Sensor Subsystem Cameras	NASA Competition	Malin Space Science Systems
Propellant Transfer System	Competition/Justification for Other than Full and Open Competition	Valve Tech, FHM Aerospace, Vacuum and Air Components Company of America, Hoffer

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

Element/Component	Acquisition Method	Developer
Motors Arm, next generation Tool Drive, Pan/Tilt Unit (camera), Motorized Zoom Lenses	Omnibus Multidiscipline Engineering Services contract	CDA InterCorp, Triump, Avior
SPIDER	Competitively selected via Tipping Point solicitation	Maxar

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Build and delivery of spacecraft bus	Maxar	Palo Alto, CA
Build and delivery of SPIDER payload	Maxar	Palo Alto, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Mission Concept Review (MCR)	-	Apr 2016	Affirm mission need, examine proposed mission objectives, and validate the concept for meeting those objectives.	Passed	SRR
System Requirements Review (SRR)	Standing Review Board (SRB)	Oct 2016	Examine the functional and performance requirements and the preliminary project plan. Ensure the requirements and selected concept will satisfy the mission.	Passed	PDR
JCL	Tecolote	Nov 2017	Determine realistic 50/70 percent confidence level on reference budget and schedule.	N/A	PDR

RESTORE & SPIDER (OSAM-1)

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Preliminary Design Review (PDR)	SRB	Nov 2017	Demonstrate the preliminary design meets all system requirements with acceptable risk and within cost and schedule constraints.	Passed	CDR
Critical Design Review (CDR)	SRB	Sep 2021	Demonstrate the maturity of the design is appropriate to support proceeding with full-scale fabrication, assembly, integration, and test.	TBD	SIR
System Integration Review (SIR)	SRB	Jul 2022	Evaluate the readiness of the program to begin system Integration and Test with acceptable risk and within cost and schedule constraints.	TBD	ORR
Operational Readiness Review (ORR)	SRB	Sep 2025	Evaluate the readiness of the program to operate the flight system and associated ground systems in compliance with program requirements and constraints during the operations phase.	TBD	N/A

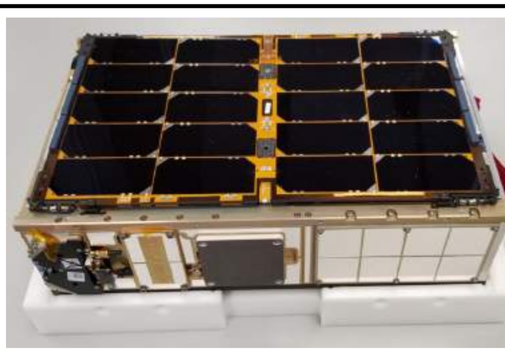
SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Small Spacecraft Technology (SST)	44.7	40.2	**46.2**	47.6	49.0	50.5	52.0
Flight Opportunities Program (FOP)	25.0	27.0	**25.0**	25.0	25.0	25.0	25.0
TDM Cryogenic Fluid Management (CFM)	36.2	60.1	**82.0**	122.1	103.5	125.7	136.4
TDM Space Nuclear Technologies Portfolio	57.9	57.9	**34.0**	34.1	87.2	186.7	258.3
TDM GreenPropellant InfusionMission GPIM	0.5	0.0	**0.0**	0.0	0.0	0.0	0.0
TDM LeO Flight Test of an Inflatable Dec	22.9	20.4	**13.0**	2.4	0.0	0.0	0.0
TDM Mars Oxygen ISRU Experiment (MOXIE)	0.8	2.3	**1.9**	0.9	0.0	0.0	0.0
Archinaut (OSAM-2)	22.0	17.7	**16.1**	16.5	0.0	0.0	0.0
TDM Deep Space Optical Comm (DSOC)	35.3	16.4	**6.2**	2.0	0.1	0.0	0.0
TDM Deep Space Atomic Clock (DSAC)	0.7	1.9	**0.0**	0.0	0.0	0.0	0.0
Tech Demo Management and Integration	5.7	15.0	**26.2**	16.9	18.2	30.1	50.6
Tech Demo Selected ACO/TP	1.2	1.4	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**252.9**	**260.1**	**250.6**	**267.4**	**283.0**	**418.0**	**522.3**
Change from FY 2021			**-9.5**				
Percentage change from FY 2021			**-3.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



The Pathfinder Technology Demonstrator-1 (PTD-1) mission will demonstrate a propulsion system that uses on-orbit electrolysis of water to generate hydrogen and oxygen propellants which are fed into a bipropellant thruster. PTD-1 launched in January 2021.

SMALL SPACECRAFT TECHNOLOGY

The Small Spacecraft Technology program expands U.S. capability to execute unique missions through rapid development and demonstration of capabilities for small spacecraft applicable to exploration, science, and the commercial space industry. Through targeted development and frequent in-space testing, the program enables execution of missions at much lower cost than previously possible, substantially reduces the time required to develop spacecraft, enables new mission architectures using small spacecraft, expands the reach of small spacecraft to new destinations and challenging new environments, and enables the augmentation of existing assets and future missions with supporting small spacecraft.

Between 2021 and 2022, the Small Spacecraft Technology program anticipates reaching initial launch readiness for 25 spacecraft across 18 current missions, including the following:

Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment

The Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) is a rapid lunar demonstration leveraging American small business that was awarded at the end of 2019. Over the course of 2020, Advanced Space LLC, Tyvak Nano-Satellite Systems, Inc., and Stellar Exploration, Inc. completed critical reviews and began assembly and ground testing of the microwave oven-sized 12U CubeSat that will serve as the first spacecraft to test the lunar near rectilinear halo orbit (NRHO) targeted for the Artemis missions and Gateway. As a precursor for the Artemis Program, CAPSTONE will help reduce risk for future spacecraft by validating innovative navigation technologies and verifying the dynamics of the NRHO. CAPSTONE represents a rapid lunar flight demonstration and is scheduled to launch in 2021 aboard a Rocket Lab Electron rocket, which will be the first mission beyond Earth for that launch vehicle.

For more information, go to: https://www.nasa.gov/directorates/spacetech/small_spacecraft/capstone

Lunar Flashlight

The Lunar Flashlight mission will precede human explorers to the Moon to prospect for water resources that can be extracted to support sustainable exploration and commercial lunar activity. The CubeSat mission will use near-infrared lasers to shine light into permanently shadowed craters at the lunar south pole while the onboard spectrometer measures surface reflection and composition to map water ice deposits and volatiles. The spacecraft is currently planned to launch with the Artemis I mission.

For more information, go to:
https://www.nasa.gov/directorates/spacetech/small_spacecraft/What_is_Lunar_Flashlight

Pathfinder Technology Demonstrator

The missions in the Pathfinder Technology Demonstrator (PTD) series will test the operation of a variety of novel CubeSat technologies in orbit, providing significant enhancements to the performance of these small and effective spacecraft. The spacecraft, payload integration, and operations are provided under a commercial contract with Tyvak Nano-Satellite System, Inc. Launch sequence and timing depends on technical progress and flight partners. The goals of the first four PTD missions are as follows:

- The PTD-1 mission launched on January 24, 2021 to test the Tethers Unlimited Inc. (TUI) HYDROS water-fueled thruster. The development of this thruster was supported through a Tipping Point public-private partnership between TUI and NASA. The HYDROS is intended to provide safe, high-performance propulsion for secondary payloads. The propulsion system is launched with only liquid water as the propellant and then uses electrolysis to split the water into gaseous hydrogen and oxygen for a simple bipropellant thruster once deployed in orbit. This capability will allow manufacturers an option to avoid use of toxic or explosive propellant systems that limit rideshare opportunities for small spacecraft. In the future, this propulsion technology could be used with water found from lunar soil. Initial on-orbit testing of the HYDROS successfully produced hydrogen and oxygen from the water and, on April 2, 2021, the thruster was successfully test fired in space. As of early April, on-orbit testing of the thruster was on going.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

- The PTD-2 mission will demonstrate the Blue Canyon Technologies (BCT) Hyper-XACT attitude determination and control system. The development of this improved attitude determination and control system was supported through a Tipping Point public-private partnership between BCT and NASA. The Hyper-XACT is intended to extend the capabilities of CubeSat attitude control systems for longer duration missions with tighter performance requirements by improving pointing performance, radiation tolerance, reliability, and system life.
- The PTD-3 mission will demonstrate the MIT Lincoln Laboratory TeraByte InfraRed Delivery (TBIRD) optical communication system. The TBIRD was funded by NASA’s Space Communications and Navigation Program (SCaN) and is intended to achieve an unprecedented 200 gigabit per second data downlink rate. This will be a thousand-fold increase over the current state-of-the-art CubeSat optical downlink demonstrated by the recently completed Optical Communications and Sensor Demonstration mission.
- The PTD-4 mission will demonstrate NeXolve Materials' and Marshall Space Flight Center’s (MSFC) Lightweight Integrated Solar Array and Transceiver (LISA-T) technology. LISA-T is a 600-watt deployable solar array with an integrated antenna. Utilizing small spacecraft for missions in deep space will necessitate the need for more electrical power, and LISA-T’s thin film solar array offers lower mass, lower stowed volume, and 300 percent more power per mass and volume allocation than current alternatives. The LISA-T project was initiated as a Space Technology Mission Directorate (STMD) Early Career Initiative project in 2015.

Starling

Starling is a technology demonstration mission that will deploy a formation of four CubeSats to test multiple distributed mission technologies. Distributed systems of small spacecraft can responsively provide cost-effective multi-point science data collection, communications, monitoring, and inspection infrastructure in Earth orbit and for support of Artemis and explorations destinations beyond. The Starling mission will: test network communication protocols with the goal of demonstrating a network that is resistant to multiple lost nodes and scalable to hundreds of spacecraft; test formation flight control algorithms; test relative navigation methods that do not rely on Earth-centric resources like GPS; and demonstrate autonomous reactive operations that allow the distributed mission to reconfigure in response to external sensor data. The Starling mission includes contributions from Stanford University, BCT, Emergent Space Technologies, CesiumAstro, and NASA’s Game Changing Development program.

CubeSat Laser Infrared Crosslink

The CubeSat Laser Infrared Crosslink (CLICK) mission will demonstrate technology to advance the state-of-the-art in communications between small spacecraft as well as the capability to gauge their relative distance and location. CLICK is comprised of two sequential missions: CLICK A will test elements of an optical (i.e., laser) communications system with a single 3U CubeSat and serves as a risk reduction mission for CLICK B/C, which will demonstrate full duplex (i.e., send and receive) spacecraft-to-spacecraft optical communications crosslinks between two 3U CubeSats in low-Earth orbit (LEO). MIT, in partnership with the University of Florida, will design and build the three miniature optical transceiver payloads to be integrated into small spacecraft built and operated by BCT.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Tipping Point CubeSat Demonstration Missions

STMD's fourth competitive Tipping Point public-private partnership solicitation included the selection of four CubeSat missions: three for the development and flight demonstration of efficient and affordable propulsion systems and one in autonomous operations.

University Partnerships and Collaborative Opportunities

At the start of 2021, the Small Spacecraft Technology program had 17 active collaborations between university teams and NASA under the SmallSat Technology Partnerships activity that seeks to advance small spacecraft capabilities in support of human and robotic exploration. Through STMD's Announcement of Collaborative Opportunities (ACO) the program also manages four partnerships between NASA and the commercial space industry to help mature industry-developed space technologies for the Moon and beyond.

Payload Accelerator for CubeSat Endeavors

V-R3x, a collaboration with Stanford University and Carnegie Melon University, is a low-power, low-cost swarm of three 1U spacecraft that was launched on January 24, 2021 to demonstrate autonomous networking and radio navigation processes that are key to reducing heavy reliance on ground-based infrastructure and increasing the autonomy of large swarms of spacecraft. V-R3x is the first mission managed within the rapid development and demonstration Payload Accelerator for CubeSat Endeavors (PACE) project. PACE is jointly funded with the Flight Opportunities program to promote a unique approach that combines suborbital flight testing opportunities followed by orbital launches. Immediately upon deployment from the launch vehicle, the three V-R3x spacecraft established a mesh network and began autonomous relative ranging. As of April 2021, the PACE team was preparing to test autonomous sensor driven operations with the spacecraft. PACE has two payloads manifested on suborbital flights in 2021 followed by orbital launches in 2021 and 2022: 1) the Advanced Developments Projects (ADP) avionics suite consisting of radio frequency communications, navigation, and attitude determination and control systems; and 2) the Intrepid payload, a gamma ray/neutron particle detector Small Spacecraft Systems Virtual Institute.

The Small Spacecraft Technology program, in partnership with the Science Mission Directorate (SMD), also maintains the Small Spacecraft Systems Virtual Institute, hosted at NASA’s Ames Research Center (ARC) in Moffett Field, California. This program leverages the growing small spacecraft community, promotes innovation, identifies emerging technology opportunities, and provides an efficient channel for communication about small spacecraft systems with the commercial space industry, academia, and other Government agencies.

Recent and Planned Achievements

In March 2020, the Small Spacecraft Technology program announced its selection of nine university teams for its SmallSat Technology Partnerships initiative to mature new systems and capabilities to help pave the way for human and robotic lunar exploration. The technology development projects focus on three technical areas related to needs of Moon-bound missions: use of small spacecraft to help provide lunar communications and navigation services; small spacecraft propulsion for lunar missions and potential return of lunar samples using small spacecraft; and small spacecraft electrical power and thermal management systems tailored for the distant and harsh environment between Earth and the Moon. A 2020 partnership led by the University of Texas at Austin with mentoring from NASA’s Johnson Space Center (JSC), “On-Orbit Demonstration of Surface Feature-Based Navigation and Timing,” received a funded

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

extension for infusion into the Game Changing Development program's Safe and Precise Landing-Integrated Capabilities Evolution (SPLICE) project.

Successfully completing several reviews and milestones during FY 2020, the following small spacecraft missions are projected to launch in the 2021-2022 timeframe:

- PTD-1 launched on January 24, 2021 and is testing the HYDROS, a water-based propulsion system.
- The V-R3x mission launched on January 24, 2021. The V-R3x mission will demonstrate autonomous networking and radio navigation processes in early 2021 that are key to the autonomy of large swarms of spacecraft.
- The CAPSTONE mission is planned to launch in 2021 from Rocket Lab USA's launch site in New Zealand.
- Two PACE missions will demonstrate the ADP and Intrepid payloads and are planned for launch in mid-FY 2021 and early FY 2022.
- PTD-3 is anticipated to launch in late 2021 on a U.S. Space Force launch. The mission will target very high-bandwidth optical downlink at 200 gigabits per second from a CubeSat.
- The CubeSat Laser Infrared Crosslink mission is targeting flight of a risk reduction mission in 2021 ahead of demonstrating full duplex spacecraft-to-spacecraft optical communications crosslinks between two small CubeSats in FY 2022.
- The CubeSat Proximity Operations Demonstration mission is anticipated to launch in late 2021. Rendezvous, proximity operations, and docking of two 3U CubeSats will be demonstrated.
- The Starling distributed spacecraft demonstration mission will launch in early 2022 on a Venture Class Launch Services 2 demonstration to test formation flight, inter-satellite networking, and other enabling capabilities for future mission architectures that use multiple small spacecraft to achieve a coordinated objective.
- The Advanced Composite Solar Sail System (ASC3) mission will demonstrate deployment of an 80 square meter sub-scale composites boom-supported solar sail system in LEO as precursor for a future 500 square meter solar sail system suitable for low-cost deep space missions for heliophysics, small body planetary science, and human space flight support. ACS3 is targeted for launch in late 2021 or early 2022.

With an objective of expanding the capability of small spacecraft to execute missions at new destinations and in challenging new environments, Small Spacecraft Technology anticipates reaching initial launch readiness for 25 spacecraft across 18 current missions between 2021 and 2022.

FLIGHT OPPORTUNITIES PROGRAM

The Flight Opportunities program facilitates rapid demonstration of promising technologies for space exploration, discovery, and the expansion of space commerce through suborbital testing with industry flight providers. The program matures capabilities needed for NASA missions while strategically investing in the growth of the U.S. commercial spaceflight industry. These flight demonstrations take technologies from ground-based laboratories into relevant environments to increase technology readiness and validate feasibility while reducing the costs and technical risks of future missions. Awards and

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

agreements for flight demonstrations are open to researchers from industry, academia, non-profit research institutes, NASA, and other Government organizations. These investments help advance technologies of interest to NASA while supporting commercial flight providers and expanding space-based applications and commerce.

In FY 2020, the Flight Opportunities program facilitated the commercial suborbital flight testing of 46 technology payloads across five rocket-powered vehicle flights, three high-altitude balloon flights, and eight parabolic aircraft flights. U.S. commercial vendors providing flight services in FY 2020 included: AM0CAL, Blue Origin, Masten Space Systems, Raven Aerostar, Virgin Galactic, World View, and Zero Gravity Corporation. These capabilities across flight providers were used to test technologies integral to returning U.S. astronauts to the Moon, establishing a presence there, and enabling future missions to Mars. By exposing the innovations to many of the rigors and characteristics of spaceflight, without the expense of an orbital flight, suborbital testing can help ensure these technologies work correctly when they are deployed on future missions.

In FY 2020, the program concluded several prior investments in orbital small launch vehicle development. These investments have provided critical support to multiple U.S. companies to mature capabilities thereby enabling their entrance in this globally competitive market. In FY 2021, the program entered into partnerships with U.S. companies to expand suborbital capabilities to meet testing needs relevant to NASA and expanded commercial activities in space.

Recent and Planned Achievements

In February 2020, the "Tech Flights 2020" solicitation was released to provide funding to industry, academia, and private research organizations for the suborbital testing of technologies that support NASA's current priorities. In October 2020, Flight Opportunities selected over $16 million of proposed technology demonstration activities. These selections included 31 promising space technologies, the most ever chosen through the solicitation and included the first selection under a new NASA policy that allows non-NASA researchers to propose to fly with their research on NASA-supported suborbital spacecraft flights.

Flight tests conducted in FY 2020 helped advance a variety of technologies that support NASA objectives. The impacts of a few of these tests are highlighted below.

- The Orbital Syngas Commodity Augmentation Reactor (OSCAR), a system from NASA's Kennedy Space Center (KSC) designed to convert space waste into valuable gases, was tested aboard Blue Origin's New Shepard rocket-powered system. The technology has the potential to address both waste and power-generation challenges associated with long-duration space missions.
- Psionic tested its commercial version of navigation Doppler LIDAR (NDL) technology on Masten Space Systems' Xodiac, a rocket-powered vertical takeoff and vertical landing vehicle that simulates some of the maneuvers of a lunar lander. Designed for precision landing in a very tightly defined area, NDL was originally developed by NASA's Langley Research Center (LaRC) and licensed by Psionic in 2016.
- An experiment from the University of Florida in Gainesville, FL was conducted aboard Blue Origin's New Shepard rocket-powered system to explore what happens to the genes of biological organisms as they travel from Earth to space. The flight added to data previously gathered aboard flights with Zero Gravity Corporation and Virgin Galactic and offered researchers the first clues about how these

adaptations happen during transitions between gravity levels, knowledge which is essential to understanding the impact of space travel on biological organisms.

- The Affordable Vehicle Avionics (AVA) project from NASA's ARC flew aboard UP Aerospace's SpaceLoft rocket-powered system. AVA is a low-cost flight computer designed specifically for guidance and control of dedicated small launch vehicles - rockets that would send individual payloads into orbit on short notice and at lower cost than with currently available launch vehicles.

Several technologies matured through Flight Opportunities transitioned to additional testing, exploration missions, and industry uses beyond the program, including work with other Government agencies, NASA's Mars 2020 mission, and more. Recent highlights of these types of infusions include:

- The Terrain Relative Navigation (TRN) and Lander Vision System (LVS) for NASA's Mars Perseverance Rover from NASA's Jet Propulsion Laboratory is a navigation and hazard avoidance system that photographs the terrain beneath a descending spacecraft and matches it with onboard maps to determine vehicle location while also looking for rocks and other unmapped hazards. Tested on Masten Space Systems vehicles, the technology was infused into NASA's Mars 2020 mission and played a critical role in the successful landing of the Perseverance rover on February 18, 2021. The TRN and LVS were used to guide the rover to a safe landing site among scientifically interesting but geographically challenging terrain on the Red Planet.
- The Radio Frequency Mass Gauge from NASA's Glenn Research Center (GRC) is a propellant-quantity gauging technique that accurately determines the amount of cryogenic propellant in a tank while in low-gravity or under maneuver conditions where sloshing is an issue. Parabolic flight testing helped advance the technology, which has been transferred to Intuitive Machines for integration on the company's Commercial Lunar Payload Services lander vehicle that has a lunar mission scheduled for 2021.

While largely driven by the flight cadence of commercial flight providers, the Flight Opportunities program typically facilitates 15 or more suborbital flights each year and could see as many as 28 in 2021. Between the program's inception in 2011 and the end of FY 2020, Flight Opportunities supported 198 successful fights and has enabled 694 tests of payloads with the participation of 12 active commercial providers.

OTHER TECH DEMO

Nuclear Propulsion

The FY 2022 budget does not support Nuclear Propulsion activities and Nuclear Propulsion is not included in the Space Nuclear Technologies (SNT) portfolio.

SNT portfolio activities for propulsion have included trade assessment studies of nuclear thermal and nuclear electric propulsion capabilities that inform strategic Agency investments. In FY 2019, NASA initiated a nuclear thermal propulsion flight demonstration study that completed in FY 2020. The study identified demonstration options and evaluated the benefits and risks associated with implementing a meaningful effort. Nuclear thermal propulsion efforts in FY 2021 focused on the technology maturation of high-temperature fuels and reactor materials, and those results are discussed further below.

NASA continues to fund cryogenic fluid management technologies, which is a critical technology for enabling nuclear propulsion, as well as effective and efficient storage, transfer, and utilization of cryogenic propellants and reactants in-space in support of other stakeholders (e.g., Department of Defense, U.S. Space Force, Defense Advanced Research Projects Agency, and commercial entities).

Cryogenic Fluid Management

In order to establish a human presence on a planetary surface and to support deep space travel, cryogenic fluid management is an enabling technology for a variety of NASA exploration missions. Improved cryogenic fluid management is critical to in-space transportation systems such as human lander systems and lunar or Mars surface operations, including in-situ resource utilization. These missions will have durations ranging from months to multiple years, far beyond the current state-of-the-art for in-space cryogenic fluid management capabilities.

As part of the 2020 Tipping Point solicitation, NASA requested proposals that would develop cryogenic fluid management tipping point technologies and integrated system capabilities for demonstration in relevant environments including in space (including free flyers), the International Space Station (ISS), Lunar Gateway, and lunar payloads. The solicitation requested proposals to advance technologies in the areas of passive thermal control, tank pressure control, active thermal control, and tank-to-tank propellant transfer. NASA selected four companies to issue milestone-based firm-fixed price contracts lasting up to five years to demonstrate these cryogenic fluid technologies.

At the end of FY 2020, the Evolvable Cryogenics (eCryo) project completed its keystone demonstration with a series of pre- and post-vibration ground tests at NASA's Plumbrook Station to validate the performance of novel propellant storage tanks designs for long-term on-orbit storage. In addition to this major demonstration, the eCryo project has advanced several other cryogenic fluid technologies including reuse of boil-off gases to replace existing pressurization and attitude control systems and development of new cryogenic monitoring instrumentation and analytical models. For NASA, these technologies will enable exploration missions beyond LEO, while industry will likely infuse the technologies on next generation launch vehicles and on-orbit stages, making them more efficient and capable. By taking an incremental ground test approach, NASA prioritized technologies needed by Deep Space Exploration Systems, including Space Launch System Upper Stage development and the long-term needs of the aerospace industry. The project successfully built on the knowledge gained from previous investments and utilized existing Agency assets and test facilities capable of maturing cryogenic propellant transfer and storage technologies.

Green Propellant Infusion Mission

Green Propellant Infusion Mission was a dedicated spacecraft to demonstrate non-toxic propellant propulsion with the goal to provide an alternate to hydrazine propellant applicable to a small to medium-sized spacecraft. Higher performing and safer propellant alternatives are at a tipping point. The Green Propellant Infusion Mission successfully completed its in-space demonstration. The rapid incorporation of this propellant into a variety of spacecraft could occur in the near future. NASA selected AF-M315E/ASCEND as an innovative, low-toxicity monopropellant alternative with improved performance over hydrazine. The AF-M315E propulsion system is expected to improve overall vehicle performance by 40 percent and processing efficiency, while decreasing operational costs by reducing health and environmental hazards. The green propellant formula, thrusters, and related systems performed a series of in-space demonstration tests.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Recent and Planned Achievements

- Nuclear thermal propulsion efforts in FY 2021 included the technology maturation of high-temperature fuels and reactor materials. Fuel element fabrication trials and performance tests were also performed to demonstrate the durability of the block reactor design approach and validate thermal models. The Space Nuclear Project also completed the industry-led flight demonstration study and extended the study to include an examination of high-performance reactor systems. The project also formulated a procurement strategy and statement of work to solicit industry reactor designs. The first phase of this strategy was executed in February 2021 through a request for proposal process managed through the DOE Idaho National Laboratories.
- In FY 2021, through Public Private Partnership arrangements, NASA selected Eta Space, Lockheed Martin, SpaceX, and United Launch Alliance to develop and test technologies that enable long-term cryogenic fluid storage and management. These cryogenic fluid management technologies are essential for establishing a sustainable presence on the Moon, enabling crewed missions to Mars, and providing enhanced in-space transportation capabilities for commercial and Government needs.
- The eCryo project completed its Structural Heat Intercept-Insulation-Vibration Evaluation Rig (SHIIVER) thermal testing in January 2020. This test used both liquid nitrogen and liquid hydrogen to demonstrate the effectiveness of new multi-layer insulation and evaluate the potential benefit of using vapor vented from a propellant tank to intercept heat coming into the tank through structural elements. Final reports were completed in the first quarter of FY 2021.
- NASA completed its Green Propellent Infusion Mission and all data collected to-date indicates that the propulsion system performed nominally, and all requirements were satisfied.

Terrain Relative Navigation (TRN)

The Terrain Relative Navigation (TRN) project will improve targeting accuracy for landing and provide hazard avoidance to enable access to scientifically compelling sites with acceptable risk. All of NASA's current human and robotic precursor mission architectures for planetary surface exploration require this technology. Using TRN the Mars 2020 powered descent vehicle estimated its location while descending through the Martian atmosphere. This allowed the vehicle to determine its position relative to the ground with an accuracy of approximately 5-meters, required performance was 200-feet (60-meters) or less. This technology will provide the capability to land near pre-deployed assets, provide the capability to avoid large-scale landing hazards during entry, descent, and landing operations, and will reduce post-landing surface drive distances. The project launched in July 2020 and landed in February 2021.

Low-Earth Orbit Flight Test of Inflatable Decelerator (LOFTID)

NASA, in partnership with United Launch Alliance, will conduct a flight test of inflatable aerodynamic decelerator technology to demonstrate its performance in environments relevant to several mission infusion opportunities. The Low-Earth Orbit Flight Test of Inflatable Decelerator (LOFTID) reentry vehicle (RV) will be flown as a secondary payload on an Atlas V launch vehicle. After the primary payload is delivered to the desired Earth orbit, the Atlas V Centaur upper stage will de-orbit the LOFTID RV. Prior to atmospheric entry, the RV will inflate the aeroshell, and then the Centaur will orient, spin-up, and release the RV for its spin-stabilized ballistic reentry. The flight will demonstrate the high-mass entry, descent, and landing technology at a scale (6-meter) and atmospheric conditions similar to landing large payloads on Mars as well as return from Earth orbit. This capability could also enable applications such as launch vehicle flight hardware recovery and reuse and return of products manufactured in space for terrestrial use. Conducting this effort with an industry cost-sharing partnership allows NASA to significantly reduce the overall cost of this technology development while enabling a potential commercial user to gain insight into utilizing this technology for future booster recovery.

Recent and Planned Achievements

- TRN successfully operated on Mars 2020 in February 2021, landing the rover with an accuracy of five meters.
- LOFTID completed a successful Critical Design Review/System Integration Review (CDR/SIR) in October 2020 and a successful KDP-D review in December 2020.
- LOFTID flight hardware fabrication and testing is in progress. Comprehensive System Test is scheduled for October 2021, with delivery of LOFTID to the launch site planned for June 2022.
- NASA and United Launch Alliance finalized plans to fly LOFTID as a rideshare with the Joint Polar Satellite System-2 (JPSS-2) spacecraft on the Atlas V. The launch is scheduled for September 2022.

Mars Oxygen In-Situ Resource Utilization (ISRU) Experiment (MOXIE)

The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) is designed for in-situ resource utilization technologies to enable propellant and consumable oxygen production from the Martian atmosphere for future exploration missions. Specifically, MOXIE produces oxygen from a Mars atmosphere, demonstrates the feasibility of ISRU on Mars, validates analytical models for scaling up of future ISRU systems, and provides valuable knowledge needed for future mission development. MOXIE is part of SMD's Mars 2020 mission.

Fission Surface Power (FSP)

Nuclear power is part of the Space Nuclear Technologies portfolio and will enable long-duration lunar surface operations with extended application development for Mars via a small, lightweight fission power system. The goal is to demonstrate an integrated fission power system on the lunar surface across an operational spectrum that verifies full functionality and power performance. The fission surface power system will optimize the design for the reactor, reactor shielding, power conversion subsystem, and thermal radiators as a low-mass integrated system. The project will explore industry system solutions and identify a primary design approach with industry. To the extent feasible, the project will take advantage of the interagency investment in a common reactor designs, fuel forms, and materials.

Following a successful demonstration, this power technology will form a key capability for long-duration human surface missions on the Moon and eventually Mars. The technology will enable mission operations in harsh environments, such as permanently shadowed craters, and satisfy mission needs for continuous solar-independent power operations. This work is being conducted in collaboration with DOE.

Recent and Planned Achievements

- MOXIE was launched in July 2020. The instrument was delivered to the Mars surface in February 2021. On April 20, 2021, MOXIE converted some of Mars' thin, carbon dioxide-rich atmosphere into oxygen and is continuing to conduct testing.
- NASA completed feasibility studies for low-enriched uranium reactor designs, formed a solicitation strategy for soliciting industry fission surface power designs, and drafted a statement of work for a Phase I preliminary design effort with industry. A draft request for proposals for the Phase I effort was released in December 2020 for an industry comment period.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

- In FY 2022, the FSP project will award up to three industry contracts for preliminary designs of a 10-kilowatt class fission power system. Additional FY 2022 investments will advance space-rated power conversion systems, and mature high-risk reactor technologies on low-enriched moderator materials and lighter weight radiation shielding.

On Orbit Servicing and Manufacturing Demonstration-2 (Archinaut)

In partnership with the commercial space industry, NASA develops and demonstrates technologies required to manufacture, assemble, and aggregate large and/or complex systems in space utilizing robotic and additive manufacturing technology.

Archinaut (Made in Space/Redwire) was awarded in July 2019 to develop a flight demonstration payload of their Phase I ground demonstration technology. Once deployed and positioned in orbit, a small spacecraft will 3D-print two beams; the first beam will extend nearly 33-feet from one side of the spacecraft while deploying a solar array surrogate. The second beam will extend nearly 20-feet from the opposite side of the spacecraft. This disruptive capability could transform the traditional spacecraft-manufacturing model by enabling in-space creation of large spacecraft systems. No longer will developing, building, and qualifying a spacecraft focus so heavily on an integrated system that must survive launch loads and environments. Archinaut could also greatly reduce cost while increasing capabilities for both NASA and commercial space applications.

Deep Space Optical Communication

Deep Space Optical Communication technologies are considered essential for future human missions to Mars and have a wide range of applications for planetary science missions including those to Mars and the Jovian systems. The Deep Space Optical Communications project, led by the Jet Propulsion Laboratory (JPL), will develop key technologies for the demonstration of a deep space optical flight transceiver and ground receiver that will provide greater than 10 times the data rate of a state-of-the-art deep space radio frequency system (Ka-band). This capability will enable advanced instruments, live high-definition video, and telepresence that allow for deep space human exploration of the solar system.

NASA successfully completed and reduced significant risks on technologies including a low-mass spacecraft disturbance isolation assembly, a flight qualified photon counting detector array, a high-efficiency flight laser amplifier, and a high-efficiency photon counting detector array for the ground-based receiver. Deep Space Optical Communication will demonstrate the high-bandwidth flight laser optical communication terminal on the SMD's Psyche mission.

Deep Space Atomic Clock

The Deep Space Atomic Clock project led by JPL has the objective to validate a miniaturized, mercury-ion atomic clock that is 50 times more stable than today's state-of-the-art space clocks used for spacecraft navigation systems. Launched in June 2019, the Deep Space Atomic Clock is demonstrating ultra-precision timing in space and its benefits for one-way radio-based navigation. If successful, it will free up precious deep space communications bandwidth to perform greater scientific data return. The enhanced navigation and increased communications bandwidth permitted by the new clock will dramatically improve the exploration mission's capability for on-board navigation required for robust, safe human exploration beyond the Earth. Precision timing and navigation provided by the new clock will also have the potential to improve the Nation's next generation GPS system. The demonstration launched via rideshare on a SpaceX Falcon Heavy (STP-2) in June 2019 and is funded in a partnership with SCaN.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Recent and Planned Achievements

- On Orbit Servicing and Manufacturing Demonstration-2 (Archinaut) conducted a Preliminary Design Review (PDR) in March 2020 and a successful Post-PDR Assessment in September 2020. The mission was approved to enter Phase C (Final Design and Fabrication) at a STMD Program Management Council meeting in October 2020. In addition, the Extended Structure Additive Manufacturing Machine (ESAMM) Engineering Development Unit Vertical Print Test completed a 7-meter beam under expected flight loads in November 2020. The CDR is currently planned for Summer 2021 and the Flight Readiness Review for December 2022. Launch is currently planned for February 2023.
- Deep Space Optical Communications held KDP-C in June 2019 and completed its CDR in December 2019 and Ground CDR in September 2020. DSOC hardware assembly, integration and testing began April 2020 in support of its targeted delivery to Psyche by June 2021.
- Deep Space Atomic Clock was successfully activated and continues to operate normally. All requirements were successfully satisfied (e.g., mass, power, stability, orbit determination) while also meeting the one-year of mission operations requirement. NASA recently added a second year of operations to provide further characterization of clock behavior on long-time scales, assess life limiting elements, and confirm operability in an extended period space environment.

Acquisition Strategy

These critical technology projects are defined as part of the strategic framework and capabilities, and through requirements determined by Federated Team, and through STMD's Strategic Technology Architecture Roundtable process. In addition, Space Technology embraces competition and external partnerships, as such some of the technologies are selected through annual Tipping Point, Announcement of Collaboration Opportunity, and other NASA solicitations.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
OSAM-2 (Archinaut)	Made in Space/Redwire	Jacksonville, Florida

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Industry Review Board (IRB)	NASA	Mar 2020	OSAM-2 Preliminary Design Review	Passed	Critical Design Review Jul 2021

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Independent Review Team (IRT)	NASA	Sep 2020	DSOC Ground Critical Design Review	Passed	Operations Readiness Review of DSOC ground terminal Mar 2022
IRT	NASA	Oct 2020	LOFTID Critical Design Review	Passed	Operations Readiness Review Sep 2022

SBIR AND STTR

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**225.5**	**227.0**	**287.0**	**292.7**	**298.6**	**304.6**	**310.7**
Change from FY 2021			**60.0**				
Percentage change from FY 2021			**26.4%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The Volatiles Investigating Polar Exploration Rover (VIPER), shown above, is being sent to the Moon's south pole to sample water ice in the region where the first woman and next man will land under the Artemis Program. Instruments on VIPER are being created by Honeybee Robotics who received their first SBIR award in 2007 and has now graduated from the program.

NASA's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs leverage the Nation's innovative small business community to fund research and development in support of NASA's mission in human exploration, science, and aeronautics. This program will support NASA's Artemis Program objectives by identifying and accelerating relevant technologies drawn from the SBIR and STTR portfolios through Post Phase II awards. Post Phase II awards may involve matching funding from investors and further encourage the advancement of innovations and commercialization of technologies developed under Phase II. These programs provide the small business sector with an opportunity to develop technology for NASA and to commercialize that technology to spur economic growth. NASA's SBIR/STTR programs will expand efforts to increase participation by women, socially or economically disadvantaged businesses, historically black colleges and universities (HBCU), and minority serving institutions (MSI), while also emphasizing entrepreneurial engagement.

The Agency actively works to facilitate the commercialization of NASA-funded SBIR and STTR technologies into missions and projects as well as commercial applications. Research and technologies funded by SBIR and STTR contracts have made important contributions to the Agency's mission. Examples include:

- Compact lunar rover and precision lunar lander technology, which will deliver payloads to the lunar surface
- Real-time rice mapping and production forecasting tool that is being piloted in the United States through NASA SBIR and further developed to reduce greenhouse gas emissions in Vietnam
- A line of carbon nanotube materials in macro formats that can be used to replace heavier materials for spacecraft, defense platforms, and a host of other commercial applications

SBIR AND STTR

- Uncrewed aerial vehicle (UAV) tracking, even in network-deficient areas, and enabling UAVs to detect and avoid oncoming traffic
- Eight technologies on the recently launched Mars Perseverance Rover including: high-rate, high-energy density lithium-ion batteries; dust mitigation tool; scroll compressor; robotic arm; six-axis force-torque transducer; and technologies supporting the SHERLOC (Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals) instrument
- A collaborative and highly customizable tool designed to allow astronauts to document and mark progress on procedures in real-time, display system data, and issue commands—all from a single application. The versatility of the software also caught the eye of a major oil field service company.

These investments seek to achieve the program's vision of empowering small businesses to deliver technological innovation that contributes to NASA's missions, provides societal benefit, and grows the U.S. economy.

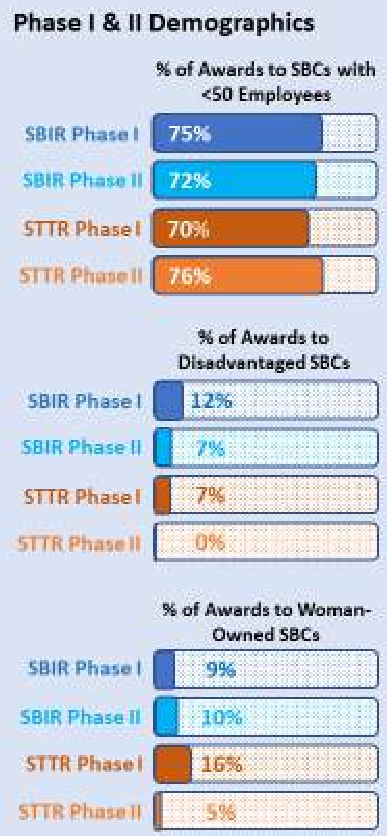
EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

SBIR AND STTR

ACHIEVEMENTS IN FY 2020

AWARDS MADE IN FY 2020



Post Phase II Awards

Program	# of Awards	SBIR/STTR Funding	Non SBIR/STTR Investor Funding
Phase II-Extended	32	$8.9 Million	$9.4 Million
CCRPP	8	$6.8 Million	$5.3 Million
Lunar-Focused Sequentials	4	$17.1 Million	N/A
Phase III	81	N/A	$44.0 Million

- In FY 2020, NASA further streamlined (streamlined previously in 2019 due to the Government shutdown impacts) the Phase I review and selection process to aid small businesses impacted by COVID-19.
- Early in 2020, the Small Business Administration (SBA) approved a waiver to SBIR/STTR policy, which has allowed the SBIR/STTR program to make high-value (up to $5 million) Sequential Phase II awards to support the Artemis Program and Moon to Mars objectives. Seven selections were made in support of SmallSat optical communications: In-Situ Resource Utilization (ISRU) production of oxygen and steel; autonomous fault management for Gateway; traction control for rovers/vehicles; advanced manufacturing for fission power systems; secure and disruption-tolerant distributed communications beyond low-Earth orbit; and advances in at-destination manufacturing/servicing/assembly capabilities.

WORK IN PROGRESS IN FY 2021

- In November 2020, NASA released the FY 2021 annual solicitation two months early in order to give small businesses and research institutes an earlier opportunity for Phase I funding. In March 2021,

SBIR AND STTR

NASA announced 365 new SBIR/STTR Phase I selections, valued at $45 million. In addition, NASA announced Phase II selections - 19 STTR from the FY 2019 solicitation with an approximate value of $14 million in December 2020 and will award approximately 125 SBIR awards, with an approximate value of $94 million, from the 2020 solicitation in May 2021.

- To increase technology transitions and commercialization, NASA will continue to offer Post Phase II award opportunities through vehicles such as the Phase II Extended (II E) program and the Civilian Commercialization Readiness Pilot Program (CCRPP). In FY 2021, the maximum CCRPP award value will increase to $3 million. The program will continue the SBIR Phase II sequential vehicle focused on developing existing Phase II technologies related to the return to the Moon and on to Mars.
- In partnership with the National Science Foundation (NSF), NASA will continue to make I-Corps training grant awards for Phase I awardees to encourage commercialization of technology and will expand I-Corps participation to CCRPP and Phase II E awardees.
- NASA will continue to seek small business feedback to improve program responsiveness through a Section 280 customer experience clearance to conduct focused surveys and requests for information (RFIs). It will use the information gathered to modernize its business capabilities to reduce barriers to entry for firms, increase the quality of proposals, and improve the value proposition for firms.
- NASA will continue to pilot opportunities to accelerate NASA efforts in deep space exploration and those of the commercial aerospace sector, including continuing our coordination with the NSF SBIR program and AFWERX/SPACEWERX to support growth-oriented commercial space entrepreneurs.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- The program office will place additional emphasis on engaging a broad, diverse base of innovators through the program, especially in engagements with MSIs, including HBCUs, in addition to an increased emphasis on entrepreneurial engagement to encourage commercialization and economic impact.
- The SBIR and STTR program office will continue to work with all the NASA mission directorates, centers, and industry to identify subtopics including technologies to support human exploration to the Moon and eventually Mars as well as climate change challenges.
- In addition, this program will support NASA's Artemis Program and climate objectives by identifying and accelerating relevant technologies drawn from the SBIR portfolios through Post Phase II awards.
- The SBIR and STTR program office will explore new opportunities to seek, select, advance technology R&D from small businesses, research institutions, and entrepreneurs where there is both NASA and commercial sector interest.

SBIR AND STTR

Program Elements

SBIR

The SBIR program was established by statute in 1982 and was most recently reauthorized in 2016 to increase research and development opportunities for small businesses. The program stimulates U.S. technological innovation, employs small businesses to meet Federal research and development needs, increases the ability for small businesses to commercialize innovations they derive from Federal research and development, and encourages and facilitates participation by socially disadvantaged businesses. The SBIR program budget is based on a level of at least 3.2 percent of NASA's extramural research and development budget. The current maximum value for an SBIR Phase I contract will be $125,000 for a period of performance of six months. For Phase II, the maximum total value of an SBIR award will be $750,000 over a 24-month period of performance. NASA also supports several Post Phase II vehicles:

- Phase II E contract options with incentives for cost sharing to extend the research and development efforts of the current Phase II contract.
- Civilian Commercialization Readiness Pilot Program (CCRPP) contracts with incentives for cost sharing to extend the research and development efforts of the previous Phase II contract with strong customer pull for technology maturation, commercialization, and ultimately utilization versus incremental development.
- Phase II sequential contract options to help raise the Technology Readiness Level (TRL) value of technologies to the point that other investors will then advance the technology or to rapidly advance the TRL of a technology to enable NASA programs.
- I-Corps training grants to enable small businesses to commercialize their innovations through an Interagency Agreement with the NSF.

STTR

The STTR program was established by statute in 1992 and reauthorized in 2016 to award contracts to small businesses for cooperative research and development with a non-profit research institution, such as a university. NASA's STTR program facilitates transfer of technology developed by a research institution through the entrepreneurship of a small business, resulting in technology to meet NASA's core competency needs in support of its mission programs. Modeled after the SBIR program, STTR is funded based on 0.45 percent of the NASA extramural research and development budget. The maximum value for an STTR Phase I contract is $125,000 for a period of performance of 13 months. For Phase II, the maximum total value of an STTR award is $750,000 over a 24-month period of performance. Phase II E, CCRPP, Phase II sequential contract options, and I-Corps are also available to STTR participants.

SBIR AND STTR

Program Management & Commitments

Program Element	Provider
SBIR and STTR	Provider: Various Small Businesses and their research partners Lead Center: NASA HQ; Level 2: Ames Research Center (ARC) Performing Center(s): All centers play a project management and implementation role. Cost Share Partner(s): SBIR/STTR Phase II E matches cost share funding with SBIR and STTR up to $375,000 of non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, other Government agency, or third-party commercial investor to extend an existing Phase II project to perform additional research. SBIR/STTR CCRPP matches cost share funding up to $3,000,000 of non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, other Government agency, or third-party commercial investor to continue a former Phase II project to perform additional research for strong customer pull for the technology maturation, commercialization, and ultimately utilization versus incremental development.

Acquisition Strategy

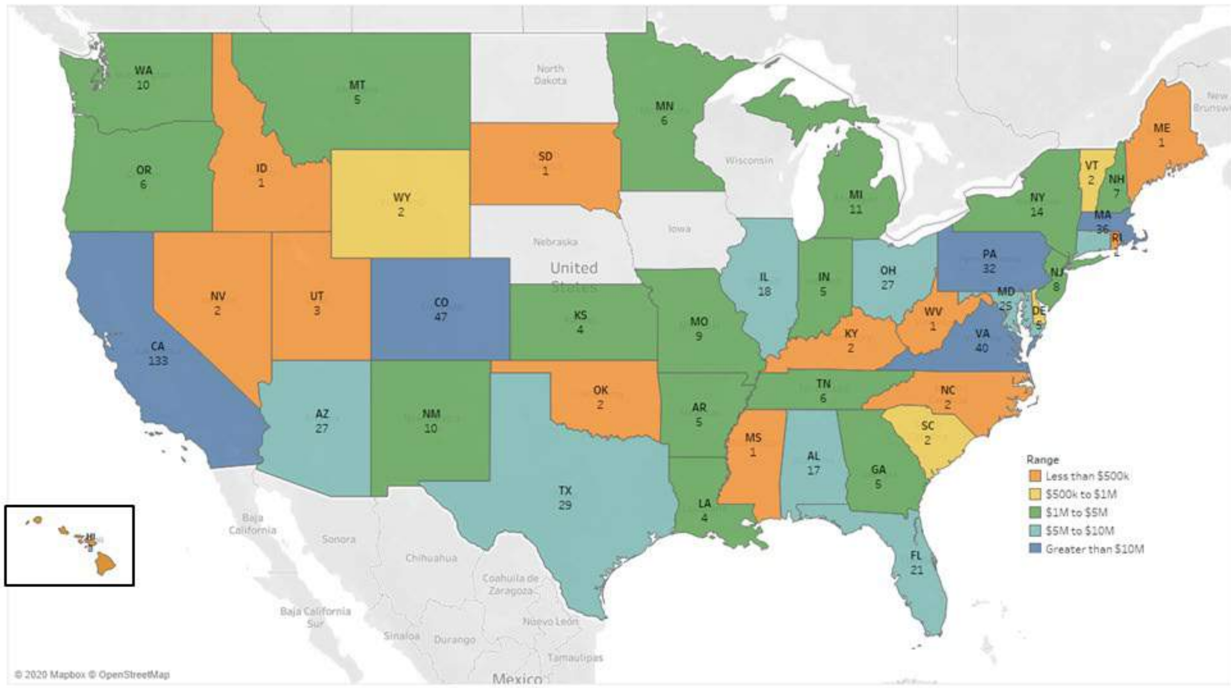
NASA issues annual SBIR and STTR program solicitations, setting forth a substantial number of topic areas open to qualified small businesses. There are three phases for SBIR and STTR funding awards. Phase I awards give small businesses the opportunity to establish the scientific, technical, and commercial merit of the proposed innovation in alignment with NASA interests. The most promising Phase I projects are selected for Phase II awards through a competitive selection process based on scientific and technical merit, expected value to NASA, and commercialization potential. Phase II awards focus on the development, demonstration, and delivery of the proposed innovation. Phase II E and the CCRPP support advancement of innovations developed under Phase II. Phase III supports the commercialization of innovative technologies, products, and services that result from a Phase I or Phase II contract. Commercialization includes further development of technologies and getting feedback to discover infusion opportunities into NASA programs, other Government agencies, or the private sector. Phase III contracts receive funding from sources other than the SBIR and STTR programs and may be awarded without further competition.

SBIR and STTR program management works collaboratively with NASA center Chief Technologists (for STTR) and the mission directorates (for SBIR) during the SBIR and STTR acquisition process. This collaboration, from topic development through proposal review and ranking, supports final selection of proposals of high value to NASA. Mission directorates and center program personnel interact with SBIR and STTR award winners to maximize alignment and implementation of the SBIR and STTR products with NASA’s future missions and systems.

SBIR AND STTR

Award Distribution

The map below represents the FY 2020 SBIR and STTR investments through Phase I, Phase II, Phase II E, Sequential, and CCRPP awards.



SPACE OPERATIONS

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
International Space Station	1,516.1	1,321.6	**1,327.6**	1,309.7	1,279.4	1,284.5	1,284.5
Space Transportation	1,746.2	1,872.9	**1,771.7**	1,827.1	1,849.0	1,843.7	1,843.7
Space and Flight Support (SFS)	857.4	776.6	**817.0**	786.4	788.8	789.0	789.0
Commercial LEO Development	15.0	17.0	**101.1**	186.1	186.1	186.1	186.1
Total Budget	**4,134.7**	**3,988.2**	**4,017.4**	**4,109.3**	**4,103.3**	**4,103.3**	**4,103.3**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

SPACE OPERATIONS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
International Space Station	1,516.1	1,321.6	**1,327.6**	1,309.7	1,279.4	1,284.5	1,284.5
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Commercial LEO Development	15.0	17.0	**101.1**	186.1	186.1	186.1	186.1
Total Budget	**4,134.7**	**3,988.2**	**4,017.4**	**4,109.3**	**4,103.3**	**4,103.3**	**4,103.3**
Change from FY 2021			**29.2**				
Percentage change from FY 2021			**0.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

NASA astronauts Kate Rubins (left) and Jeff Williams (right) are shown here preparing to grapple the SpaceX Dragon supply spacecraft from aboard the International Space Station.

The Space Operations account is dedicated to continued support of ISS operations and research in low-Earth orbit (LEO) that enable future exploration and advance discoveries that benefit life on Earth, while laying the foundation for America to maintain a constant human presence and develop a commercial economy in LEO. Comprised of the International Space Station (ISS), Space Transportation, Space and Flight Support, and Commercial LEO Development themes, Space Operations is developing American-led space infrastructure enabled by a commercial market, enhancing space access and services to both Government and commercial entities, and researching and developing capabilities to safeguard our astronaut explorers. These activities, which support existing and future space operations for both NASA and non-NASA missions, are catalysts for economic development. Additionally, these activities advance scientific knowledge and foster new technologies that improve our lives.

NASA's Commercial LEO Development effort is intended to stimulate both the development of commercially owned and operated LEO destinations from which NASA can purchase services as one of many customers and the continued growth of a commercial ecosystem in LEO. As those commercial LEO destinations become available, and without a gap in a U.S. presence in LEO, NASA intends to implement an orderly transition from current ISS operations to the new commercial enterprise as laid out in NASA's ISS Transition Report, dated March 30, 2018 NASA is updating the Transition Report to provide more strategic and tactical transition planning.

ISS is an example of American leadership in global space exploration, enabling a U.S.-led multinational partnership to advance shared goals in space. As a testbed for deep space exploration, ISS is helping us learn how to keep astronauts healthy during long-duration space travel and demonstrating technologies for human and robotic exploration beyond LEO, to the Moon, and to Mars. ISS enables commercial industry, academic institutions, U.S. Government agencies, and other diverse users to access a unique research platform for developing and demonstrating new technologies, treatments, and products for improving life on Earth.

The Crew and Cargo Program manages transportation services provided by both international partners and domestic commercial providers. Through the program, NASA and its partners have greatly strengthened U.S. competitiveness, and continues to advance commercial spaceflight and supports American jobs.

Commercial Crew Program (CCP) partnerships with the private sector are developing and operating safe, reliable, and affordable crew transportation systems capable of carrying humans to and from space, including the ISS. Working with industry to develop and provide human transportation services to and from space lays the foundation for more affordable and sustainable future human space transportation. These partnerships bolster American leadership in space, reduce our current reliance on foreign providers for this service, help stimulate the American aerospace industry, and allow NASA to focus on building the capabilities and expertise necessary for missions to the Moon and Mars.

The Space and Flight Support Program continues to provide mission critical space communications, launch and test services, and astronaut training to support its customer missions. The Space Communications and Navigation Program provides communication to missions in LEO, including ISS, suborbital missions, and some lunar orbital missions, utilizing the Near Space Network (formerly the Space Network and Near Earth Network). The Deep Space Network communicates with the missions most distant from Earth. The Communication Services Program focuses on demonstrating the feasibility of using commercially provided data relay services to support NASA missions. The Launch Services Program provides expertise and active launch mission management for more than 70 NASA and other Government missions in various stages of development. The Rocket Propulsion Test Program manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions, a critical foundation for the success of NASA and commercial rocket programs. The Human Space Flight Operations Program provides the training and readiness to ensure crew health and safety and mission success.

For more information, go to: https://www.nasa.gov/directorates/heo/index.html

INTERNATIONAL SPACE STATION PROGRAM

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
ISS Systems Operations and Maintenance	1,056.0	1,013.8	**1,048.2**	1,043.9	1,013.5	1,013.5	1,013.5
ISS Research	460.1	307.8	**279.4**	265.8	265.9	271.0	271.0
Total Budget	**1,516.1**	**1,321.6**	**1,327.6**	**1,309.7**	**1,279.4**	**1,284.5**	**1,284.5**
Change from FY 2021			**6.0**				
Percentage change from FY 2021			**0.5%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

This picture was taken from a window on the SpaceX Crew Dragon vehicle as the International Space Station orbited above the Atlantic Ocean near the mouth of the Amazon River. Two other spacecraft, including the Cygnus cargo craft with its two prominent cymbal-shaped solar arrays, and behind it, Russia's Soyuz MS-17 crew ship with its rectangular solar arrays, are also pictured docked to the orbiting lab (November 27, 2020).

The International Space Station (ISS) is the largest and most complex space-based research facility ever constructed. ISS enables distinct research opportunities, including research vital to the Artemis human lunar exploration missions and future Mars human exploration programs. Returns from the ISS research investment are not limited to scientific discovery and technology advancement. The ISS international partnership is composed of five space agencies representing 15 nations, led by the United States. NASA's international partners include the Canadian, European, Japanese, and Russian space agencies. Engineers, scientists, and managers from around the world have directed their resources for the peaceful use of space and are now reaping the benefits to humanity. The ISS partnership uses global engagement and diplomacy to provide a cooperative foundation for the global enterprise of space exploration. The partnership allows members to collectively allocate resources and manage operational risks in a way that benefits all parties. ISS provides a high visibility opportunity for American presence and leadership of human and robotic capabilities in low-Earth orbit (LEO).

ISS orbits the Earth about every 90 minutes and has been continuously occupied since 2000. November 2, 2020, marked the 20th anniversary of human occupation aboard the ISS.

NASA and its partners use this unique reference point to advance science, technology, engineering, and mathematics (STEM) education efforts to inspire youth to pursue those fields. Over 2.8 million U.S. students have designed, launched, operated, or used data from more than 800 student experiments launched to ISS. ISS also provides a unique opportunity for STEM inspiration through direct engagement between astronauts and students. ISS inspires future generations and helps foster greater interest in STEM careers.

The launch of the first U.S. commercial crew post-certification mission supported by the Commercial Crew Program occurred in November 2020, which enabled NASA to increase its crew size on the U.S. Orbital Segment (USOS) by one, to a total of four astronauts. On average, this increase will double the total available hours of crew time allocated to perform research on board the ISS each week. USOS is the portion of the ISS operated by the U.S. and its Canadian, European, and Japanese partners. Russia exclusively operates the Russian segment. The ISS spans the area of a U.S. football field (with end zones) and weighs more than 465 tons (930,000 pounds). Its solar arrays, which help power the vehicle, are longer than a Boeing 777's wingspan at 240 feet. The ISS has eight docking and berthing ports for visiting vehicles delivering crew and cargo. Orbiting Earth 16 times per day at a speed of 17,500 miles per hour, the ISS maintains an altitude that ranges from 230 to 286 miles. The complex has more livable room than a conventional five-bedroom house, with two bathrooms, fitness equipment, a 360-degree bay window, and state-of-the-art scientific research facilities. In addition to external test beds, the USOS houses three major science laboratories (U.S. Destiny, European Columbus, and Japanese Kibo).

The four major focus areas of activity for the ISS program include: (1) serving as a key stepping stone on the pathway to deep space exploration; (2) maintaining U.S. global leadership of space exploration; (3) enabling the development and advancement of a commercial marketplace in LEO; and (4) returning benefits to humanity on Earth through space-based research and technology development.

The ISS plays an essential role in facilitating the expanding sphere of human space exploration from LEO to the Moon (via the Artemis Program) and eventually to Mars. The ISS is currently the only microgravity platform capable of long-term testing of new life support and crew health systems, advanced habitation modules, and other technologies needed to expand NASA's exploration horizons. This research and development program will continue to focus on capabilities needed to maintain a healthy and productive crew in deep space, including the Gateway and future missions to the moon and Mars. Manifested or planned experiments and demonstrations to enable human exploration at the Gateway, lunar surface, and into deep space include: tests of improved long-duration life support technologies; advanced fire safety equipment; on-board environmental monitors; techniques to improve logistics efficiency; in-space additive manufacturing; advanced exercise and medical equipment; radiation monitoring and shielding; human-robotic operations; and autonomous crew operations. The facility enables scientists to identify and quantify risks to human health and performance and to develop and test preventative techniques and technologies to protect astronauts during extended time in space. The ISS platform and future commercial LEO destinations provide a rich environment for research in basic and applied research.

NASA will continue research and technology efforts in LEO using the ISS to enable exploration with humans to the Moon and to Mars, while continuing to perform research that benefits humanity and leads to a robust ecosystem in LEO. NASA is working to implement a stepwise transition of ISS from the current model of NASA sponsorship and direct NASA funding to a model where NASA is one of many customers purchasing services from a LEO human spaceflight enterprise via the Commercial LEO Development Program. NASA will gradually transition from current ISS operations to this new model when these commercial platforms and services become available, to ensure that the U.S. always has a human presence in LEO.

The ISS program aims to provide direct research benefits to the public through its operations, research, and technology development activities. As a National Laboratory, the U.S. segment of the ISS enables partners in Government, academia, and industry to utilize its unique environment and advanced facilities to perform investigations. The ISS National Laboratory (ISSNL) is managed by the Center for the Advancement of Science in Space (CASIS). The focus of the ISSNL is to provide ISS access to academia, the commercial sector, and other Government agencies through partnerships, cost-sharing agreements, and other arrangements for research, technology development, LEO commercialization, and education. Observing from and experimenting aboard ISS provides the opportunity to learn about Earth, life, and the solar system from a very different perspective. ISS serves as an innovation laboratory for experiments that cannot be accomplished on Earth. Earth observation instruments on ISS expand our Nation's understanding of the climate and carbon cycle. It also allows other NASA mission directorates to conduct research and demonstrate technologies, often at a lower cost than would be otherwise possible. This includes technology demonstrations sponsored by the Space Technology Mission Directorate, human research activities funded by the Human Research Program, and basic and Earth research funded by the Science Mission Directorate. The results of the research completed on ISS can be applied to many areas of science, improving life on Earth; fueling American innovation and enhancing U.S. overall economic competitiveness; and furthering the experience and increased understanding necessary to journey to other worlds.

For more on the ISS program, go to: https://www.nasa.gov/mission_pages/station/main/index.html

For specific information on the many experiments conducted on ISS, go to: https://www.nasa.gov/mission_pages/station/research/experiments_category.html

EXPLANATION OF MAJOR CHANGES IN FY 2022

Biological and Physical Sciences (BPS) budget has been transferred to the Science Mission Directorate. Demand stimulation content in the Commercial LEO Development program is being transferred to ISS Research.

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FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**1,056.0**	**1,013.8**	**1,048.2**	**1,043.9**	**1,013.5**	**1,013.5**	**1,013.5**
Change from FY 2021			**34.4**				
Percentage change from FY 2021			**3.4%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

NASA astronaut Kate Rubins is pictured here during a March 5, 2021 spacewalk to install solar array modification kits to ready ISS for newer, more powerful solar arrays being delivered on upcoming SpaceX Dragon cargo missions.

The International Space Station (ISS) is a complex research facility and human outpost in low-Earth orbit (LEO) developed in a collaborative, multinational effort led by the United States with partners in Canada, Europe, Japan, and Russia. It is supported by the commercial industry via the Crew and Cargo Program and Commercial Crew Program (CCP). The facility's primary goals are to advance exploration of the solar system, enable unique scientific research, and promote commerce in space with industry partners as new commercialization concepts are explored. The Operations and Maintenance (O&M) project supports vehicle operations in the harsh conditions of space with constant, around-the-clock support. The ISS systems operate in extreme temperatures, pressures, and energies that challenge engineering techniques with minimal margin for error. The risks associated with operating the ISS are significant and must be effectively managed to protect against catastrophic consequences to mission success and human life. Successful risk mitigation activities on ISS in LEO pave the way for a more successful Artemis Program and missions to Mars.

Safely operating the ISS in the severe conditions of space and ensuring the crew always have a sufficient supply of food, water, oxygen, and repair parts demands precise planning and logistics. The 465-ton vehicle requires routine maintenance and is subject to unexpected mechanical failures, given its highly complicated systems and the harshness of space. Resolving problems can be challenging and often requires the crew to make repairs in space with support from ground teams on Earth. Astronauts aboard the ISS must rely on the materials available to them onboard. This requires the support team on Earth to monitor and meticulously plan for replacement parts and consumables, such as filters and gas, as well as Orbital Replacement Units (ORUs) like the Inlet De-ionizing Bed, Microbial Check Valves, and Multi-Filtration Beds, which are key components of the Regenerative Environmental Control Life Support

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System (Regen ECLSS). The coordination and support necessary for the ISS crew to live and work comfortably in space requires intensive Earth-based mission operations. Ground teams continually monitor ISS performance, provide necessary vehicle commands, and communicate with the crew.

Even before the astronauts leave Earth, the Systems O&M project, in conjunction with the Human Space Flight Operations program, provides the crew training to prepare them for their stay aboard the ISS. One example includes operation of the Neutral Buoyancy Laboratory, an indoor underwater training facility, where astronauts, in a safe environment, can simulate specific extravehicular (EVA) activities to repair, replace, or install new instruments and operational systems. During training exercises, neutral-buoyancy diving is used to simulate the weightlessness of space operations. To achieve this effect, suited astronauts or pieces of equipment are lowered into the pool using an overhead crane and then weighted in the water by support divers so that astronauts experience minimal buoyant force and minimal rotational moment about their center of mass.

The ISS program considers all aspects of the mission when developing operations plans to meet program objectives. These include scheduling crew activities, choreographing docking and undocking of visiting crew and supply ships, evaluating supplies of consumables, managing flight plan variability, and resolving stowage issues. The Systems O&M project ensures the ISS is always operational and available to perform its research mission.

Because the ISS is an international partnership, program decisions are not made in isolation. Rather, they require collaboration with multiple countries to ensure all technical, schedule, and resource supply considerations are taken into account. The experience NASA is gaining through integration with its ISS partners is helping the Agency to better prepare for future partnerships in human space exploration, such as on the Gateway or the lunar surface.

A critical component of the Systems O&M project is immediate emergency services and analyses conducted by mission control teams on Earth, known as vehicle and program anomaly resolution. Engineers and operators diagnose system failures and develop solutions, while program specialists respond to changing program needs and priorities through re-planning efforts. These teams ensure appropriate redundancy, training, and procedures are in place to respond to any type of failure at any time. The project requires sparing and repairing nine highly complex on-orbit systems made up of hundreds of unique ORUs. Additionally, software sustainment manages and executes millions of lines of flight code to support operation and control of the ISS.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

The ISS System O&M project continued to maintain resources both on-orbit and on the ground to operate and utilize the ISS. The O&M project funded Mission Control Center operations monitoring the safety of crew and integrity of ISS 24/7 (Other MCC activities are funded by the programs they support). This is required to maintain success in providing all necessary resources, including power, data, crew time, logistics, and accommodations, to support research while operating safely with a typical crew of seven astronauts, four United States Orbital Segment (USOS) crew, and three Russian crew.

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One overarching accomplishment is the successful navigation of ISS Operations through the COVID-19 pandemic. While NASA had to adjust some launch schedules, ISS and CCP successfully launched the first crew from U.S. soil since 2011. Operations on-orbit and Earth continued 24/7 and the ISS program successfully pivoted and quickly adjusted to the practices required to continue working as safely as possible.

The O&M project supported the arrival and departure of 13 flights, both domestic and international crew and cargo missions, to the ISS. This resulted in supporting almost one flight per month. Each flight required extensive planning and analyses to support on-orbit operations, as well as launching, docking, undocking, berthing, unberthing, deorbiting, packing, manifesting, hardware processing, and on-orbit configuration.

NASA ground teams continued to monitor overall vehicle health and oversee general maintenance and performance of all the ISS vehicle systems, including command and data handling, communication and tracking, crew health care, environmental control and life support, electrical power, extravehicular activities (EVAs), robotics, flight crew equipment, propulsion, structures and mechanisms, thermal control, guidance, navigation, and control.

In FY 2020, the team supported an unprecedented 13 USOS EVAs. In January, two EVAs completed the final P6 battery installations without issue and the fourth and final Alpha Magnetic Spectrometer (AMS) EVA was accomplished. The AMS is a cosmic ray particle physics experiment mounted outside the ISS producing science data is valuable for the understanding of the formation of the Universe and informs the search for evidence of dark matter. The AMS EVA completed the final replacement thermal system leak check and multi-layer insulation installation for the AMS. When initial leak checks showed one of the swaged fittings did have a leak, the fitting was tightened two times to repair the leak. Once the multi-layer insulation installation was completed, the replacement thermal system was fully pressurized and AMS is once again producing science data. The AMS series of EVAs completed very difficult tasks that have never been undertaken during a spacewalk. These repairs will allow AMS to provide several additional years of data collection.

The last of the Lithium Ion batteries were installed within a four EVA series in July 2020 to complete the complement of ISS batteries. The new batteries provide an improved and more efficient power capacity for operations. Along with battery installation, EVA crew moved several large items outside ISS, including a robotic compatible box called the Robotic Tool Stowage that houses two ammonia sniffing devices, called the Robotic External Leak Locators. They routed cabling for the ISS Ethernet System, and prepared ISS for the NanoRacks Bishop Airlock arrival on SpaceX -21 mission. The new airlock significantly increases the capacity for public and private research on the outside of the orbiting lab. It also enables the deployment of larger satellites and the transfer of spacewalking tools and hardware inside and outside the station.

FY 2020 contained ISS advances in software vital to its on-orbit safety and day-to-day operations. The software updates included new hardware support for the Mini Pump Module and Space-to-Ground Transmitter Receiver Controller and adds interfaces for Sierra Nevada Corporation Dreamchaser and docking of SpaceX's Dragon cargo vehicle. Due to the COVID-19 pandemic, the Software Development Integration Laboratory at the Johnson Space Center (JSC) was updated to support remote testing with all International Partners (each was a unique configuration) due to travel and NASA center access restrictions. This update was critical to ensure the necessary testing could continue to support the ISS visiting vehicle traffic.

In the Avionics area, ISS was able to complete the S3 Wireless Access Point/E-ultra New Radio Dual Connectivity Wireless Access Points (WAP) and External High Definition Camera/boom installation,

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which improved Earth views for High Definition Earth Viewing science and increased WAP coverage for the High Definition EVA Camera Assembly and EVA Data Recorder.

In the ISS vehicle and hardware area, successes included the delivery of HTV-9 Batteries, external leak locator system and first two solar array modification kits, as well as ISS sparing and repairs (e.g., valves, gas outlets, hoses, sequential shunt unit). Significant verification work for new commercial vehicle certification/integration was performed. Additionally, preparations for increased crew member compliment, work on the Main Bus Switching Unit failure, and critical contingency robotics Replace & Repair/Battery Charge/Discharge Unit (BCDU) failure investigation and fleet recovery also commenced. Anomaly investigations for recovering and maintaining ISS habitability and research capability (e.g., benzene, atmosphere leaks) were successfully performed.

WORK IN PROGRESS IN FY 2021

Throughout the year, NASA ground teams will continue to monitor overall vehicle health and oversee general maintenance and performance of all the ISS vehicle systems. The O&M project will continue to manage resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. The O&M project is expected to support several U.S. Commercial Crew flights including the first post-certification mission, six U.S. Commercial Resupply Services cargo flights, two Progress flights, two crewed Soyuz flights, and one Russian hardware flight.

The program plans to support five Russian EVAs and nine U.S. EVAs in FY 2021. The first series of EVAs will install the Columbus Ka-Band system to the Columbus Module. This communication system will enhance and add new capabilities to the existing Columbus on-orbit and ground communications systems and create an additional bi-directional Ka-Band data transmission link for ISS. This EVA will also install cables to connect the Bartolomeo external payload platform on the Columbus Module of the ISS. The Bartolomeo platform will allow new, unique payload hosting opportunities and will offer ISS the only unobstructed view of Earth and space. An additional EVA is planned in this series to complete several upgrades on ISS, including installation of HD cameras and the final battery adapter plate, and prepare ISS for installation of the ISS Roll Out Solar Array.

In the area of software, ISS plans to complete the R19 software transition, and start R20 development and testing. The R19 software transition includes support for: Exploration ECLSS, four Bed Carbon Dioxide Scrubber and Supplemental Heat Rejection Evaporative Cooler, and Lab Starboard water vent valve modification. The capability to install Portable Computer System software via Joint Station Local Area Network will enhance future software transitions. The total payload health and status data bandwidth will be increased to support customer requirements. The Software and Avionics branch is planning 32 joint tests (19 specifically to support commercial vehicle provider flights; 11 to support integrated R19/R20 testing; and two to support Commercial LEO – Private Astronaut Mission activities).

In the Avionics area, EVA work will include replacing failed Extra High Definition Camera and improving external wireless coverage (EWC)/posture. This will complete the fully planned EWC expansion; which is essential to providing improved two-way high-data rate wireless communications for various payloads across ISS and live feed ISS footage back for use on Earth.

In the vehicle area, ISS is poised to extend the Functional Cargo Block through 2024; deploy the large equipment launch carrier development Ammonia Tank Assembly, BCDU, and Mini-Pump Module; and continue spares procurements for cupola scratch panes, heat exchanger parts, tanks, pump assembly, catalytic reactor, hydrogen dome, and ancillary components and parts. The new configuration Oxygen

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Generation System Cell Stack will be installed and checked out, and the new solar array launch package will be launched and activated.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The ISS Program will continue to support CCP and its commercial crew partners to ensure any challenges with the initial missions are addressed with minimal impact to ISS operations and research. NASA plans to work with international partners to maintain a continuous ISS crew member capability by coordinating and managing resources, logistics, systems, and operational procedures. The O&M project will continue to manage resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. In addition to providing anomaly resolution and failure investigation (as needed), they plan and provide real-time support for activities, such as EVAs and visiting vehicles. The O&M project plans to support the launch of approximately 16 flights in FY 2022. The team is currently reviewing and rescheduling FY 2022 USOS EVAs.

PROJECT SCHEDULE

The table below provides a schedule for FY 2021 and FY 2022 completed and planned EVAs. The ISS conducts near-term, real-time assessments of EVA demands, along with other program objectives, to efficiently plan all required ISS activities. NASA remains postured to conduct EVAs on short notice in response to specific contingency scenarios. In addition, the ISS program balances routine maintenance EVAs against overall astronaut availability to maintain focus on utilization and research.

Date	Significant Event
Nov 2020	Russia EVA
Jan 2021	U.S. EVA
Feb 2021	Two U.S. EVAs
Mar 2021	Two U.S. EVAs
Jun 2021	Two U.S. EVAs
Jun 2021	Russian EVA
Aug 2021	Two U.S. EVAs
Sep 2021	Two Russian EVAs
Jan 2022	Four Russian EVAs

Project Management & Commitments

While NASA maintains the integrator role for the entire ISS, each partner has primary authority for managing and operating the hardware and elements they provide. Within NASA, JSC in Houston, TX, leads project management of the ISS Systems O&M.

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Acquisition Strategy

The current Boeing vehicle sustaining engineering contract extends through September 2024. Requirements of this contract include sustaining engineering of U.S. on-orbit segment hardware and software, technical integration across all the ISS segments, end-to-end subsystem management for most of the ISS subsystems and specialty engineering disciplines, and U.S. on-orbit segment and integrated system certification of flight readiness.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
U.S. on-orbit segment Sustaining Engineering Contract	The Boeing Company	JSC

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Jan 2021	Provides independent guidance for the NASA Administrator.	The panel provided no new formal recommendations or findings for the ISS	May 2021
Other	NASA Aerospace Safety Advisory Panel	Feb 2021	Provides independent assessments of safety to the NASA Administrator.	The panel provided no new formal recommendations or findings for the ISS, but commented that "it is very important that there be a U.S. astronaut onboard at all times."	May 2021

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FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**460.1**	**307.8**	**279.4**	**265.8**	**265.9**	**271.0**	**271.0**
Change from FY 2021			**-28.4**				
Percentage change from FY 2021			**-9.2%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Flight Engineer Jessica Meir (NASA) is shown here setting up the Multi-use Variable-g Platform-02 inside the portable glovebag to support cardiac research (Cell-03) aboard the International Space Station. The Cell-03 investigation cultures heart precursor cells on the space station to analyze and compare with cultures grown on Earth. Results may help treat spaceflight-induced cardiac abnormalities and contribute to accelerated development and reduced cost of drug therapies on Earth. (March 13, 2020)

The International Space Station (ISS) is an orbiting platform that astronauts and researchers use to understand the effects of space on human health and to develop technologies to mitigate those effects that are a barrier to future human exploration missions. The unique microgravity environment enables scientific investigation of physical, chemical, and biological processes in an environment very different from Earth.

November 2, 2020 marked the 20th anniversary of continuous human presence in space aboard ISS. In that span, the orbiting platform has evolved into a dynamic laboratory that hosts an increasing variety of government and privately-owned science facilities, external testbeds, and observatory sites. The ISS provides the only current capability for human-assisted space-based research and is a foundation for efforts to expand commercial use of low-Earth orbit (LEO) and to enable a sustained U.S. presence in this region of space.

This budget line supports the ISS National Laboratory (ISSNL), which is dedicated to enabling non-NASA use of the ISS. The ISS Research budget also funds support for all research users of the ISS through NASA's multi-user systems support (MUSS).

In 2005, the U.S. segment of the ISS was designated as a National Lab by Congress. The 2010 Authorization Act then designated that 50 percent of crew time, cargo upmass, and access to research facilities on the ISS should be allocated for non-NASA use of the ISS. Non-NASA use of the ISS is managed through the ISSNL. NASA was directed by Congress to enter into a cooperative agreement with a single purpose non-profit, non-government organization (NGO) to manage non-NASA use of the ISS in

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cooperation with NASA. NASA selected the Center for the Advancement of Science in Space (CASIS) as the operating manager of ISSNL activities in 2011. The ISS National Laboratory Program allows non-NASA users to conduct Research and Development (R&D) activities on ISS that benefit life on Earth and foster commerce in space. Non-NASA users of ISSNL include other government agencies - such as the National Science Foundation (NSF), National Institutes of Health (NIH), and the Department of Defense (DOD) - as well as multiple academic institutions and commercial companies. Since 2012, almost 450 payloads have flown under the ISSNL allocation and, for the past three fiscal years, more than 70 percent of payloads launched represent investigations from the private sector that aim to spur economic growth.

MUSS provides strategic, tactical, and operational support to all ISS research, whether sponsored by NASA, international partners, or ISSNL. Through MUSS, the ISS Research budget supports the execution of the broader portfolio of research and technology development activities undertaken on the ISS and funded through other NASA budget items (e.g., Biological and Physical Sciences [BPS], Human Research Program [HRP], and Space Technology Mission Directorate [STMD]). ISS external research platforms enable research recommended by the National Academy Decadal and funded by NASA's Science Mission Directorate (SMD) to provide access to Earth and space vantage points. Taken as a whole, these R&D activities enable future human exploration, pioneer scientific discovery, expand our understanding of the universe and our home planet, and benefit our economy and life on Earth. MUSS continues to support new capabilities and technologies that benefit multiple ISS users and operation of in-orbit and ground control research facilities.

Research conducted aboard ISS, supported by this budget line item through MUSS and ISSNL activities, have made fundamental contributions to human knowledge and have advanced goals set by the National Academies of Science through a series of Decadal Surveys. At the conclusion of Expedition 63 in October 2020, more than 4,200 investigators from 108 countries have performed more than 3,000 research investigations and technology demonstrations utilizing ISS. Over 2,100 papers have been published in scientific journals and magazines based on results of these investigations.

ISS research also supports the development of technologies of use in exploration campaigns such as Artemis, and longer-duration missions to Mars and beyond. ISS provides the best existing means to demonstrate technology and system readiness for use on a human occupied exploration vehicle by documenting performance in a spacecraft environment with humans-in-the-loop, piloting operational procedures and training requirements, determining logistics requirements, safety, and interoperability concerns with respect to overall space systems infrastructure. From an Environmental Control and Life Support Systems perspective (ECLSS), ISS is host to multiple long-duration flight experiments and projects; which include investigations in water purification, recovery and utilization; oxygen generation and filtration systems, carbon dioxide filtration systems, crop production and mitigation of known medical issues. A major focus is upon systems reliability and reduction in the amount of hardware spares needed in long-duration spaceflights. Another example includes, Roll out Solar Array (ROSA) technology, which improves the power density, stowage efficiency, and scalability of previously used rigid panel arrays. ROSA was tested on ISS in 2017 for strength, structural dynamics, and operations and will be used as part of the Gateway's Power and Propulsion module. In addition, this technology will be used to upgrade ISS power systems as soon as 2021.

ISS Research also contributes to Agency efforts to spur economic growth of LEO and to enable a sustained U.S. presence in this region of space. NASA's plans for expanding activities in LEO build on and apply the lessons learned from over a decade of work and experience with private companies in ISS research. For example, research facilities onboard ISS continue to evolve from primarily government funded and operated to privately owned and operated. Since 2012, privately owned research facilities have greatly increased the breadth and volume of ISS-supported research, with more than 20 such

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facilities in operation at the start of FY 2021, with the managing entities servicing 40 percent of ISSNL payloads delivered in FY 2020. In addition, some 40 companies provide services as payload developers, guiding researchers to build and ship flight hardware to be executed on the station. These activities validate business models and expand the numbers of entities with experience in conducting business in space.

An additional step for commerce in space, a new airlock, privately owned and operated, will be integrated into the station in FY 2021. The Nanoracks Bishop Airlock will significantly increase the ability to transfer payloads to and from the stations external platforms and allow more small satellites to be deployed from station, while demonstrating the capabilities of a new airlock design for use in future exploration missions.

EXPLANATION OF MAJOR CHANGES IN FY 2022

BPS budget and content has been transferred to the Science Mission Directorate. Demand stimulation content in the Commercial LEO Development program is being transferred to ISS Research.

ACHIEVEMENTS IN FY 2020

FY 2020 saw new research facilities come online, new capabilities piloted, and an astrophysics instrument repaired and cleared for operation through the life of the station.

The delivery and installation of the NASA Cold Atom Laboratory (CAL) Science Module-2 has allowed the CAL research teams to continue their investigations into studies that require atom-interferometry measurement capability, a first of its kind in LEO. Atom interferometry can be used to precisely measure a host of phenomena including gravity, acceleration, rotation, electric fields, magnetic fields, and chemical interactions. Teams of Nobel-laureate-led scientists now have access to this capability in an environment that allows for unparalleled observations.

The Bartolomeo External Science and Payload Hosting Facility platform launched to the ISS and will support commercial use of LEO for applications including remote sensing, in-orbit manufacturing, and materials science and can be accessed through ISSNL Implementation Partner Airbus DS Houston.

The Mobile SpaceLab research platform from HNu Photonics also launched in FY 2020. The platform enables ISSNL investigators a quick turnaround automated platform to perform sophisticated microgravity biology experiments. The Mobile SpaceLab allows observations of sub-cellular functions through an advanced microscope. It is self-contained and requires no crew interaction while the experiment is running. The technology may reveal previously unknown aspects of cell biology that are medically relevant for human health on Earth. An experiment developed in partnership with Space Tango supported the development and validation of a Flow Chemistry CubeLab system for the ISS that allows researchers to explore microgravity's effects on chemical processes. The system may result in significant new knowledge and opening new R&D opportunities on the ISS in advanced materials, in-orbit production, and biology. The platform should have the ability to support multiple applications, potentially beyond basic research.

FY 2020 also saw an increasingly diverse portfolio of public-private partnerships, fundamental science, and technology demonstration investigations conducted. The ISS Research budget supported, either directly or through MUSS integration services, an estimated 378 active investigations across all ISS partners. NASA and ISSNL combined to sponsor an estimated 174 U.S. research investigations. These

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totals included 65 payloads for ISSNL, more than 80 percent representing projects from the private sector that aim to spur economic growth in LEO.

For more information, go to: https://www.nasa.gov/mission_pages/station/research/index.html and https://www.issnationallab.org/

ISSNL continued to drive upward trends for industry involvement in supply, demand, and investment related to its R&D portfolio. R&D activities onboard ISSNL in FY 2020 included projects from large industry partners like Delta Faucet and Co., Lockheed Martin Corp., Anheuser-Busch, Lamborghini, and adidas; innovative startup companies funded in collaboration with Boeing; and research entities such as Emory University, The Jackson Laboratory, National Stem Cell Foundation, and DARPA.

Several companies secured external funding in FY 2020 to continue building on ISSNL R&D initiatives. Startup Orbit Fab and biotech company Pheronym each received a grant from NSF's program America's Seed Fund, and remote sensing company Orbital Sidekick received one of only 20 grants through the Air Force's AFVentures funding. Also, Space Tango (together with the University of California-San Diego and LambdaVision), Made In Space, and Axiom received NASA grants for work that builds on the success of multiple ISSNL projects. To date, more than $215 million has been raised post-ISSNL award by startups in the ISSNL portfolio from venture/private capital and via public and private grants.

Additional examples of accomplishments in FY 2020, representing both MUSS support and ISSNL efforts, include:

- The Biosentinel investigation used living cells as biosensors to test the radiation environment of the ISS as a pathfinder for developing radiation biosensors that could be used on future exploration platforms. This investigation seeks to measure DNA damage-and-repair response to space radiation in living cells for long-term space exposure; and correlate the biological response with radiation measurement data to validate models of radiation effects on biology.
- Electromagnetic levitation of metals and bulk metallic glasses in the microgravity environment provided data for: (1) better manufacturing of cast superalloy components to improve efficiency, safety, and reliability of rocket and jet engines; (2) understanding formation of Bulk Metallic Glasses, which are an emerging class of materials with applications such as cryogenic gears for planetary exploration; and (3) investigating thermophysical properties of high-temperature materials to allow more efficient and reliable production of metallic parts using these alloys.
- NASA's STEM on Station website had over 1.2 million views with the STEMonstration video library accessed nearly 600,000 times (see: http://www.nasa.gov/stemonstation and https://www.nasa.gov/stemonstrations).
- Lockheed Martin Corporation (in collaboration with StemRad) tested the performance of the AstroRad radiation shielding vest on ISS crew members. AstroRad uses a selective shielding technology to protect organs that are most sensitive to radiation exposure. This investigation is beneficial not just to protect astronauts from radiation in space but also for people on Earth whose professions involve periodic exposure to radiation.
- Techshot Inc.'s BioFabrication Facility completed its first space-based prints in December 2019. The facility used human heart cells and announced the successful bioprinting of a meniscus (cartilage) through the ISSNL.

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In FY 2020, commercial users of the ISSNL published 26 articles in peer-reviewed journals. Examples include:

- Merck Sharp & Dome Corp. published results from their efforts to identify key variables in the crystallization of pembrolizumab, the active pharmaceutical agent in an immunotherapy cancer treatment drug called Keytruda®. Results from this project were applied to the production of the drug that resulted in improved properties that will allow the drug to be administered via an injection instead of through an intravenous (IV) line. The study could lead to widen drug delivery options to improve safety, reduce cost, and improve patient and caregiver quality of life.
- The Mayo Clinic published results from an investigation that established the feasibility and safety of growing mesenchymal stem cells (MSCs) in microgravity for human clinical applications on Earth. MSCs are cells that play an important role in the activation of immune cells and promoting tissue repair and regeneration. Many MSCs are required to advance regenerative medicine applications but are difficult to grow on Earth. Growing these cells in microgravity could increase the number of MSCs available for clinical applications to treat patients with age related conditions, such as stroke, cancer, dementia, and neurodegenerative diseases.
- Seven papers were published containing detailed results from rodent research flown to the ISS over multiple years. Two discussed liver function and chronic stress, while five discussed changes to musculoskeletal health—one of which made the cover of Advanced Therapeutics and another that detailed findings of the "Mighty Mice" investigation. The results suggested that myostatin, a type of protein, may be effective in preventing or treating muscle and bone loss not only in astronauts but also in people with disuse atrophy, a type of muscle atrophy, on Earth.
- Fredrick National Laboratory (sponsored by the National Cancer Institute) published results from an investigation that mapped protein structures which could not be done using Earth-grown protein crystals. The focus of the experiment was on mapping the protein KRAS. KRAS is the most frequently mutated member of the RAS family of genes which are responsible for more than 30 percent of all human cancers, including some of the deadliest (and most costly to treat) such as pancreatic, lung, and colon cancers. Successful mapping of this protein crystal may lead to the development of inhibitors to treat the cancers associated with the KRAS gene.

NASA is committed to management of ISSNL as a resource for the American people and ensuring that it returns benefits to Earth and in the opportunities for the future as the Agency is working to enable a robust LEO economy. NASA and CASIS are responding to the findings of Independent Review Team (IRT) report requested by the NASA Administrator in 2019 and are executing six ISSNL transformation activities to ensure that ISSNL continues to evolve in response to the growing user community and to address the management issues identified by the review. These activities include developing a new CASIS Board with an interim Board Chairperson, searching for a new Executive Director, assigning an ISSNL program executive at NASA Headquarters as the primary liaison to CASIS, and developing a User Advisory Committee for ISSNL.

WORK IN PROGRESS IN FY 2021

FY 2021 planned activities will continue to increase the number of commercial research facilities onboard the ISS. Those facilities will be enabling an increasingly diverse portfolio of commercial, fundamental science, and technology demonstration investigations. In the first half of FY 2021 alone, 239 investigations are scheduled to be active, over half of which are NASA and ISS NL sponsored. Of these

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investigations, 57 are new. Also, increases in USOS crew complement are expected as a result of three scheduled commercial crew missions leading to roughly a doubling of crew-time available for research activities.

New facilities launched in FY 2021 include Nanoracks's Bishop Airlock aboard SpaceX-21's Commercial Resupply Services in December 2020. An airlock is a module used to transfer payloads, including CubeSats, between the interior and exterior of the space station. Bishop will be the first privately owned airlock to operate on ISS and is expected to increase capabilities in both R&D as well as station operations. This airlock will have five times more capacity than the current airlock and can accommodate the deployment of larger satellites (up to 150 kilograms). Finally, it will add six sites for additional external payloads and increase ISS capacity to downlink data from external instruments.

Technology development and proof-of-concept missions using access to ISS capabilities have contributed significantly to the rapid maturation of small satellite capabilities and helped to spur the rapid growth in this new market. When the first CubeSat was deployed from the station in 2012, it was one of only 23 launched worldwide that year. As of October 2020, more than 300 have been deployed from the ISS. By providing deployment access for start-ups and researchers, the station has served as a business incubator for a growing new commercial services sector in LEO. Flocks of hundreds of CubeSats are providing Earth imagery and internet access services worth billions of dollars. The expanded capabilities of the Bishop Airlock will further support the technological maturation of these small satellites.

Highlights of research planned in FY 2021, representing both NASA and ISSNL efforts include:

- The first scheduled user of the Bishop Airlock from the space robotics startup GITAI. The project will perform two technology demonstrations related to robotic intra-vehicular activity and in-space assembly. GITAI ultimately seeks to optimize the functionality and capabilities of robots in space and to thereby lower the cost of space operations 100-fold. The demonstration is specifically designed to perform tasks critical to future in-orbit servicing and/or lunar base development
- Several new technologies and systems supportive of Artemis exploration missions are scheduled for demonstration on ISS in FY 2021, including upgrades to the Universal Waste Management System, improvements to carbon dioxide removal, and a brine processor.
- Airbus's Multipurpose Active Target Particle Telescope on the ISS will use the unique radiation profile of the ISS to test novel radiation detection technology with the ability to monitor radiation levels from all directions in real time.
- L3Harris will test 3D-printed radio frequency circuits, communications systems, and other materials for small satellites in the harsh space environment.
- Seven satellites comprising the Nanoracks CubeSat Deployer (NRCSD) Mission-19 mission reflect the variety of R&D supported by the multiple deployments planned in FY 2021. Bobcat 1, tests measurement of Global Navigation Satellite System (GNSS) estimates of time differences between constellations of satellites; SPOC, a camera used to create high spectral resolution images that can monitor coastal wetlands and water quality; NEUTRON-1, maps neutron abundance in LEO to advance understanding of the relationship between Earth and the Sun; two members of the LEMUR2 constellation of remote sensing satellites will monitor weather as well as global aviation and maritime traffic; DESCENT, tests wires that collect and eject electrons from Earth's magnetic field, called electrodynamic tethers, for use to slow down and eventually remove satellites from orbit; and SAT-LLA, is a platform for testing optical communication technology between satellites and the ground.

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- The Industrial Automated Single Crystal Growth Chamber for microgravity product manufacturing and applied research in the Industrial Crystallization Facility (ICF, from Made in Space) will enable the near real-time observation of crystal growth patterns and rates during flight experiments. These adaptations to facilitate ICF operations will enable Made in Space to conduct early-stage phenomenological studies of high-value single crystal production in microgravity, especially for ISSNL partners like the National Science Foundation (NSF), and establishes a repeatable, low-incremental-cost system for repeated experiments over sustained science campaigns.
- Three companies will continue to explore the value of microgravity to produce high-quality optical fibers for next-generation communications hardware and capabilities.
- SharkSat from Northrup Grumman will collect telemetry data to demonstrate the feasibility of new communications technologies in space.

Additionally, ISS NL R&D sponsored by the NSF will continue to fly in FY 2021. Beginning in 2016, ISSNL partnered with the NSF Engineering Directorate to sponsor annual research solicitations in fundamental science that leverage the persistent microgravity environment of the ISS in LEO to advance scientific discovery for the benefit of Earth. These joint NSF/ISSNL annual research announcements have resulted in 6 annual solicitations from 2016-2021 in the physical sciences topic area of Transport Phenomena and four annual solicitations from 2018-2021 in the biomedical topic area of Tissue Engineering and Mechanobiology.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

NASA will continue to innovate, implementing new processes for payload development and integration that are focused on sending investigations to ISS as soon as they are ready, as opposed to the traditional process of being assigned to a specific flight that could be up to a year away. The improved timelines offered by these processes will better meet the demands of its users, resulting in quicker payload deliveries to ISS (within months in some cases). Thus, private sector users looking to leverage space-based activities to accelerate time to market for product enhancements will have a rapid path from project concept to flight. This bolsters the value proposition for space-based R&D. Similarly, R&D sponsored by NASA, by private companies, or by non-NASA government agencies can be executed within a timeline that enhances the relevance of the research projects. For these cutting-edge projects, scientific discovery and technological advancement moves quickly and will benefit by optimized timelines to flight.

Under the streamlined payload development and integration processes, the flight manifest for FY 2022 is still in development. However, upcoming investigations expected to fly in FY 2022 include:

- An investigation from Clemson University, co-sponsored by ISSNL and Target Corp., will use the Advanced Plant Habitat to study how agricultural production might evolve to feed more people using less water and the same amount of land.
- Tissue engineering and regenerative medicine improve human health and longevity, and FY 2022 flight projects from multiple sponsors, including both NIH and NSF, will explore a range of related topics from stem cell biology to 3D printing.
- Multiple projects sponsored by the NSF (for physical science research) and by Boeing (as part of the MassChallenge Accelerator program) are expected to launch in FY 2022.

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- The HNu Photonics BioChip SpaceLab will be the first system on the ISS allowing researchers to observe sub-cellular functions in real time with mission, science, and engineering support. This is the next iteration of the Mobile SpaceLab.
- Nanohmics, the University of Maryland, and the NASA Langley Research Center will fly the world's smallest spectrograph (miniature hyperspectral camera) for demonstration on the MISSE-FF platform, toward ultimate application in atmospheric and ground environmental studies, precision agriculture, medical and defense applications, and planetary science.
- A 3D printed satellite from Craig Technologies will be the first deployment by a private entity for SSIKLOPS, which fills the payload deployment gap between small CubeSat launchers and major payloads by supporting the microsatellite market.
- Axiom's UNIGLO (Intelligent Glass Optics), flying under ISS NL allocation but funded by a NASA Small Business Innovation Research (SBIR), will join other investigations that examine fiber optic cable production in space.

Project Schedule

An increment, or expedition, is a period of time for ISS operations that spans from one crew return mission to another. Three to five expeditions typically span a calendar year and each consists of cargo ship arrivals and departures, extensive research investigations, as well as standard crew maintenance and logistical tasks. The table below provides a schedule for FY 2021 and FY 2022 completed and planned start dates for the upcoming increments to ISS.

Date	Significant Event
Oct 2020	Increment 64
Apr 2021	Increment 65
Oct 2021	Increment 66
Feb 2022	Increment 67
Jun 2022	Increment 68
Aug 2022	Increment 69
Dec 2022	Increment 70
Mar 2023	Increment 71
Jun 2023	Increment 72
Sep 2023	Increment 73

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Project Management & Commitments

The ISS Program Office meets commitments to international partners for utilization access under the ISS Intergovernmental Agreements and follows statutory guidance in the NASA Authorization Act of 2010 in providing access to on-orbit capabilities for ISSNL research. The ISS Program interfaces with ISSNL and personnel from a wide variety of NASA organizations to integrate objectives into strategic plans and implement research.

Within NASA, mission directorates also prioritize their research investments for ISS based on exploration roadmaps for technologies needed to support NASA's exploration goals, the Human Research path to risk reduction, and recommendations from the relevant National Academies of Science decadal surveys. These are demonstrated in non-ISS budgets of HRP, some activities in STMD, and specific SMD projects (including the transferred BPS).

Element	Description	Provider Details	Change from Formulation Agreement
MUSS	MUSS activities support all research on ISS (NASA sponsored and non-NASA sponsored)	Provider: ISS program and contractors Lead Center: Johnson Space Center (JSC) Performing Center(s): MSFC, ARC, GRC, KSC, JPL Cost Share Partner(s): N/A	N/A
ISSNL	Manages ISSNL through the National Laboratory Cooperative Agreement	Provider: Center for the Advancement of Science in Space (CASIS)	N/A

Acquisition Strategy

NASA awards contracts and grants for conducting research on ISS. NASA prioritizes ISS research based on an established Agency process that prioritizes NASA's use for exploration critical research needs (human research for exploration and technology research for systems to support long-duration lunar and Mars missions) followed by research that aligns with the National Academies' Decadal Surveys that are related to science that can be done in space. NASA manages non-NASA ISS research activities through the ISSNL in cooperation with CASIS and that research is prioritized separately from the NASA research. Peer review is practiced in each selection and is the means to ensure a high-quality research program. Engaging leading members of the research community to assess the competitive merits of submitted proposals is essential to ensuring the productivity and quality of ISS research.

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MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Vehicle Sustaining Engineering Contract	The Boeing Company	Houston, TX
Huntsville Operations Support Center	COLSA Corporation	Huntsville, AL
Mission Operations and Integration (MO&I) Contract	Teledyne Brown Engineering	Huntsville, AL
ISSNL Management Entity	CASIS	Melbourne, FL

INDEPENDENT REVIEWS

Independent reviews for the ISS program as a whole are cited in the ISS O&M section of this document. The independent reviews cited below are unique to ISS Research.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
One-time Independent Review Board (IRB)	IRB	Jan / Feb 2020	IRB to evaluate NASA and CASIS management of ISSNL to ensure that the ISSNL mission is successfully executed and appropriately resourced to produce breakthroughs that improve lives on Earth and encourage economic growth.	IRB report complete, with the report and NASA response available at: https://www.nasa.gov/feature/nasa-shares-findings-recommendations-and-response-to-review-of-international-space-station (also see above section "Achievements in FY 2020" for related FY 2020 activities in response to this review).	N/A

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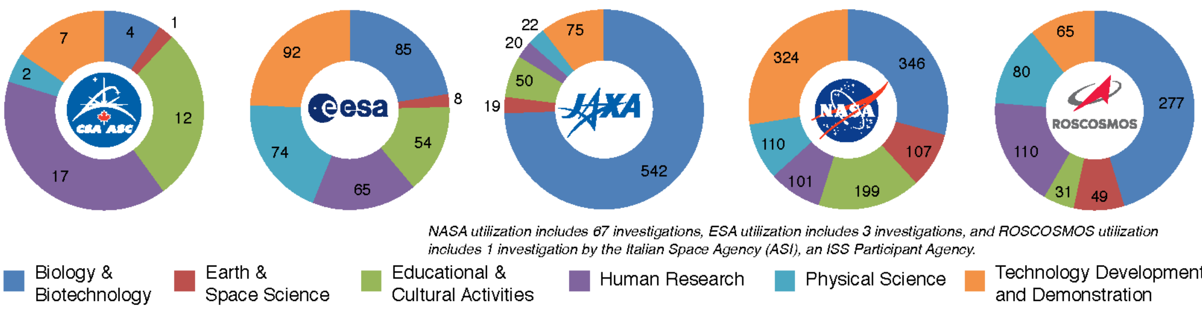
HISTORICAL PERFORMANCE

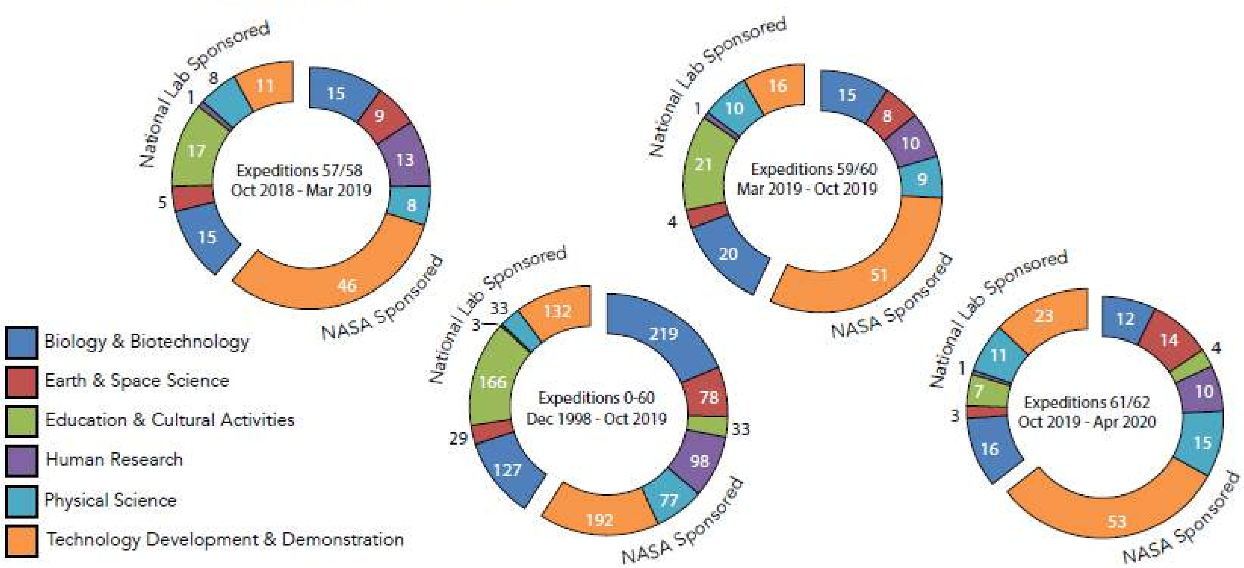
In FY 2019, the ISS Research budget supported, either directly or through MUSS integration services, 471 active investigations across all ISS partners. NASA and ISSNL combined to sponsor 243 U.S. research investigations, an increase of 8 percent from the previous fiscal year. The charts below display historical data, by partner agency, for research investigations performed on ISS from 1998 through October 2019, and a comparison of NASA-sponsored and National Lab-sponsored investigations.

RESEARCH DISCIPLINES OF INTERNATIONAL SPACE STATION INVESTIGATIONS BY PARTNER AGENCIES



NASA utilization includes 67 investigations, ESA utilization includes 3 investigations, and ROSCOSMOS utilization includes 1 investigation by the Italian Space Agency (ASI), an ISS Participant Agency.

Investigations by Research Discipline



SPACE TRANSPORTATION

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Crew and Cargo Program	1,511.3	1,573.2	**1,617.2**	1,763.6	1,784.1	1,778.7	1,778.7
Commercial Crew Program	234.9	299.7	**154.5**	63.5	64.9	64.9	64.9
Total Budget	**1,746.2**	**1,872.9**	**1,771.7**	**1,827.1**	**1,849.0**	**1,843.7**	**1,843.7**
Change from FY 2021			**-101.2**				
Percentage change from FY 2021			**-5.4%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The SpaceX Crew Dragon spacecraft is pictured here approaching the International Space Station for a docking. The Crew Dragon, with astronauts Michael Hopkins, Victor Glover, Shannon Walker and Soichi Noguchi aboard, would dock to the Harmony module's forward port shortly afterward (November 17, 2020).

Space Transportation's objective is to transport U.S. astronauts and cargo safely to and from space, including the International Space Station (ISS). This theme includes the Commercial Crew Program (CCP) and the Crew and Cargo Program. Maintaining ISS requires a fleet of vehicles and launch locations to transport astronauts, science experiments, critical supplies, and maintenance hardware; replenish propellant; and dispose of waste.

CCP partners with the U.S. commercial sector to develop and operate safe, reliable, and affordable crew transportation to low-Earth orbit (LEO). NASA awarded Commercial Crew Transportation Capability (CCtCap) contracts to Boeing and Space Exploration Technologies Inc. (SpaceX) in September 2014. Through its certification efforts, NASA will ensure the selected commercial transportation systems meet NASA's safety and performance requirements for transporting crew to ISS.

Within the Crew and Cargo Program, NASA purchases cargo transportation to ISS under Commercial Resupply Services (CRS) contracts with Northrop Grumman, Sierra Nevada Corp., and SpaceX. NASA has transitioned from purchasing crew transportation to ISS from the Russian Roscosmos State Corporation, known as Roscosmos, to purchasing from commercial providers Boeing and SpaceX. Beginning with the SpaceX commercial crew Demo-2 flight in May 2020, the U.S. is again launching astronauts into space and to ISS. The first commercial crew service mission was the SpaceX Crew-1 flight on November 15, 2020. The budget also supports other space transportation-related activities, such as integration work required to ensure that these visiting vehicles can safely dock or berth to ISS and the development of hardware such as the NASA docking system.

SPACE TRANSPORTATION

As of September 2020, NASA had allocated approximately $19.5 billion towards the commercial crew and cargo program. These funds have supported the completion of two rockets, two cargo vehicles and one crew vehicle, the ongoing development of one other crew vehicle and one other cargo vehicle, and 34 successful cargo flights to ISS. Of that amount, NASA contributed $6 billion towards the development of the commercial crew and cargo systems. This is the amount NASA refers to as its “investment” in the systems. The $6 billion includes NASA’s share of the commercial cargo development costs as well as all NASA Commercial Crew Program development costs (Commercial Crew Development [CCDev] Phases 1 and 2, the Commercial Crew Integrated Capability [CCiCap] initiative, Certification Products Contract [CPC], and CCtCap). The remaining $13 billion is the amount NASA has contracted for services (i.e., the transportation of cargo and crew to the ISS). This amount includes the current contract values for both CRS-1 and CRS-2 cargo contracts, as well as CCtCap crewed missions to the ISS. Within the current maximum contract value, NASA can still award another $8.5 billion under the CRS-2 contracts. Of the $19.5 billion NASA has allocated to these programs, $14.9 billion has been paid to the companies to date.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

CREW AND CARGO PROGRAM

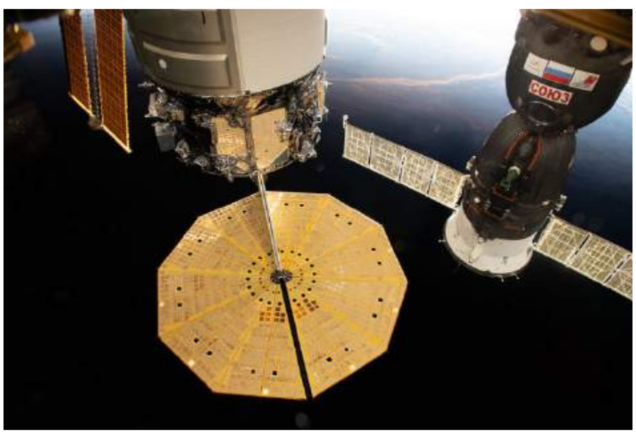
Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**1,511.3**	**1,573.2**	**1,617.2**	**1,763.6**	**1,784.1**	**1,778.7**	**1,778.7**
Change from FY 2021			**44.0**				
Percentage change from FY 2021			**2.8%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Two spacecraft are pictured docked to the International Space Station. At left, with its prominent cymbal-shaped solar arrays, is Northrop Grumman's Cygnus cargo resupply vehicle. To the right, is the Soyuz MS-17 crew vehicle (October 18, 2020).

Maintaining the International Space Station (ISS) requires a fleet of launch vehicles to sustain a constant supply line of both crew and cargo that is crucial to ISS operations and research. Deliveries not only provide science experiments, supplies, and maintenance hardware, but also rotate crewmembers, return research and equipment for repair, and dispose of waste.

The Crew and Cargo Program manages transportation services provided by both international partners and domestic commercial providers. NASA’s commercial service contracts to resupply the ISS have changed the way the Agency does business in low-Earth orbit (LEO). With these contracts, NASA continues to advance commercial spaceflight while simultaneously supporting the American jobs created by this industry.

Through FY 2020, NASA purchased cargo delivery to the ISS from Northrop Grumman (formerly Orbital ATK) and Space Exploration Technologies Inc. (SpaceX) under the original Commercial Resupply Services (CRS) contracts. These vehicles provided between 2,200 and 3,700 kilograms of cargo to ISS with each mission. The cargo provided to ISS includes crew supplies, operations hardware, and numerous science research and technology demonstration investigations.

Northrop Grumman, SpaceX, and Sierra Nevada are working under the follow-on CRS-2 contracts with missions beginning in FY 2020. Under CRS-2, SpaceX and Sierra Nevada will launch CRS missions from Cape Canaveral, FL, as SpaceX does today. Both of these providers also have or will have the

Formulation	Development	Operations

capability to return science experiments to Earth. SpaceX uses its Falcon 9 rocket to launch the Dragon-2 docking cargo vehicle, while Sierra Nevada will use United Launch Alliance's Vulcan rocket to launch its Dream Chaser berthing cargo vehicle. Northrop Grumman primarily launches its Cygnus berthing cargo vehicle on the Antares rocket from the Mid-Atlantic Regional Spaceport at NASA's Wallops Flight Facility (WFF) in Virginia. Northrop Grumman provides trash disposal and conducts additional experiments before the Cygnus spacecraft burns up in the atmosphere after leaving ISS. These capabilities enable studies of fire suppression, the deployment of small satellites at altitudes above the ISS, and other activities not suited for ISS on-board operation. The Crew and Cargo Program budget supports all milestone payments for these contracted flights to provide cargo transportation for a multitude of users, including transportation for National Laboratory science research payloads.

The CRS contract vehicle is among NASA's most successful public-private partnerships. NASA used a series of fixed-price, milestone-based Space Act Agreements to support the development of several companies' efforts to develop commercial cargo resupply capabilities. As a result, NASA is now able to purchase these commercial services from several providers using fixed-price contracts, which have more predictable budget requirements and provide cost savings to the Federal Government. This arrangement has resulted in a stronger U.S. space launch industry, redundancy in the cargo resupply mission area that has increased mission assurance, and robust private sector employment. NASA is leveraging the lessons learned in this program to expand science and research capabilities that these vehicles provide for CRS-2 missions. The CRS contract vehicle has been used as an example by other programs, such as Gateway and the Human Lander System, to expand the successful use of public-private partnerships.

Since the Space Shuttle was retired in 2011, crew transportation to ISS has been provided using the Russian Soyuz vehicle. However, beginning with the SpaceX commercial crew Demo-2 flight in May 2020, the U.S. is again launching astronauts into space and to ISS. The Commercial Crew Program (CCP) manages these activities to develop and provide domestic crew transportation to the ISS under the Commercial Crew transportation Capability (CCtCap) contracts with Boeing and SpaceX. CCP is funding the first Post Certification Missions (i.e., crew missions) to the ISS for each provider; the Crew and Cargo Program is funding the second and all subsequent missions. The first Post Certification Mission to ISS was launched on November 15, 2020 and the second mission was launched on April 23, 2021.

The Crew and Cargo Program also funds activities supporting visiting vehicles that provide transportation for the ISS, including integration activities.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

Northrop Grumman completed 12 mission milestones in support of six commercial resupply flights, including milestones for successful completion of the first two CRS-2 flights in FY 2020. SpaceX completed 12 mission milestones in support of eight commercial resupply flights, including milestones for successful completion of two CRS flights in FY 2020. Northrop Grumman and SpaceX have completed all seven CRS-2 integration milestones required to demonstrate new contract capabilities and

Formulation	Development	Operations

design enhancements to support science and payload research objectives. Sierra Nevada has completed five of eight integration milestones with the completion of its functional interface/demonstration testing.

The program funded CCtCap contract milestones for post-certification crew missions that will be flown by Boeing and SpaceX. More information on CCtCap progress can be found under the CCP portion of this document.

In total, the program supported one crewed Soyuz launch and the SpaceX Commercial Crew Demo-2 mission. The program also supported three launches of Progress, a Russian cargo vehicle, and one launch of H-II Transfer Vehicle (HTV), a Japanese cargo vehicle not funded by NASA.

WORK IN PROGRESS IN FY 2021

NASA expects six commercial resupply flights to deliver research and logistics hardware in FY 2021, including the first CRS-2 flights with SpaceX. Northrop Grumman plans to launch three flights and complete 14 mission milestones in support of six CRS-2 flights. SpaceX plans to launch three flights and complete 15 mission milestones in support of nine CRS/CRS-2 flights. SpaceX launched its first CRS-2 mission in December 2020. Sierra Nevada plans to complete three mission milestones in support of three CRS-2 flights. Sierra Nevada will complete one integration review milestones towards completion of their vehicle testing.

To achieve these planned FY 2021 cargo flights, NASA personnel are reviewing and concurring on vehicle design solutions through a series of integration reviews. In addition, NASA personnel are verifying spacecraft requirements are met by reviewing test and analysis data provided by the CRS-2 contractors.

The program will also continue funding CCtCap contract milestones for post-certification crew missions with Boeing and SpaceX. SpaceX missions began in November 2020 after successful completion of the test flights and NASA certification. Boeing will be conducting additional test flights in FY 2021. More information on CCtCap progress can be found under the CCP portion of this document.

After the initial flights, the regular flight plan will provide for two commercial crew flights per year carrying four crew each flight. However, the first two flights for each provider may be scheduled in a shorter timeframe to reduce risk and accomplish more research. The program will support two Soyuz crew launches, one of which (63S) was partially funded by NASA as the Agency transitioned to commercial crew services. In addition, NASA has signed a contract with Axiom Space of Houston (Axiom) to fly an astronaut on the remaining Soyuz launch (64S). The program will also support two Progress cargo launches and one Russian space station module deployment flight that are not funded by NASA.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The Crew and Cargo Program will enable continued research and technology development by providing a stable crew and cargo flight plan.

NASA expects five commercial resupply flights to deliver research and logistics hardware in FY 2022. Northrop Grumman plans to launch two commercial resupply flights and complete six mission milestones

Formulation	Development	Operations

in support of three CRS-2 flights. SpaceX plans to launch three commercial resupply flights and complete nine mission milestones in support of five CRS-2 flights. Sierra Nevada plans to complete seven mission milestones in support of three CRS-2 flights. Sierra Nevada will also complete one integration review milestones towards completion of their vehicle testing and final safety review work. These resupply flights will be vital for delivering not only the day-to-day supplies needed, but also the experiments that will enable the astronauts to continue important research on ISS. The flights will also support the increased number of research and science investigations enabled by the additional astronauts once commercial crew is available.

The program will also continue funding CCtCap contract milestones for post-certification crew missions with Boeing and SpaceX. NASA is planning for at least two commercial crew missions annually. The flight schedule also includes four Soyuz crew launches, three Progress cargo launches, and one Russian hardware flight that are not funded by NASA.

Project Schedule

Maintaining a regular rate of cargo delivery on a mix of NASA and partner vehicles ensures the ISS can sustain nominal operations and maintenance, while allowing the program to respond to any anomalies that might occur. The table below shows scheduled ISS flight plans for FY 2021 and FY 2022. Commercial crew vehicles began flying in November 2020 with SpaceX Crew-1, followed by SpaceX Crew-2 on April 23,2021. Boeing Orbital Flight Test (OFT)-2 is scheduled for July 2021. However, future flight dates are under review and not included in the table below. NASA funds SpaceX (SpX), Northrop Grumman (NG), and Sierra Nevada Corporation (SNC) cargo missions, Boeing and SpaceX crew missions, as well as Soyuz seats related to USOS crew requirements. The planned spacing of the Soyuz crew rotation flights ensures a continuous crew presence on the ISS and smooth transitions between crews.

Date	Significant Event
Oct 2020	NG-14
Oct 2020	Soyuz 63S
Nov 2020	SpX Crew-1
Dec 2020	SpX-21
Feb 2021	NG-15
Feb 2021	Progress 77P
Apr 2021	SpX Crew-2
Apr 2021	Soyuz 64S
Jun 2021	SpX-22
Jun 2021	Progress 78P

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Date	Significant Event
Jul 2021	Boeing OFT-2
Jul 2021	3R (Russian Proton launch of Multipurpose Laboratory Module)
Aug 2021	NG-16
Aug 2021	SpX-23
Oct 2021	Progress 79P
Oct 2021	Soyuz 65S
Nov 2021	6R (Russian Proton launch of Russian Segment-Node)
Dec 2021	SpX-24
Dec 2021	Soyuz 66S
Feb 2022	Progress 80P
Feb 2022	NG-17
Mar 2022	Soyuz 67S
Apr 2022	SpX-25
Jun 2022	Progress 81P
Aug 2022	NG-18
Sep 2022	SpX-26
Sep 2022	Soyuz 68S

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Project Management & Commitments

Johnson Space Center (JSC) is responsible for management of the Crew and Cargo Program.

Element	Description	Provider Details	Change from Formulation Agreement
Crew transportation	Commercial crew transportation will be provided by Boeing and SpaceX and managed by the Commercial Crew Program.	Provider: Roscosmos; Boeing; SpaceX Lead Centers: JSC, KSC Performing Center(s): N/A Cost Share Partner(s): Canadian Space Agency (CSA), European Space Agency (ESA), and Japan Aerospace Exploration Agency (JAXA)	N/A
Cargo transportation	Northrop Grumman, SpaceX, and Sierra Nevada will provide cargo transportation to the ISS via the major contracts described below. JAXA will provide additional cargo transportation as part of the ISS partnership.	Provider: Northrop Grumman, SpaceX, Sierra Nevada, and JAXA Lead Center: JSC Performing Center(s): GSFC, KSC Cost Share Partner(s): CSA, ESA, and JAXA	N/A

Acquisition Strategy

The ISS program competitively procures all ISS cargo transportation services, excluding services obtained via barter with our international partners or nominal cargo transportation provided by Soyuz. On January 14, 2016, NASA competitively awarded CRS-2 contracts to Orbital ATK (now Northrop Grumman), Sierra Nevada, and SpaceX, with cargo transportation services that began in November 2019. Like the current CRS contracts, CRS-2 contracts are milestone-based, fixed-price, indefinite-delivery-indefinite-quantity (IDIQ) contracts.

In September 2014, NASA's CCP awarded CCtCap contracts to Boeing and SpaceX for commercial crew transportation services that began in FY 2021. CCP is funding milestones on the first Post Certification Missions for each provider. The Crew and Cargo Program will fund the second and all subsequent missions. These crewed vehicles will provide a minimum of 220 pounds of cargo as specified by the ISS program.

NASA purchased three additional crew launches from Roscosmos through October 2020 and crew rescue and return through early April 2021. To ensure continuous U.S. presence aboard the ISS, NASA signed a contract with a U.S. commercial company (Axiom Space of Houston) and flew a NASA astronaut on Soyuz rotation 64S, launched on April 9, 2021. In exchange, NASA will provide a seat on a future U.S. commercial spacecraft, expected to launch in 2023, as part of a space station crew rotation mission. Because the services are determined to be of comparable value to both parties, the contract contains no exchange of funds.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Crew transportation	Boeing	Houston, TX
Crew transportation	SpaceX	Hawthorne, CA
Cargo transportation	Northrop Grumman	Dulles, VA
Cargo transportation	Sierra Nevada	Louisville, CO
Cargo transportation	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Jan 2021	Provides independent guidance for the NASA Administrator	The panel provided no new formal recommendations or findings for the ISS	May 2021
Other	NASA Aerospace Safety Advisory Panel	Feb 2021	Provides independent assessments of safety to the NASA Administrator	The panel provided no new formal recommendations or findings for the ISS, but commented that "it is very important that there be a U.S. astronaut onboard at all times.".	May 2021

COMMERCIAL CREW PROGRAM

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**234.9**	**299.7**	**154.5**	**63.5**	**64.9**	**64.9**	**64.9**
Change from FY 2021			**-145.2**				
Percentage change from FY 2021			**-48.4%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

SpaceX Crew Dragon Endeavor pictured during its approach to the International Space Station after launching from Kennedy Space Center in Florida. (April 2021).

Boeing's Starliner crew module for the company's second Orbital Flight Test (OFT-2) is lifted in the Commercial Crew and Cargo Processing Facility at Kennedy Space Center in Florida. (January 2021).

With technical guidance and oversight from NASA, the U.S. private sector is working to develop and operate safe, reliable, and affordable crew transportation to space, including to the International Space Station (ISS). Partnering with the commercial space industry for access to ISS and other low-Earth orbit (LEO) destinations bolsters American leadership, reduces our current reliance on foreign providers for this service, and helps stimulate the American aerospace industry. Crew transportation is currently provided using the newly certified SpaceX Crew Dragon and the Russian Soyuz vehicle. The Boeing Starliner spacecraft is still in the development and test phase but making significant strides towards certification by NASA for crew transportation to ISS. By supporting the development of U.S. human spaceflight capabilities, NASA is also contributing to the foundation of a more affordable and sustainable future for human spaceflight in LEO and beyond.

Through the Commercial Crew Program (CCP), NASA provides technical insight and financial support to industry partners during development of their crew transportation systems using milestone-based contracts and certifies them to carry astronauts to and from the ISS. Under this acquisition model, NASA defines requirements up front and pays the partner only once contract milestones are successfully completed. This approach shifts financial risk from taxpayers to the private sector, incentivizes increased cost-control, and decreases the cost of developing the systems.

NASA initiated CCP in 2010 with a series of competitively awarded Space Act Agreements, partnering NASA with domestic companies capable of contributing to the development of a U.S. human spaceflight capability. CCP entered the final certification phase in late 2014 with the award of two Commercial Crew transportation Capability (CCtCap) contracts to Boeing and Space Exploration Technologies Inc. (SpaceX). CCtCap requires both partners to complete design, development, test, evaluation, and certification of an integrated Crew Transportation System. SpaceX completed this process in November of 2020 and Boeing is expected to complete it in 2022. The completed transportation systems will support four NASA or NASA-sponsored crew on each flight, and provide emergency crew return, transport/return of pressurized ISS cargo, and crew safe haven while docked to the ISS.

There are numerous benefits associated with the CCtCap acquisition strategy (e.g., controlling costs in the long-term and maximizing crew safety) as reinforced in statements by the Government Accountability Office (GAO), Aerospace Safety Advisory Panel, and NASA Office of Inspector General (OIG). The CCtCap contracts incorporate higher-level requirements than past development efforts, enabling the partners to be innovative and creative in their designs. Additionally, having more than one commercial partner creates competition and does not leave the Government dependent on a sole partner, thereby providing a strong incentive to perform, generally controlling long-term costs and schedules, and mitigating the risk of failure of an individual partner. Additionally, under this model, NASA ensures that companies retain commercial rights to intellectual property, which will allow these crew transportation systems to more easily serve customers other than NASA.

The 2014 CCtCap awards represented a significant milestone in U.S. human spaceflight, with the goal of ending our reliance on foreign crew transportation to ISS and certification of safe and cost-effective U.S. commercial crew transportation systems. In addition, this approach helped stimulate growth of new space transportation industry capabilities available to all potential customers, strengthened America’s space industrial base, and provided a catalyst for future business ventures that can capitalize on affordable, globally competitive U.S. space access. Returning these launches to American soil has significant economic benefits, with more than 1,000 suppliers working across nearly every state on commercial crew spacecraft systems.

As mentioned in the Crew and Cargo program section, CCP manages the CCtCap contracts. In addition to funding the development and risk mitigation work, CCP also funds each partner's initial Post Certification Mission (PCM). Subsequent PCMs, currently planned for FY 2021 and beyond, are funded by the Crew and Cargo program. A total of six PCMs have been awarded to each partner.

In FY 2020, NASA initiated the Suborbital Crew (SubC) activity under the Commercial Crew Program. This activity will develop a system qualification process to enable NASA personnel to leverage suborbital human space transportation capabilities to meet Agency needs and procure commercial suborbital space transportation services for NASA Astronauts and other NASA personnel. After several years of development, commercial suborbital human space transportation systems are becoming operational. The flight profiles of these vehicles include flying to altitudes of approximately 100 kilometers, which results in periods of microgravity longer than can be created with NASA’s Flight Opportunities program led by the Space Technology Mission Directorate. Potential uses include human-tended microgravity research, astronaut training, and testing and qualification of spaceflight hardware. Suborbital human spaceflight has the potential to provide an effective and affordable way to meet the Agency’s needs and continue efforts to enable a robust spaceflight economy.

COMMERCIAL CREW PROGRAM

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

NASA’s CCP completed its first crewed flight test, advancing NASA’s goal of returning human spaceflight launches to U.S. soil on commercially built and operated U.S. rockets and spacecrafts. Under CCtCap development activities, SpaceX and Boeing continued to develop, test, and integrate their unique space transportation systems. NASA CCP continued to engage with both providers as they performed critical test and verification activities, as well as make progress toward risk burn-down of key certification products. To meet NASA's requirements, the commercial partners must demonstrate that their systems are ready to begin regular flights to ISS.

Successfully completing the last CCiCap milestone in January 2020 (an In-flight Abort Test) as well as the final flight test, SpaceX paved the way for NASA to officially certify the company's transportation system for regular crewed flights to the orbiting laboratory. In May of 2020, NASA rolled out the Launch America campaign and 10.6 million viewers watched SpaceX’s Demo-2 mission, a crewed flight test of the Crew Dragon capsule launched atop a Falcon 9 rocket to the ISS with U.S. astronauts Douglas Hurley and Robert Behnken onboard. The Demo-2 mission autonomously docked with ISS and marked the first time a spacecraft with crew has launched from American soil since the end of the Shuttle Program in 2011. After spending 64 days in space docked to ISS, Crew Dragon returned safely to Earth, splashing down in the Gulf of Mexico off the coast of Pensacola, Florida, and brought the program a step closer to regularly launching crew once again from Florida’s space coast. By the end of FY 2020, SpaceX completed all 32 milestones deemed prerequisite for certification.

In November of 2019, Boeing successfully performed their Pad Abort Test to validate end-to-end performance and functionality of the launch abort system. This test was designed to verify that each of CST-100 Starliner’s systems will function not only separately, but also in concert, to protect astronauts by carrying them safely away from the launch pad in the unlikely event of an emergency prior to lift off. This was followed up by the Boeing CST-100 Starliner's uncrewed Orbital Flight Test 1 (OFT-1) on December 20, 2019. The Starliner atop the United Alliance Atlas V rocket lifted off from Space Launch Complex 41 at Cape Canaveral Air Force Station in Florida. The test was able to demonstrate a successful launch and landing as well as some on-orbit operations; however, anomalies occurred that precluded fully completing on-orbit, rendezvous, and docking test objectives. Boeing convened a joint Independent Review Team (IRT) to investigate the OFT-1 mission anomalies and identified areas that needed to be improved to fully achieve success in future flights. Boeing has successfully closed most of the actions recommended in the IRT findings. In parallel, NASA CCP has implemented several mitigation strategies to complement the Boeing action plans and augmented the CCP software team to significantly increase insight and strengthen oversight. Boeing also decided to fly an additional uncrewed test flight, OFT-2, to demonstrate the full suite of mission objectives. These combined actions are expected to reduce the risk to future CCP flight missions. By the end of FY 2020, Boeing completed 38 of 47 milestones towards certification.

In support of Suborbital Crew, NASA released a formal request for information (RFI) from industry to solicit input on: (1) ideas for a NASA approach to system qualification of commercial suborbital systems for NASA Astronauts and other NASA personnel, and (2) commercial availability for eventual purchase of Suborbital Crew Space Transportation Services to enable NASA capabilities. RFI responses were reviewed and will be used in the development of recommendations for the best approach to system qualification of the suborbital crew systems.

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WORK IN PROGRESS IN FY 2021

In November of 2020, NASA certified that all human rating requirements and crew transportation system requirements were met. NASA's Launch America continued as the Agency and SpaceX prepared for Crew-1, the first PCM to the ISS with crew, launched on November 15, 2020. The Crew Dragon 'Resilience' spacecraft carried astronauts Michael Hopkins, Victor Glover, and Shannon Walker of NASA and Soichi Noguchi of JAXA (Japan Aerospace Exploration Agency) to the station for a full 180-day duration. This is the first operational mission following the Agency’s certification of SpaceX’s crew transportation system. The crew launched from Kennedy Space Center’s (KSC) Launch Complex 39A in Florida.

Boeing will continue the production and outfitting of their spacecraft crew and service modules inside the Commercial Crew and Cargo Processing Facility at KSC. Boeing is planning to complete several significant CCtCap milestones necessary to perform the remaining flight test of their crew transportation systems and certify the Starliner crew transportation vehicle. Planned FY 2021 missions include OFT-2, expected to launch in the fourth quarter of FY 2021, followed by Boeing's first Crewed Flight Test (CFT) later in 2021. CCP will focus on mission planning and preparations for future CCP missions as well as remain actively engaged with the providers as they continue space hardware manufacturing, critical testing, and qualification and verification events. Final NASA certification of the Boeing Starliner crew transportation system will occur after a successful CFT.

Suborbital Crew will continue progress towards refining the system qualification approach and determining how NASA will qualify commercial suborbital crew systems for NASA personnel.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

Boeing plans to launch its first PCM, Starliner-1, to ISS with crew. Once CCtCap development and certification is complete, both partners' space transportation systems will begin regularly flying astronauts to and from ISS. These missions will represent major milestones in the return of human spaceflight from the United States. CCP will transition to sustaining operations at a level needed to safely operate with two commercial providers. CCP will continue to manage the CCtCap contracts, including providing technical oversight and managing modifications and upgrades to the transportation systems.

NASA will begin to leverage commercial suborbital crew systems to fly NASA personnel to perform microgravity research and other testing and qualification for spaceflight hardware, as well as conduct astronaut training.

Program Schedule

NASA funds SpaceX and Boeing crew missions related to United States Orbital Segment (USOS) crew requirements. Commercial crew vehicles began flying in November 2020 with SpaceX Crew-1 followed by SpaceX Crew-2 on April 23, 2021. However, future crewed flight mission dates are under review (U/R) and not included in the table below.

Date	Significant Event
Launch: Nov 2020 Return: May 2020	SpX Crew-1

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Date	Significant Event
Apr 2021	SpX Crew-2
Jul 2021	Boeing OFT2
No Earlier Than Late 2021	Boeing CFT

Program Management & Commitments

The Human Exploration and Operations Mission Directorate (HEOMD) team at NASA Headquarters performs strategic management and oversight of Commercial Spaceflight, while KSC is responsible for CCP management, in collaboration with the Johnson Space Center (JSC). CCP partners with industry leaders and is utilizing a combination of Space Act Agreements and Federal Acquisition Regulation (FAR)-based fixed-price contracts to stimulate efforts to develop and demonstrate crew transportation capabilities.

Program Element	Provider
Commercial Crew Program	Providers: Blue Origin, Boeing, Sierra Nevada, SpaceX Lead Center: KSC Performing Center(s): All Cost Share Partner(s): Industry Partners (shown above)

Acquisition Strategy

CCP facilitates development of a U.S. commercial crew space transportation capability with the goal of achieving safe, reliable, and cost-effective access to and from space and ISS. Under the CCP's partnership approach, NASA engineers have insight into a company’s development process and evaluate the systems for overall safety, reliability, and performance. The Agency’s technical expertise and resources are also accessible to partner companies. Because companies are only paid a fixed amount, they are incentivized to reduce costs and to apply their most efficient and effective manufacturing and business operating techniques throughout the process. Additionally, the companies own and operate their own spacecraft.

In the early lifecycle stages, CCDev activities focused on stimulating industry efforts that successfully matured subsystems and elements of commercial crew spaceflight concepts, enabling technologies and capabilities. This was followed by CCDev2, which addressed new concepts to mature design and development of primary elements, such as launch vehicles or spacecraft. Subsequently, NASA continued this effort with CCiCap to continue partner progress in their integrated design and development efforts. For these initial efforts, NASA utilized Space Act Agreements, which provided maximum flexibility to the provider and maximum affordability to the Government. Concurrently with CCiCap agreements, NASA awarded Certification Products Contracts (CPCs) to industry to begin the two-phased process of NASA certifying their crew transportation systems in 2012. The scope of the CPCs included the submission and technical disposition of specific, early development certification products. The CPC effort allowed the partners to gain insight into NASA human spaceflight requirements and gave NASA early insight into partner designs and approaches.

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The current and final stage of the acquisition lifecycle began with the award of two FAR-based fixed-price CCtCap contracts in September of 2014 for the development, test, evaluation, and final NASA certification of a Crew Transportation System. CCtCap contracts include demonstration of crewed ISS missions and subsequent service missions, assuming sufficient budget and technical progress. The contracts also include a Special Studies Services section for special studies, tests, or analyses, as needed by NASA to reduce Program risk. NASA's FAR based fixed-price contracts during this phase allow for compliance with NASA's existing mission and safety requirements for transporting crew to and from ISS.

NASA measures partner progress against fixed-price milestones, based on performance of agreed upon entrance and success criteria. Although the content varies by partner, milestones are designed to demonstrate progress toward completing crew transportation system development, such as risk reduction testing, design reviews, hardware development, and flight tests. The Government pays for milestones only after completion. Also, the partners will own and operate their completed transportation systems.

Major Contracts/Awards

Element	Vendor	Location (of work performance)
CCDev2 (follow-on)	Blue Origin	Kent, WA
CCtCap	Boeing	Houston, TX
CCiCap	Sierra Nevada	Louisville, CO
CCiCap/CCtCap	SpaceX	Hawthorne, CA

Independent Reviews

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	Aerospace Safety Advisory Panel	Feb 2021	Provide independent assessments of safety to the NASA Administrator	No new formal recommendations or findings	May 2021
Other	NASA Advisory Council	Jan 2021	Provide independent guidance for the NASA Administrator	No new formal recommendations or findings	May 2021

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Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	Standing Review Board (SRB)	Nov 2018	Assess funding and schedule reserve requirements, cost effectiveness during development and impacts to future sustaining operations, and efforts required for successful program implementation	While the SRB identified some risks, issues, and concerns, it found that the program has made good progress in the last year proceeding towards the production and test phase of the program	Not currently scheduled

Historical Performance

The tables below represent historical performance through FY 2020, as of September 30, 2020, and only includes funded milestones.

Commercial Orbital Transportation System (COTS) Partner	No. of Milestones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
SpaceX	40	396.0	40	396	100%	100%	Completed
Orbital	29	288.0	29	288.0	100%	100%	Completed
Rocketplane-Kistler	15	206.8	3	32.1	20%	16%	Terminated

CCDev1 Partner	No. of Milestones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Sierra Nevada	4	20	4	20	100%	100%	Completed
Boeing	36	18	36	18	100%	100%	Completed
Blue Origin	7	3.7	7	3.7	100%	100%	Completed
Paragon Space Development Corporation	5	1.4	5	1.4	100%	100%	Completed
United Launch Alliance	4	6.7	4	6.7	100%	100%	Completed

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CCDev2 Partner	No. of Milestones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Sierra Nevada	13	105.6	13	105.6	100%	100%	Completed
Boeing	15	112.9	15	112.9	100%	100%	Completed
SpaceX	10	75	10	75	100%	100%	Completed
Blue Origin	10	22	10	22	100%	100%	Completed

CCiCap Partner	No. of Milestones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Sierra Nevada	11	227.5	11	227.5	100%	100%	Completed
Boeing	20	480	20	480	100%	100%	Completed
SpaceX	15	460	15	460	100%	100%	Completed

CCtCap Partner	No. of Milestones	Total Potential Value (in $M)*	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Boeing	47	2199.3	38	1817.5	81%	83%	Active
SpaceX	32	1230.5	32	1230.5	100%	100%	Active

** Total Potential Value cited is limited to the design, development, test, and evaluation portion of the contracts. Excludes post certification mission, special studies milestones, and milestones not deemed a prerequisite for certification.*

SPACE COMMUNICATIONS AND NAVIGATION

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Space Communications Networks	478.1	398.3	**390.5**	378.6	374.2	374.0	373.8
Space Communications Support	120.7	107.7	**132.1**	111.2	109.6	109.9	110.1
Total Budget	**598.7**	**506.0**	**522.6**	**489.8**	**483.8**	**483.8**	**483.8**
Change from FY 2021			**16.6**				
Percentage change from FY 2021			**3.3%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Deep Space Network 34-meter antenna near Madrid, Spain.

NASA’s Space Communications and Navigation (SCaN) capabilities provide mission-critical communications and navigation services required by all NASA human and robotic missions. These missions range from high-altitude balloons, to the International Space Station (ISS) in low-Earth orbit (LEO), to Voyager 1, which is the most distant manmade object, currently more than 14 billion miles from Earth. SCaN retrieves science, spacecraft, and crew health data for all these missions, uploads commands, and sends data to individual control centers. Navigation services determine the precise location of a satellite so it can control its trajectory through space, gather valid scientific data, and avoid space debris or other spacecraft.

Without services to move data and commands between spacecraft and Earth, space assets worth tens of billions of dollars would be little more than orbital debris. SCaN provides secure, reliable, and adaptable communication services to NASA missions, as well as external customers who rely on space communications services daily. External customers include foreign governments, international partners, commercial entities (e.g., launch service providers), and non-NASA U.S. missions to which SCaN provides services on a reimbursable basis.

Working with the Goddard Space Flight Center (GSFC), SCaN completed a restructure/reorganization of the Goddard managed Space and Near Earth Networks. The two networks were combined into one new network called the Near Space Network (NSN). SCaN created the Advanced Communications Capabilities for Exploration and Science Systems (ACCESS) organization to be responsible for the operation and maintenance of all Government assets, including Direct-To-Earth (DTE) ground stations and the TDRS infrastructure. The NSN will use both Government-owned and operated capabilities and commercial capabilities to provide communications services to NASA users. This change facilitates better alignment with the large and growing commercial market, allowing SCaN to leverage industry innovations and make better use of already-ubiquitous commercial services. NSN will primarily support

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LEO and Earth Science missions, while the Deep Space Network (DSN) will focus its support on deep space missions, utilizing its global network of large antenna ground assets. The NSN supports missions using a mixture of commercial and government owned ground assets, along with relay spacecraft which allow for near real-time, low latency support, including support for human spaceflight operations.

Both networks will support Commercial Crew providers, launches of the Space Launch System (SLS), and the upcoming Artemis lunar missions.

ACCESS will be responsible for maintaining and operating both the space relay component and the remaining ground-based Government assets. This will allow SCaN to offer 24/7 global telecommunication services via the NSN for telemetry, tracking, and command of LEO spacecraft. The relay component is comprised of a constellation of Tracking and Data Relay Satellites (TDRS) and various ground terminals.

NSN supports an extensive and diverse customer base from suborbital to Lagrangian orbits by providing direct-to-ground data transfer from spacecraft at S, X, and Ka-band frequencies up to data rates of gigabits per second. The NSN utilizes a mix of ground antennas owned by NASA, universities, and private companies to maximize the network's geographic coverage. Additionally, NSN supports users that require low latency global coverage by using TDRS. Such users include the Hubble Space Telescope and ISS (for which the NSN provides constant communication), as well as commercial and international partner servicing vehicles. The newly created Commercialization, Innovation, and Synergies (CIS) office at GSFC will lead the way to ensure that SCaN eventually migrates completely from Government owned assets by ensuring constant engagement with private industry to foster new technology and capabilities. A key part of this migration will include commercial services that will be demonstrated in a series of pilot programs managed by the Communications Services Program.

DSN is a keystone of NASA's exploration of the solar system. It provides reliable, high-performance, and cost-effective telecommunications and tracking services to planetary missions. The DSN is an international network of 34-meter and 70-meter antennas that supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the universe. The DSN currently consists of three deep space communications facilities placed approximately 120 degrees apart around the world: at Goldstone, in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia.

NASA uses the SCaN-provided Goldstone Solar System Radar to track and characterize near-Earth objects that pass within nine million miles of Earth and to determine their orbits for use by the Science Mission Directorate’s (SMD) Planetary Science Division in assessing the probability of a possible collision with Earth. The installation of new radar equipment, planned for completion in FY 2025, will extend the radar's capability to 42 million miles, which increases the time to develop viable solutions to avoid orbital collision for planetary defense.

Both networks require maintenance, replenishment, modernization, and capacity expansion to ensure continued operation and to meet new mission needs. Human exploration of the Moon requires communications to support video, telemedicine, and advanced instruments that locate and identify exploitable resources on the Moon (e.g., subsurface ice). SCaN is engaged in the planning of the Artemis Program's lunar missions to ensure that communications and navigation capabilities meet mission needs.

Space Communications Support provides efficient planning and integration of current and future network capabilities to meet customer mission needs while reducing costs. It provides systems engineering, architecture planning, communications data standards, technology development, testbeds for future capabilities, radio frequency spectrum management, and navigation policy.

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Operating in space requires significant international coordination. SCaN participates in several international organizations that coordinate compatibility and interoperability in space communications and navigation. SCaN's standards development and management activity maintains a portfolio of international interoperability standards that enable joint space missions with other nations. SCaN also promotes new technologies and provides technical leaders and domain experts who ensure appropriate space communication standards are available to NASA missions. The research and technology avenues within SCaN aim to predict the needs of future communications missions in a manner that will yield initiatives with performance advancements and reduced costs.

Amid soaring demand for wireless broadband, such as 5G mobile services, radio frequency spectrum management has become increasingly critical to the world's spacefaring nations. SCaN coordinates nationally and internationally to protect radio frequencies critical to NASA space and science missions.

For more information, go to http://www.nasa.gov/scan

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

SPACE COMMUNICATIONS NETWORKS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**478.1**	**398.3**	**390.5**	**378.6**	**374.2**	**374.0**	**373.8**
Change from FY 2021			**-7.8**				
Percentage change from FY 2021			**-2.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Deep Space Network's DSS-43 70-meter Antenna near Canberra, Australia.

The Space Communications and Navigation (SCaN) Program networks provide 24/7, global, near-Earth and deep space communications capability, plus tracking and navigation services to more than 100 NASA programs and other U.S. Government, international civil space agencies, and commercial missions. This capability ensures reliable and near-continuous communication with NASA and customer spacecraft. While the Deep Space Network (DSN) remains unchanged in its role and organization, the Space Network (SN) and Near Earth Network (NEN) have reorganized into the Near Space Network (NSN) to better align with commercial cislunar (i.e., between Earth and Moon) activity. Managed from the Goddard Space Flight Center (GSFC), the NSN enables the utilization of a reliable, robust, and cost-effective set of commercial services in which NASA is one of many customers. Existing SN and NEN Government assets are maintained and operated by the newly formed Advanced Communications Capabilities for Exploration and Science Systems (ACCESS) organization and are also utilized by the NSN. To aid with the infusion of future commercial capabilities into the NSN, a new Commercial Services, Innovation, and Synergies (CIS) office at GSFC has also been created.

SCaN provides services both to new spacecraft that are increasingly powerful, complex, and capable of acquiring an expanding amount of mission data, as well as to legacy missions such as the two Voyager spacecraft launched more than 40 years ago that are still returning valuable science data. NSN and DSN support a different set of customer requirements for spacecraft orbit, signal strength, and real-time coverage. Both networks provide service to customer missions at a proficiency above 99 percent. To continue providing this level of support, each network requires regular maintenance, modernization and capacity expansion, and IT security upgrades to combat the ever-growing cybersecurity threats toward U.S. assets.

NASA's space communications networks provide ongoing services to Agency and customer missions, averaging approximately 600 tracking passes per day. Without these capabilities, customer missions such

SPACE COMMUNICATIONS NETWORKS

as Parker Solar Probe (PSP), Joint Polar Satellite System (JPSS), Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight), Ice, Cloud and land Elevation Satellite (ICESat-2), Mars Perseverance, Commercial Crew, and Transiting Exoplanet Survey Satellite (TESS) would not be able to deliver key science data or advance NASA's exploration goals. The networks will support the Artemis Program as the Agency aims toward the goal of landing the first woman and first person of color on the Moon. Human exploration of the Moon requires communications to and from the Moon to support video, telemedicine, and advanced instruments to locate and identify exploitable resources on the Moon, such as subsurface ice.

The DSN, which has been in operation for more than 50 years, provides reliable, high-performance, and cost-effective communication and tracking services to approximately 35 NASA and non-NASA missions beyond geosynchronous orbit (i.e., more than 22,000 miles above the Earth’s surface). It is a worldwide network of 34-meter and 70-meter antennas that supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the universe. The DSN currently consists of three deep-space communications facilities located approximately 120 degrees of longitude apart around the world: at Goldstone in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. The site separation ensures that any spacecraft in deep space can always communicate with at least one DSN facility as the Earth rotates and the spacecraft continues to move along its trajectory. Additionally, NASA uses the Goldstone Solar System Radar (GSSR) capability to track and characterize near-Earth objects that pass within nine million miles of Earth. The orbits of the near-Earth objects are determined and utilized by the Science Mission Directorate’s (SMD) Planetary Science Division to assess the probability of a conjunction between the object and the Earth. Investments in GSSR, such as installation of a new klystron, are underway to increase its capability to support planetary defense research.

In FY 2020, SCaN started a Deep Space Network "Road to Green" study to determine the long-term maintenance and network health requirements to maintain reliability and meet future Agency needs. The initiative will assess the current state of the network, evaluate operational risks and budget requirements, and address the findings and recommendations in the 2020 Office of Inspector General (OIG) report "NASA’s Planetary Science Portfolio." The ongoing DSN Aperture Enhancement Project (DAEP) is modernizing and upgrading the DSN to expand capacity, improve flexibility to support customer missions, and reduce operations and maintenance costs. The Project is augmenting the capabilities of the existing 70-meter antennas by completing arrays of four 34-meter Beam Waveguide (BWG) antennas at each of the three DSN facilities in California, Spain, and Australia by 2026. The BWG antennas allow for antenna arraying and are less complicated, more flexible, and more cost effective to maintain than conventional antennas. Antenna arraying combines the signals received by two, three, or four 34-meter antennas to offer performance beyond that of one 34-meter antenna and up to the equivalent of a 70-meter antenna. When missions do not require all four 34-meter antennas to be arrayed, the 34-meter antennas can support multiple spacecraft individually, offering greater flexibility than a single 70-meter antenna. The new 34-meter antenna construction efforts use Construction of Facilities funds appropriated in NASA’s Construction and Environmental Compliance and Restoration account. As part of future DAEP requirements, SCaN plans to install an 80-kilowatt transmitter on one 34-meter BWG antenna per DSN facility to match the transmit capabilities of a 70-meter antenna. Thus, 70-meter antenna capability redundancy will be achieved via arraying of 34-meter BWG antennas for signal receipt and via an 80-kilowatt transmitter on one 34-meter BWG antenna per complex for signal transmission.

NSN will provide near-continuous communication services to users from ground level through low-Earth orbit (LEO) and up to cislunar distances via commercial and government assets. NSN is the prime user interface for current and future missions to ensure compatibility, complete pre-mission planning, and provide communication services during mission operations. NSN will act as the Government interface to the commercial service providers located in the United States and internationally.

NASA's Tracking and Data Relay Satellites (TDRS) are a system of Government-owned, contractor-operated communications satellites in geosynchronous orbit matched with a set of space-to-ground link terminals located at NASA's White Sands Complex in New Mexico, Guam, and in Blossom Point, MD. As part of the NSN, NASA will continue to maintain any remaining Government-owned ground stations necessary to communicate with geosynchronous, lunar, and highly elliptical Earth orbits, as well as spacecraft launched from certain suborbital launch locations. The NASA-owned ground stations are currently located at White Sands in New Mexico; U.S. McMurdo Antarctic Station; and Wallops Flight Facility (WFF) in Chincoteague, VA.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

Consistent with prior years' successes, the three (currently two) legacy space communications networks (DSN, SN, and NEN) provided approximately 245,000 tracking passes while maintaining a high level of proficiency of approximately 99.1 percent or higher. A proficiency of 95 percent is required by the SCaN Program Commitment Agreement.

NSN continued transition and integration activities in preparation for the completion of the Space Network Ground Segment Sustainment (SGSS) project in FY 2021. As a result of COVID-19 imposed site closures, training and minor testing continued through remote access of the Maintenance and Training Facility (MTF) terminal, but significant testing on the SGSS system was delayed. SGSS was able to complete the initial Operations Readiness Review (ORR-1) remotely in April 2020, a milestone on the critical path to Final Acceptance in FY 2021. As on-site access resumed in August 2020, the SN was able to support General Dynamics system release regression testing which determines software functionality in preparation for the initial operation's capability (IOC) test readiness, a milestone necessary to enable ORR-2.

NSN continued Ka-band upgrades by installing the first LEO tracking Ka-band antenna at the Alaska Satellite Facility (ASF). This upgrade will provide data rates as much as 10 times higher than previous systems. The improved data rates are a major advancement in data transfer capability that will benefit future polar-orbiting missions, such as the NASA Indian Space Research Organization (ISRO) Synthetic Aperture Radar (NISAR) mission. In September 2020, the antenna completed the site acceptance testing (SAT) and is currently responding nominally.

DSN is nearing final check out of the Three Links per Operator (3LPO) capability after successfully completing Network-Wide Downtime Tests on August 6, 2020 and September 23, 2020 and is on plan for transition in late FY 2021. The 3LPO capability is the final phase of the Follow-the-Sun Operations task that further increases operational efficiency of the network. 3LPO allows for the operation of additional assets, such as the two new 34-meter BWG antennas being completed at the Madrid, Spain, DSN complex, without increasing operational costs.

The Madrid Deep Space Communications Complex (MDSCC) assumed antenna and facility maintenance activities for Deep Space Station (DSS)-56. DAEP began installation, integration, and test activities on

SPACE COMMUNICATIONS NETWORKS

DSS-53 with facility construction nearing completion. The DSS-53 substation has been tested, certified, and is supplying power. Pavement, fencing, and gates are being finalized. At completion, these DSN antennas at MDSCC and future planned DAEP antennas will transmit and receive data across a wide range of radio frequencies for deep space communication with interplanetary robotic spacecraft. The additional capacity and enhanced capabilities will support the expected growth of deep space missions launching over the next decade.

WORK IN PROGRESS IN FY 2021

SCaN Networks will continue providing communications, tracking, and navigation services to more than 100 NASA, U.S. Government, international civil space agencies, and commercial missions at a 95 percent or higher proficiency rate. This includes providing launch support on all new human spaceflight, Commercial Launch Vehicle (CLV), and robotic missions. DSN and ACCESS will both continue to identify and implement more advanced and efficient methodologies and processes, as well as upgrade equipment to achieve improvements over historical operational efficiencies and goals.

NSN will complete software training on the SGSS system following the level 6 test completion. SGSS will support the IOC and will complete transition to operations for Main Mission Antenna-1 (MMA-1 the first operational SGSS terminal. On April 12, 2021 General Dynamics support for IOC testing and operations of the SGSS Project was completed and contract closeout activities began.

SCaN will implement Delay Tolerant Networking (DTN) Operations in support of future missions, including the Artemis Program. DTN completed phase one IOC in spring 2021. The phase two cislunar Operating Capability will begin in summer 2021.

DAEP successfully delivered DSS-56 to operations at MDSCC on January 21, 2021 with a virtual ribbon cutting ceremony held on January 22, 2021. DSS-53 major construction has been completed with the antenna undergoing integration and testing (I&T) activities through the end of FY 2021 and into Q1 FY 2022. DSS-53 is scheduled for delivery to operations in January 2022. During Q2 FY 2021, contracts were awarded, and site preparations began for DSS-23 at the Goldstone Deep Space Communications Complex (GDSCC). DSN will undergo a DSS-65 downtime maintenance period in late FY 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

SCaN Networks will continue to provide communications, tracking, and navigation services to more than 100 NASA, U.S. Government, international civil space agencies, and commercial missions at a 95 percent or higher proficiency rate. This includes launch support on all new human spaceflight, CLV, and robotic missions. DSN and NSN will both continue to identify and implement methodologies and processes, as well as upgrade equipment, to achieve improvements over historical operational efficiencies and goals.

NSN will begin transitioning SGSS to Operations. After significant impacts from COVID-19 restrictions, external delays, and operational constraints, SGSS has adjusted the contractor minimum success criteria to include IOC with Generation-2 TDRS spacecraft and the SGSS required mission set. SGSS MMA-2 through 6 will transition to an NSN sustainment effort.

NSN will initiate an implementation plan to fully commercialize the direct-to-Earth (DTE) communications services for LEO customers. NASA will be able to more fully leverage the evolving capabilities of the private sector while still ensuring reliable support of user communication and navigation requirements through a robust, interoperable, and comprehensive network.

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The DSN and NSN will complete network upgrades in support of lunar missions as human and robotic exploration of the Moon will require extensive communications to and from the Moon including support for video, telemedicine, and advanced instruments. The DSN Lunar Exploration Upgrades (DLEU) effort provides capability upgrades to the DSN 34-meter subnet to support enhanced communications requirements for Artemis. Specifically, two antennas per complex will have K-band (22.5 GHz) uplinks and will support 20 Mbps data rates modulation. Downlink processing will be upgraded through the use of improved error-correcting decoding for downlink data rates up to 150 Mbps and data delivery from a deep space complex to a mission operations center (MOC) to allow real-time video from the Moon. The Lunar Exploration Ground System (LEGS) will provide additional capacity in support of Lunar Exploration and other missions while preserving DSN capacity for Mars and outer planet missions. The DLEU task is anticipated to start compatibility testing with Gateway in early FY 2022.

PROJECT SCHEDULE

The table below includes significant SCaN network milestones in FY 2021 and FY 2022.

Date	Significant Event
Q1 FY 2021	DAEP DSS-56 Delivery Review
Q2 FY 2021	DAEP DSS-56 Operational
Q2 FY 2021	DAEP DSS -53 Subsystem Acceptance Testing Complete
Q3 FY 2021	DTN Phase 1 IOC
Q3 FY 2021	DAEP DSS-23 Excavation Start
Q4 FY 2021	DSN DSS-65 Downtime
Q4 FY 2021	DAEP DSS-53 System Performance Test/Project Interface Test Complete
Q4 FY 2021	SGSS IOC for MMA-1
Q1 FY 2022	DAEP DSS-53 Operational
Q1 FY 2022	DLEU Compatibility testing with Gateway
Q3 FY 2022	LEGS Preliminary Design Review (PDR)

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Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
ACCESS	ACCESS provides the project management and subject matter expertise required to operate, maintain, and sustain assigned Government Owned / Contractor Operated ground- and flight-based systems and assigned facilities in order to provide NASA, other Government agencies, and partners optimal communications and navigation mission services through its alignment to and interfaces with the NSN.	Provider: ACCESS Project Office Lead Center: Goddard Space Flight Center (GSFC) Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A
NSN	NSN provides the project management and subject matter expertise required to provide continuous LEO communication services to users via commercial and Government assets and providers. NSN will act as the Government interface to the commercial service providers located in the U.S. and internationally.	Provider: NSN Project Office Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A
CIS	CIS functionally will provide project management leadership and subject matter expertise required to identify opportunities, extend invitations, implement collaborative solutions, and nurture diverse relationships in order to leverage commercial capabilities across the space communications industry.	Provider: CIS Project Office Lead Center: GSFC Performing Center: N/A Cost Sharing Partner(s): Non-NASA customers	N/A
DSN	DSN provides communication and navigation services to customer missions in deep space.	Provider: DSN Project Office Lead Center: Jet Propulsion Laboratory (JPL) Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A

SPACE COMMUNICATIONS NETWORKS

Element	Description	Provider Details	Change from Formulation Agreement
SGSS	Replace outdated and deteriorating ground systems at Space Network ground terminals.	Provider: SGSS Project Office Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Non-NASA U.S. Government partners	N/A

Acquisition Strategy

The major acquisitions for the networks are in place. NASA uses reimbursable, international, and barter agreements, as well as competitive procurements. NASA's JPL provides the management of the DSN. The Communications Services Program (CSP) is managing pilot programs for commercial communications services for NASA missions. If these pilots are completed successfully, subsequent operational services would be transitioned from CSP to SCaN.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
DSN	JPL/California Institute of Technology	Pasadena, CA
NSN	Peraton	Herndon, VA
SGSS	General Dynamics Mission Systems	Scottsdale, AZ

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
SCaN	Standing Review Board	FY 2021	Program Implementation Review with focus on interdependencies, implementation planning, and risk gaps or shortfalls.	Success criteria met; major strengths, observations, concerns, and issues were identified	FY 2026

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**120.7**	**107.7**	**132.1**	**111.2**	**109.6**	**109.9**	**110.1**
Change from FY 2021			**24.4**				
Percentage change from FY 2021			**22.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The Laser Communications Relay Demonstration payload, shown here in the clean room at GSFC, will be hosted and flown on a U.S. Space Force technology satellite in June 2021. LCRD will be communicating with two dedicated optical ground stations in California and Hawaii and eventually with a test payload on ISS.

The Space Communications Support project supports NASA and the Space Communications and Navigation (SCaN) program through communications and navigation planning, management, and technology development.

Evolving space communication systems will transform future NASA mission capabilities. SCaN’s technology development effort invests in leading-edge communications technologies that will enable, improve, and mature available spacecraft communication and navigation technologies for both ground and space-based use. Technology items are created and tested in laboratory settings before they are taken into space for further testing. Demonstrable technologies have proven themselves in laboratory tests and have begun experimentation and testing in space. Key technologies that SCaN is currently developing include wideband tunable user terminals and software-defined radios for use with commercial satellite communication (SATCOM) providers and cognitive networking. These technologies will demonstrate use of a common radio to provide cross-service support for NASA, commercial, and Department of Defense (DoD) networks.

Another key space communications technology is optical (i.e., near-infrared laser) communications. NASA's Space Technology Mission Directorate (STMD) and SCaN are jointly developing the Laser Communications Relay Demonstration (LCRD), with SCaN funding the ground operations and STMD funding the spacecraft payload. LCRD will be NASA's first long duration optical communications project and will demonstrate a set of technologies that could be used on future missions. Transmitting a

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

30-centimeter resolution map of the entire Martian surface (at one bit/pixel) would take current radiofrequency (RF) systems two years, while a laser communications system operating at projected capacity would be able to complete transmission in nine weeks, a nearly 12 times reduction in task time. Other LEO optical technology demonstrations include: an optical user terminal called the Integrated LCRD Low-Earth Orbit User Modem and Amplifier Terminal (ILLUMA-T), that will fly on ISS and communicate to the LCRD relay, demonstrating a 1.244 gigabits per second relay link in 2022; Optical to Orion (O2O), a terminal on the Orion spacecraft that will provide 260 megabits per second of bandwidth, a rate not available with the current Orion communications system; and the TeraByte InfraRed Delivery (TBIRD), a CubeSat payload capable of delivering 200 gigabits per second from LEO to Earth. The TBIRD payload technology is based on 1550 nanometer commercial components used for terrestrial fiberoptic connections.

Deep Space Optical Communications (DSOC) is another critical technology being developed through a joint SCaN/STMD collaboration. DSOC will conduct optical communications from deep space, demonstrating key capabilities related to pointing accuracy and implementation of the High Photon Efficiency signaling standard. SCaN sponsors the ground network, including the five-kilowatt uplink beacon at the JPL Table Mountain facility and a superconducting single-photon-sensitive nanowire detector and real time receiver at the Palomar Observatory in California. DSOC is currently on track to be integrated onto the Psyche planetary science mission, scheduled to launch in FY 2022.

SCaN continues to invest in the Deep Space Atomic Clock (DSAC) technology to mature designs for future mission use. DSAC technology allows a spacecraft to calculate its own timing and navigation data in real-time. With existing technology, a spacecraft can navigate autonomously to the top of the Martian atmosphere with uncertainty of one to two kilometers. It is expected that DSAC will enhance deep space navigation and reduce positional uncertainty to 100 meters, an improvement factor of 10 to 20 over today's capabilities, which will save fuel and enable more accurate scientific measurements. DSAC's improved long-term stability will also enhance on-board, autonomous navigation for future robotic and crewed missions, and enable investigations of fundamental physics (e.g., relativity).

SCaN is researching opportunities to leverage investments, experience, and accomplishments from optical communications to build foundational capabilities needed for future spaced-based quantum communications and networking.

SCaN is an active member of multiple international organizations (e.g., Interagency Operations Advisory Group [IOAG], Consultative Committee for Space Data Systems [CCSDS]) that coordinate space communications and navigation compatibility and interoperability, as well as the development of communications and data systems standards for spaceflight. Space communications data standards enable the world space agencies and industry to interoperate and provide communications and/or backup communications services with each other, reducing mission risk and reducing or eliminating the need to build and deploy their own space and ground assets. These standards provide significant cost savings to NASA without reducing services or coverage to space missions and serve as a compatibility and interoperability guide for industry.

Electromagnetic spectrum is a valuable and limited natural resource that all NASA missions and most operations require for communications, navigation, remote sensing, and data services in the areas of Earth science, space science, human space exploration, and aeronautical research. All forms of wireless communication systems used by the Federal Government or by commercial entities use the electromagnetic spectrum, so the spectrum must be carefully controlled and coordinated. SCaN is

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

responsible for ensuring access to the portions of the electromagnetic spectrum necessary to support NASA's mission needs. This responsibility includes ensuring interference-free operations and bandwidth availability. SCaN serves as the Agency's Spectrum Manager and provides NASA representatives to advocate for NASA's requirements at domestic spectrum governing bodies, including the Interdepartment Radio Advisory Committee (IRAC) at the National Telecommunications and Information Administration (NTIA) within the Department of Commerce. Internationally, SCaN participates as NASA's representative at multiple technical forums, the most important of which are the World Radiocommunication Conferences (WRCs), which convene every three to four years and include delegates from more than 150 nations. NASA's delegates play leading roles in several key WRC working groups and regional committees throughout the year. Among the purposes of these conferences is to review and revise the International Telecommunication Union's Radio Regulations, which govern the international use of the electromagnetic spectrum. In both the domestic and international arenas, NASA continues to engage with the commercial sector to identify more flexibility in the use of spectrum resources that will meet mission objectives for the entire space community.

NASA spacecraft in Earth Orbit and up to halfway to the Moon already employ Global Positioning System (GPS) signals for precision positioning, navigation, and timing (PNT), allowing NASA to minimize the network communications and tracking burdens while maximizing spacecraft autonomy and operations. SCaN is leading NASA efforts to conduct flight experiments to validate the use of GPS, and other Global Navigation Satellite System (GNSS), signals to provide improved PNT services throughout cislunar space. SCaN also manages NASA’s policy on GPS use, represents NASA at the U.S. PNT Executive Committee, works with the Air Force to improve GPS capabilities, and leads U.S. efforts at the United Nations International Committee on GNSS (ICG) to develop interoperable multi-GNSS capabilities to support space users. Another key role is working with other U.S. departments and agencies in mitigating threats to the GPS spectrum, and protecting GPS users from data-spoofing (GPS cybersecurity). SCaN manages two advisory boards, the National PNT Advisory Board and the National Space Council (NSpC) Users' Advisory Group (UAG). SCaN continues in its role as Designated Federal Official (DFO) and Executive Director of the National Space-Based PNT Advisory Board, which reports to the National Space-Based PNT Executive Committee (EXCOM). The PNT EXCOM is co-chaired by the Deputy Secretary of Defense and the Deputy Secretary of Transportation.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

In late FY 2019, NASA initiated a wideband RF risk reduction initiative. The wideband effort will take two years to design, develop, and conduct benchtop testing of a prototype tunable wideband terminal. The task will integrate NASA, commercial, and DoD waveforms into a common platform to demonstrate technology feasibility and conduct laboratory characterization testing.

SCaN continued collaborations with STMD. In September 2020, LCRD passed Key Decision Point (KDP)-D and progressed toward conducting the ORR scheduled for later this year. DSAC completed its first year of operations in August 2020, successfully meeting all level one requirements.

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Formulation	Development	Operations

SCaN conducted component testing and integration for the ILLUMA-T, which will test and mature optical technologies in space. The Systems Design Review for O2O Ground Terminal was completed in September 2020.

The DSOC optical ground station project completed its Critical Design Review (CDR). Assembly and test of the ground laser transmitter and ground laser receiver continued in FY 2020 and is on track to start integrated system testing in FY 2021.

SCaN continued pre-formulation quantum communications studies focusing on technology development and maturation. SCaN and the National Institute of Standards and Technology jointly sponsored a workshop on space quantum communications and networks, hosted by the Space Sciences Laboratory at the University of California – Berkeley. This workshop brought together over 70 esteemed technical and program leaders from academia, industry, and Government agencies. This group determined which critical quantum technologies for space communications and networking should be developed and matured, and developed Quantum technology roadmap recommendations.

In November 2019, SCaN participated in the U.S. delegation, led by the Department of State, to the WRC-2019 in Sharm el-Sheikh, Egypt, to ensure continued access to the RF spectrum supporting NASA's mission requirements, U.S. Government space interests, and the U.S. commercial space community. SCaN continued coordinating spectrum use for all domestic and international deep space missions, as well as NASA near-Earth missions.

SCaN supported the U.S. PNT Advisory Board and the NSpC UAG, both of which were very active in FY 2020.

NASA engaged key GNSS providers to develop multi-GNSS flight receivers (to augment the capabilities GPS already provides). The objective is to incorporate GPS (and potentially other GNSS such as Galileo) measurements with other nav sources (e.g., inertial, X-ray, optical) through sensor fusion and on-board filtering. The GPS-Galileo Receiver on ISS (GARISS) Project (2017-2019) developed and tested a combined GPS-Galileo STRS-compliant waveform for future space software defined radios (SDR). This was followed by the GPS/Galileo Receiver for Human Exploration Directorate (GARHEO) Project, which flew a GPS-Galileo receiver flight experiment in November 2019 on the Space Loft 14 sounding rocket to record the performance of a GPS-Galileo receiver under highly dynamic conditions.

WORK IN PROGRESS IN FY 2021

SCaN and the Communications Services Program are transitioning NASA's future near-Earth missions towards the use of commercial space relay services. There are plans for a benchtop ground demonstration in FY 2021 that includes the NSN and at least one commercial provider. SCaN continues to develop a prototype RF wideband ground terminal to support low-latency space relay links across NASA, commercial, and DoD assets and provide future NASA near-Earth missions capability to roam and utilize potential commercial relay services.

NASA continues progressing toward LCRD's launch, currently scheduled for June 2021. LCRD ORR is scheduled in May 2021. The LCRD Optical Ground Station (LOGS), which supports high-bandwidth bi-directional GEO-ground optical links is continuing testing and development and will be operational in FY 2021.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

ILLUMA-T will implement laser communications for NASA with the demonstration of operational utility between a user terminal on ISS and Earth using LCRD as the relay. The first component hardware deliveries have been made and the remainder was delivered in Q2 FY 2021. Integration and testing of the electro-optical components on the Flight Sled structure will begin Q3 FY 2021 at Massachusetts Institute of Technology Lincoln Laboratory (MITLL) with the integrated terminal delivery in Q4 FY 2021 to Goddard Space Flight Center (GSFC) for final environmental testing prior to shipment to KSC in Q3 FY 2022.

TBIRD will demonstrate a new approach for large volume data delivery of 5-10 terabytes per day from LEO to a single low-cost optical ground station. TBIRD will enable an optical communications capability that is more compact and less expensive than existing optical communications technologies. CDR was completed in early FY 2021 to prepare for a CubeSat demonstration in FY 2022.

SCaN continues efforts to mature DSAC technologies and improve hardware designs.

SCaN completed preliminary assessment of the TRL and risk levels of critical space and ground-based technologies and continued to mature key quantum technologies.

Through participation in the IOAG and CCSDS, SCaN will continue international coordination of space communication and navigation compatibility and interoperability, as well as the development of internationally interoperable space communication and data system standards. NASA missions use internationally interoperable standards to lower the life cycle costs and risks and provide innovative capabilities for current and future missions. Key progress is planned for optical and space internetworking standards. The IOAG will coordinate with other parts of NASA, industry, and international partners on space communications and navigation requirements.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

SCaN will continue LCRD payload operations and manage experiments, including an experiment to verify collection of metric tracking data from optical links (termed Optimetrics) post launch in FY 2021. SCaN will operate and maintain the LCRD payload through the LCRD Mission Operations Center (LMOC) after the LCRD commissioning and in support of LCRD mission demonstrations through the prime demonstration operations period of two years post launch. SCaN will manage an LCRD experiment program and conduct payload demonstrations.

NASA will launch the ILLUMA-T optical demonstration payload to ISS in FY 2022. This will demonstrate data transfer between low-Earth orbit and the ground through a geosynchronous relay (LCRD).

SCaN will develop a Ground Terminal (GT) as an element of the O2O Artemis II to prepare for operations at the Optical Communication Telescope Laboratory. The GT will support the Orion space terminal with a minimum downlink data rate of approximately 80 megabits per second and an uplink data rate of approximately 20 megabits per second.

TBIRD launch is anticipated in December 2021. This will demonstrate a low-cost burst data delivery architecture and protocols, leveraging high-rate commercial off the shelf telecom equipment for 200 gigabits per second data delivery in a CubeSat form-factor. TBIRD will demonstrate optical high data-rate capabilities designed for small payloads (a 200 gigabits per second package will be in the ~2U range for Size) that require reduced size, weight, and power (SWaP).

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

NASA will complete the DSOC ORR prior to launch currently scheduled for FY 2022.

DSAC follow-on technology maturation will leverage progress of the TRL-7 DSAC technology demonstration mission and data collected from its second year of flight operation to design a commercially manufacturable version of the clock in a reduced SWaP form-factor suitable for a wide-range of space missions.

SCaN will continue quantum entanglement pre-formulation and technology maturation focused on ground-based research and development.

NASA will leverage the record setting Navigator weak-signal tracking GPS receiver technology to develop a small form-factor, multi-GNSS receiver (e.g., GPS/Galileo) for use in cislunar and lunar space and complete TRL-6 testing in FY 2022. This will provide reliable, real-time, autonomous, onboard navigation and timing for lunar users by leveraging the always-on GNSS assets in orbit around the Earth. This receiver will reduce the tracking burden on Earth-based networks, which are a finite resource, for cislunar and lunar users, and serve as a significant risk reduction for commercial user operations. SCaN is also leading NASA's effort, in partnership with the Italian Space Agency and the European Space Agency (ESA), to conduct flight experiments of combined GPS-Galileo receivers at lunar distance.

Project Schedule

The table below includes significant Space Communication Support milestones in FY 2021 and FY 2022.

Date	Significant Event
Q1 FY 2021	DSOC Flight CDR/Ground PDR
Q2 FY 2021	LCRD OGS-2 Testing and Integration completed
Q2 FY 2021	O2O Ground Segment (Multi part) SDR
Q3 FY 2021	LCRD Launch
Q3 FY 2021	O2O Testing and Integration Complete
Q3 FY 2021	Ship O2O for Integration on ORION
Q1 FY 2022	TBIRD Launch
Q2 FY 2022	ILLUMA-T Testing and Integration Complete
Q3 FY 2022	DSOC ORR
Q4 FY 2022	ILLUMA-T Launch

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

Project Management & Commitments

The SCaN program office at NASA Headquarters manages Space Communications Support functions.

Element	Description	Provider Details	Change from Formulation Agreement
Space Communications Support	Provides critical communication and navigation architecture planning, systems engineering, technology development, standards development and management, spectrum management, and policy and strategic communications for NASA.	Provider: NASA Responsible Center: Headquarters (HQ)	N/A

Acquisition Strategy

Space Communications Support functions use multiple small contracted efforts, most of which are support services functions.

MAJOR CONTRACTS/AWARDS

None.

HUMAN SPACE FLIGHT OPERATIONS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**99.9**	**97.8**	**101.8**	**104.8**	**105.3**	**105.4**	**105.4**
Change from FY 2021			**4.0**				
Percentage change from FY 2021			**4.1%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

NASA Astronaut Christina Koch is shown here being helped out of the Soyuz MS-13 spacecraft just minutes after she landed on Thursday, February 6, 2020. Koch returned to Earth after logging 328 days in space.

The Human Space Flight Operations (HSFO) Program supports the astronaut corps, space flight readiness training, and health of crew members before, during, and after each spaceflight mission to the International Space Station (ISS). All crews on board ISS have undergone rigorous preparation, which is critical to mission success. Within the HSFO program, the Space Flight Crew Operations (SFCO) element provides astronaut selection and space flight readiness training and the Crew Health and Safety (CHS) element manages all aspects of astronaut crew health.

To pave the way to the Moon and on to Mars, NASA is working with industry to develop the transportation, habitation, and exploration systems that will enable crewed exploration of destinations beyond Earth’s orbit. NASA must also prepare the human system for living and working for extended periods in the hostile environment of space. As astronauts explore further from Earth, many different issues will arise and need investigating.

- What health risks will astronauts face and how are they resolved?
- What type of training will crews need to prepare for months of travel in the harsh space environment?
- How will they deal with medical emergencies or technical anomalies when Earth is no longer within reach?

CHS, in collaboration with NASA’s Office of Chief Health and Medical Officer (OCHMO) and the Human Research Program (HRP), answers these and other questions to ensure crew health, safety, and mission success. SFCO and CHS are responsible for astronaut space flight readiness training and health, while HRP funds research of human health and performance countermeasures, the human response to space, and technologies that enable safe, reliable, and productive human space exploration.

HUMAN SPACE FLIGHT OPERATIONS

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

SFCO provided trained astronauts for NASA human space flight efforts, including for Expeditions 61 through 63 and the first test flight of the SpaceX Crew Dragon on the Demo-2 mission. SFCO continued to operate and maintain the T-38 high-performance jets for crew space flight readiness training; Gulfstream aircraft for support of direct crew return after completion of ISS Expeditions and Demo-2, and Super Guppy aircraft for transporting oversized cargo for Artemis I Crew and Service Module, Structural Test Article (Multi-Purpose Crew Vehicle Stage Adapter and Service Module), and other NASA's programs. SFCO reviewed crew training requirements for Artemis missions to identify efficiencies and ways to acquire the needed operational and decision - making skills in a real-time environment. The 2017 Astronaut Candidate (ASCAN) class graduated and the selection process for the 2021 ASCAN class began.

CHS maintained the Astronaut Occupational Health program, including clinical certification for flight for active astronauts; clinical and behavioral health for active astronauts; fitness through training, flight, and post-mission recovery; and clinical data and health risk analytical tools. CHS worked with OCHMO to implement the To Research, Evaluate, Assess, and Treat (TREAT) Astronauts Act. TREAT expanded the monitoring, diagnosis, and treatment of former astronauts for conditions due to spaceflight exposures, enhancing behavioral health and medical data collection. CHS, in collaboration with the Office of the Chief Health and Medical officer, created the TREAT Astronauts Act Board, consistent with NASA Interim Directive (NID 1241.126). The TREAT Board will assist in determining whether medical conditions are associated with spaceflight CHS continued to refine the occupational surveillance program for former astronauts including medical data obtained through annual physicals. CHS also continued to develop and deploy tools, including the Information Management Platform for Data Analytics and Aggregation (IMPALA) data analysis system, to improve NASA's access to astronaut medical data supporting programmatic decisions. To support ISS mission increments, CHS provided preflight training, medical and behavioral health management, physical conditioning, radiation exposure reports, and baseline occupational surveillance, as well as medical risk analysis and technical expertise to NASA's Artemis, Gateway, and Lunar mission architecture and vehicles.

WORK IN PROGRESS IN FY 2021

SFCO will direct and manage the astronaut corps and provide trained astronauts for NASA human space flight efforts, including for Expeditions 64 through 67 and the first test flight of the Boeing Starliner on the Crewed Flight Test (CFT) mission. SFCO will continue to operate and maintain the T-38 high-performance jets in support of space flight readiness training, Gulfstream aircraft for support of direct crew return after completion of ISS Expeditions and CFT, and Super Guppy aircraft for transporting oversized cargo for NASA's programs. SFCO will complete interviews for the 2021 ASCAN class. In addition, SFCO will assign astronauts to be the Artemis II crew and they will begin training for the mission.

CHS will maintain the Astronaut Occupational Health program that includes clinical certification for active astronauts and health and fitness through training, flight, and post mission recovery. CHS will implement requirements of the TREAT Astronauts. This implementation will include utilization of the

TREAT Astronauts Act Board. CHS will continue development of the occupational surveillance program for former astronauts. To support ISS mission increments, CHS will provide preflight training, medical and behavioral health management, physical conditioning, radiation exposure reports, and baseline occupational surveillance, as well as medical risk analysis and expertise to NASA's Artemis missions. CHS will also medically monitor and support astronaut training activities for Exploration Extra-Vehicular Mobility Unit development and training for lunar surface EVAs. CHS will also provide medical and behavioral screening expertise to SFCO in support of the 2021 ASCAN selection. Data obtained under the TREAT Astronauts Act, as well as all CHS activities, will be added into the IMPALA data analysis tool to inform current and future operational programs and expectations of crew health, and performance.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

SFCO will direct and manage the astronaut corps and provide trained astronauts for NASA human space flight efforts, including for Expedition 68 through 70 and the Artemis II mission. SFCO will continue to operate and maintain the T-38 high performance jets in support of space flight readiness training, Gulfstream aircraft for support of direct crew return after completion of ISS Expeditions, and Super Guppy aircraft for transporting oversized cargo for NASA's programs. SFCO will select and begin new astronaut training for the 2021 ASCAN class.

CHS will maintain the Astronaut Occupational Health program that includes clinical certification for active astronauts and health and fitness through training, flight, and post mission recovery, and update this program to ensure that the unique challenges of the Artemis missions are addressed. CHS will continue to implement all aspects of the TREAT Astronauts Act. CHS will continue development of the occupational surveillance program for current and former astronauts, ensuring the unique Artemis program spaceflight exposures are considered and accounted for in the future surveillance program for those astronauts. To support ISS mission increments, CHS will provide preflight training, medical and behavioral health management, physical conditioning, radiation exposure reports and baseline occupational surveillance, as well as medical risk modeling and analysis and technical expertise to NASA's Artemis, Gateway, and Lunar mission architecture and vehicles. CHS will also medically monitor and support astronaut training activities for ISS EVAs, xEMU development, and training for lunar surface EVAs. Data obtained under the TREAT Astronauts Act as well as all CHS activities will be added into the IMPALA data analysis tool for informing current and future operational programs and paradigms for crew health, safety, and performance.

Program Elements

SPACE FLIGHT CREW OPERATIONS (SFCO)

SFCO directs and manages the astronaut corps activities, assigns flight crew, is responsible for human space flight readiness training, and maintains and operates the Johnson Space Center (JSC) aircraft fleet, including the T-38 high-performance aircraft, Gulfstream aircraft, and Super Guppy transport aircraft.

SFCO also determines the need for and selects astronaut candidates. It takes approximately two years from the decision to select a new astronaut class until the selection process is completed. Once selected, new astronauts must complete two years of training for eligibility and then 30 months of ISS training before qualifying for an ISS mission. The number of spacecraft seats U.S. astronauts will fill in the next four years of human space flight determines the manifest requirement. The manifest includes projected Commercial Crew flights to ISS, Commercial Crew test flights, and Artemis flights. Requirements for future missions, for example to Gateway and the Moon, will be planned as those missions become better defined.

Astronaut space flight readiness training activities, implemented by SFCO, put the crew into operational environments which share some aspects of the fast dynamics, physical stress, and risk found in spaceflight. The training develops the skills and ability to work as a team in an environment that is fast-paced, stressful, and carries potentially severe penalties for failure. The training also includes developing the skills necessary to respond in an emergency/high-stress environment and operate a high-performance aircraft.

CREW HEALTH AND SAFETY (CHS)

CHS enables healthy and productive crew during all phases of spaceflight missions, implements a comprehensive astronaut occupational health care program, and works to understand, prevent, and mitigate negative long-term health consequences from exposure to the spaceflight environment. Using HRP research and other findings, CHS implements enhancements to astronaut occupational health protocols to ensure crew health and safety. In this collaboration, HRP concentrates on the research aspects of crew health, whereas CHS focuses on implementing the research results and mitigation plans into occupational health protocols. As research continues on ISS, CHS is actively seeking new approaches to apply research findings to improve NASA health protocols, including collaborative opportunities with other Federal agencies and academia. Further, CHS is implementing the TREAT Astronauts Act for former astronauts. This Act enables NASA to provide monitoring, diagnosis, and treatment to astronauts for spaceflight-related medical issues following retirement from NASA. In addition, NASA will be able to obtain more medical data to supplement the occupational surveillance program for former astronauts and better assess the long-term effects of spaceflight on the human body to enable exploration.

CHS is also responsible for maintaining the health of active astronauts during non-mission periods, focusing on three aspects of health care: preventive care, risk factor management, and long-term health monitoring. CHS integrates and coordinates information relevant to human health before, during, and after spaceflight. CHS documents and assesses all emerging health risks, such as Spaceflight Associated Neuro-ocular Syndrome (a spaceflight condition that affects astronauts eye structure and can lead to impaired vision), and the risk of venous flow changes. CHS continues to collaborate with several non-NASA organizations, including the National Academies, to inform the risk decisions associated with long-duration and exploration missions.

Program Schedule

Date	Significant Event
FY 2022	Conduct annual Lifetime Surveillance of Astronaut Health (LSAH) exams for approximately 75% of former astronauts
FY 2022	Train ASCANs selected in FY 2021

Program Management & Commitments

Program Element	Provider
SFCO	Provider: SFCO Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A
CHS	Provider: CHS Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A

Acquisition Strategy

The section below identifies the current contract(s) that support SFCO and CHS.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Aircraft Logistics, Integration, Configuration and Engineering	Yulista Tactical	Ellington Field, Houston, TX El Paso, TX
Human Health and Performance Contract	KBR Wyle	Houston, TX

HUMAN SPACE FLIGHT OPERATIONS

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	National Council on Radiation Protection (NCRP) and Measurements	Nov 2014	The NCRP reviewed NASA Radiation Protection Standards for crew member exposure to spaceflight radiation.	NCRP Commentary Report 23: Radiation Protection for Space Activities: Supplement to Previous Recommendations	Next review NAS 2020-21
Performance	NCRP	Feb 2016	The NCRP conducted a Phase I review of potential central nervous system (CNS) effects from radiation exposure during space activities.	NCRP Commentary Report 25: Potential Central Nervous System Risks Following Space Radiation Exposure	Phase II in progress
Performance	National Academies of Sciences, Engineering, and Medicine	Oct 2020 - Sep 2021	Assessment of Strategies for Managing Cancer Risks Associated with Radiation Exposure During Crewed Space Missions	Based on the committee's review and assessment of NASA's proposed strategies, the committee will make recommendations to NASA for assessing and managing the processes for addressing space radiation risk for astronauts.	N/A

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FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**94.4**	**91.9**	**102.7**	**92.7**	**92.9**	**92.9**	**92.9**
Change from FY 2021			**10.8**				
Percentage change from FY 2021			**11.8%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

An Atlas V rocket (shown here) lifts off from Space Launch Complex 41 at Cape Canaveral Air Force Station in Florida on July 30, 2020, at 7:50 a.m. EDT, carrying NASA's Mars Perseverance rover and Ingenuity helicopter.

The Launch Services Program (LSP) ensures access to space for the Nation's civil sector satellite and robotic planetary missions.

In addition to NASA's science and discovery missions, civil communications, geographic survey, and civil weather missions provide key services for our Nation and the world. The National Space Transportation Policy identifies the NASA Administrator as the launch agent for the Nation's civil sector. LSP enables the Administrator to execute this role by acquiring and managing domestic commercial launch services for assigned missions, certifying new commercial launch vehicles for readiness to fly high-value spacecraft, performing mission design and launch integration activities, and directing launch mission assurance efforts to ensure the greatest probability of launch mission success. While no space mission is routine, LSP has unique launch system expertise involving payloads containing nuclear power sources for launching one-of-a-kind science exploration missions to other planets, the Sun, or other locations in space. NASA relies on LSP to provide robust, reliable, and cost-effective launch services via commercial launch providers. NASA achieves assured access to space through a competitive mixed-fleet approach utilizing the breadth of U.S. industry capabilities. In addition, LSP provides launch-related expertise to other NASA programs, such as Commercial Resupply Services (CRS), Commercial Crew Program (CCP), and programs supporting the Artemis campaign. LSP also provides launch advisory support to NASA payload missions using launch services through other Government agencies, the launch industry, or contributed by a foreign partner.

In addition to acquiring the commercial launch service, LSP arranges pre-launch spacecraft processing facility support and communications and telemetry during ascent for its customers. LSP offers insight into the commercial space launch industry, which has been utilized by CCP. LSP also tracks lessons learned to

LAUNCH SERVICES

identify and mitigate risks for future managed launches and certifies the readiness of new commercial launch vehicles for NASA and other civil sector uncrewed spacecraft. The program also conducts engineering analyses and other technical tasks to maximize launch success for every assigned payload.

EXPLANATION OF MAJOR CHANGES IN FY 2022

LSP is funding the Vandenberg Air Force Base Space Launch Complex-2 closeout and demolition cost, which is necessary because of the retirement of the Delta II launch vehicle. Per agreement with the Air Force, NASA is responsible for the final Delta II close out costs.

ACHIEVEMENTS IN FY 2020

LSP provided expertise and active launch mission management for over 70 NASA scientific spacecraft missions in various stages of development. LSP continuously works with the U.S. commercial launch industry to assess their designs and provide advice, which expands the selection of domestic launch vehicles available to NASA's missions and nurtures a competitive commercial launch service environment. LSP successfully launched three science missions: ICON, Solar Orbiter, and Mars 2020.

LSP acquired new launch services for four future NASA missions through competitively awarded launch service task orders for the Science Mission Directorate (SMD):

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives*
Dec 2021 Cape Canaveral Space Force Station (CCSFS)	Atlas V	GOES-T	NASA SMD	GOES-T is the third of the GOES series next generation of weather satellites operated by the National Oceanic and Atmospheric Administration (NOAA) that will extend the availability of the GOES satellite system until 2036.
Aug 2022 Kennedy Space Center	Falcon Heavy	Psyche/Janus (2nd)	NASA SMD	Psyche is a NASA interplanetary mission to visit the main belt asteroid "16 Psyche". The Spacecraft will take four years and one Mars flyby to reach the asteroid, which is comprised mostly of iron and nickel.
NET Nov 2023 CCSFS	Falcon 9 Full Thrust	PACE	NASA SMD	PACE will study clouds and aerosols to help us better understand how the ocean and atmosphere exchange carbon dioxide.
Feb 2025 CCSFS	Falcon 9 Full Thrust	IMAP/Lunar trailblazer/SWFO-L1+GLIDE+Solar Cruiser	NASA SMD	The IMAP mission is a heliophysics mission that will simultaneously investigate two important and coupled science topics in the heliosphere: the acceleration of energetic particles and interaction of the solar wind with the local interstellar medium.

**LSP's customers own and manage the payload mission objectives described above.*

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LSP continued pre-certification activities with Blue Origin's New Glenn, United Launch Services' Alliances' (ULS) Vulcan, Northrop Grumman's Omega, SpaceX's Falcon Heavy, and FireFly's Alpha launch vehicles. Certifying a provider's launch vehicle enhances NASA's understanding of commercially-built launch vehicles and enables LSP to better identify and manage launch risks. Certification also enhances competition as it results in multiple qualified launch vehicles and launch providers.

The Delta II Closeout/Space Launch Complex (SLC) 2 Demolition is ongoing at Vandenburg Air Force Base (VAFB) in California. Demolition of the Fixed Umbilical Tower and Mobile Service Tower are complete in addition to the Required Environmental Baseline Surveys. A contract action is in work by the 30th Space Wing to award a demolition contract for three of the 16 buildings that NASA is responsible to demolish per the cost sharing agreement signed between NASA and the United States Air Force in May 2019.

LSP continued partnering with several universities and NASA centers to launch small research satellites through the CubeSat Launch Initiative (CSLI), which provides rideshare opportunities for small satellite payloads to fly on upcoming launches when excess capacity is available. These partnerships have provided regular educational opportunities for students in Science, Technology, Engineering, and Mathematics (STEM) disciplines, which help strengthen the Nation's future workforce. To date, CubeSats have been selected from 41 states and Puerto Rico, with 107 missions launched and 51 manifested on NASA, National Reconnaissance Office, U.S. Air Force, and commercial missions. In FY 2020, 14 CSLI CubeSat missions were launched.

Venture Class Launch Service (VCLS) contracts for CubeSat satellites foster a commercial launch market dedicated to flying small satellite payloads, which provide an alternative to the current rideshare approach where one or more CubeSats or other small payloads take advantage of excess payload capacity on a rocket whose primary mission is to launch a larger satellite. Rocket Lab USA and Virgin Orbit, two VCLS contract awardees, demonstrated significant progress despite some development delays. As a result of these delays, both companies missed their contractual launch dates and offered NASA consideration flights in addition to their original VCLS demonstration launches. On June 13, 2020, Rocket Lab successfully launched an additional VCLS consideration flight, the "Don't Stop Me Now" mission from the Mahia Peninsula in New Zealand.

WORK IN PROGRESS IN FY 2021

LSP will continue mission design and launch integration support to over 70 missions in various stages of development. In addition to launch preparation activities for seven missions that will launch in FY 2022, the current manifest for FY 2021 shows LSP will manage and conduct the launch activities for two NASA missions, as shown in the table below. In addition, Virgin Orbit successfully launched 10 NASA CubeSats to low-Earth orbit on the LauncherOne launch vehicle (the second mission under the original VCLS contract) on January 17, 2021.

LAUNCH SERVICES

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Nov 2020 Vandenberg Air Force Base	Falcon 9 Full Thrust	Sentinel 6 Michael Freilich	NASA SMD	To measure sea surface topography with high-accuracy and reliability to support ocean forecasting systems, environmental monitoring. and climate monitoring. The mission provides continuity of the TOPEX and JASON missions and improvements in instrument performance and coverage.
Sep 2021 Vandenberg Air Force Base, CA	Atlas V	Landsat-9	NASA SMD	Landsat-9 is the latest satellite in the Landsat series, following its predecessor (Landsat-8). Landsat-9 will carry two science instruments that will continue the Program's observation of the Earth's land surface to reduce the build time and risk of a gap in observations.

LSP will continue to actively acquire new launch services for future NASA missions.

In December 2020, NASA awarded a second round of VCLS contracts under the Venture Class Launch Services Demonstration 2 (VCLS Demo 2) acquisition to three commercial providers. The VCLS Demo 2 contracts awarded two types of missions which are referred to in the contract as a Mission One and a Mission Two. Mission One is for a dedicated launch service for CubeSats that includes a single launch with a delivery of 30 kg payload mass to 500 km at an inclination between 40-60 degrees. Mission Two is for a single launch service with CubeSats as the primary payload. Mission Two includes a single launch with a delivery of a Constellation A (75 kg payload mass) and a Constellation B (20 kg payload mass) to 550 km and includes a minimum 10-degree plane change between constellations. The VCLS Demo 2 companies and their respective awarded missions are: Astra Space Inc. of Alameda, California (Mission One); Relativity Space Inc. of Long Beach, California (Mission One); and Firefly Black LLC of Cedar Park, Texas (Mission Two). All three missions are planned for launch in FY 2022.

Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
NET Dec 2021 Kwajalein Atoll (Omelek Island)	Rocket 3	VCLS Demo 2 (Mission One: 30 kg payload, 500 km @ 41 deg inclination)	NASA, one STEM school, and multiple universities	A demonstration flight to determine if new small launch vehicles can deliver NASA payloads to orbit at a fixed price.

LAUNCH SERVICES

Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
NET April 2022 VAFB (SLC-2)	Alpha	VCLS Demo 2 (Mission Two: (1) 75 kg payload, 550 km SSO (2) 20 kg to 550 km SSO w/ min 10-degree plane change)	NASA, one STEM school, and multiple universities	A demonstration flight to determine if new small launch vehicles can deliver NASA payloads to orbit at a fixed price.
April 2022 CCSFS (SLC-16)	Terran 1	VCLS Demo 2 (Mission One: 30 kg payload, 500 km @ 41 deg inclination)	NASA, one STEM school, and multiple universities	A demonstration flight to determine if new small launch vehicles can deliver NASA payloads to orbit at a fixed price.

In December 2020, Blue Origin's New Glenn launch service was successfully on-ramped to the NASA Launch Services (NLS) II contract. In April 2021, ULS successfully on-ramped their Vulcan Centaur launch vehicle. Both launch vehicles were on-ramped as part of the ninth NLS II on-ramp activity. During this on-ramp solicitation process, NGSS initially submitted a proposal to on-ramp their OmegA launch vehicle but withdrew their proposal once they decided to terminate the OmegA program. ULS also formally notified NASA LSP of their intention to off-ramp their Delta IV-Medium and Delta IV-Heavy launch vehicles. This off-ramp has been completed and therefore Delta IV-Medium and Delta IV-Heavy are no longer on the NLS II contract. The tenth NLS II on-ramp, initiated in the summer of 2020, concluded with no new providers or new launch services being on-ramped.

In 2021, NASA awarded one Human Exploration and multiple Science missions including Gateway's HALO+PPE, SPHEREx and TROPICS. The program is currently in the process of competitively awarding two Science missions including GOES-U and Europa Clipper.

NASA LSP also has an active procurement for the Venture-Class Acquisitions of Dedicated and Rideshare (VADR) launch service contract. This contract will enable regular, competitive acquisition of commercial launch services for small payloads, such as those successfully demonstrated through the VCLS contracts. The VADR contract is expected to be awarded in FY 2021.

Along with full end-to-end launch service management of awarded missions, LSP continues to offer advisory support, expertise, and knowledge to NASA programs and projects utilizing launch services not procured and managed by LSP. The program is currently providing these advisory and informational services to several programs and missions, including the:

- Space Launch System/Orion;
- ISS Cargo Resupply Service missions;
- Commercial Crew Program;
- James Webb Space Telescope (Webb); and
- NASA-Indian Space Research Organization Synthetic Aperture Radar (NISAR) missions.

LAUNCH SERVICES

LSP will continue work towards certifying new commercial launch vehicles to launch high-value payloads. Certification activities are ongoing with Blue Origin's New Glenn, ULS' Vulcan, SpaceX's Falcon Heavy, and Alpha's Firefly launch vehicles.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

LSP will continue to execute the role of launch agent for the NASA Administrator on behalf of the U.S. civil sector, as described in the National Space Transportation Policy. The Program will provide management of NASA Launch Services contracts, launch mission assurance, mission design, and launch integration support to scientific spacecraft missions in various development phases. The current manifest for FY 2022 shows LSP will manage and conduct launch activities for six NASA missions contracted under NLS II, in addition to the TROPICS mission which was contracted outside of NLS II to meet the special needs of that mission. The VCLS Demo 2 missions are also planned to launch in FY 2022 as well as the additional consideration flights for Virgin Orbit (under the original VCLS contract) which will also take place no later than September 2022. LSP will continue work towards certifying new commercial launch vehicles to launch high-value payloads, as needed, and will continue launch service acquisition activities necessary to support NASA and other approved Government missions.

The program will support commercial logistics acquisition services for Gateway and Human Landing System (HLS) and provide launch advisory services for Webb and NISAR.

**FY 2022 Launch Dates shown in this table correspond to launch dates listed as Management Agreements elsewhere in this document.*

Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
Oct 2021 Cape Canaveral Air Force Station	Atlas V	Lucy	NASA SMD	A planned NASA space probe that will tour five Jupiter trojans, asteroids which share Jupiter's orbit around the Sun, orbiting either ahead of or behind the planet, and one main belt asteroid.
Nov 2021 Kennedy Space Center	Falcon 9 Full Thrust	Imaging X-ray Polarimetry Explorer (IXPE)	NASA SMD	Exploits the polarization state of light from astrophysical sources to provide insight into our understanding of X-ray production in objects (e.g., neutron stars, pulsar wind nebulae), as well as stellar and supermassive black holes.
Nov 2021 Vandenberg Air Force Base, CA	Falcon 9 Full Thrust	Double Asteroid Redirection Test (DART)	NASA SMD	Demonstrates kinetic impactor technology impacting an asteroid to adjust its speed and path. DART will be the first-ever space mission to demonstrate asteroid deflection by kinetic impactor.

LAUNCH SERVICES

Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
Dec 2021 Cape Canaveral Air Force Station	Atlas V	GOES-T	NASA SMD	GOES-T is the third of the GOES series next generation of weather satellites operated by NOAA that will extend the availability of the GOES satellite system until 2036.
Jan 2022 - July 2022 (3 in 120 days) Kwajalein Atoll (Omelek Island)	Rocket 3	Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of SmallSats (TROPICS)	NASA SMD	The CubeSats, each the size of a shoebox, will provide rapid-refresh microwave measurements that can be used to determine temperature, pressure, and humidity inside hurricanes as they form and evolve. The TROPICS mission's high-revisit imaging and sounding observations are enabled by microwave technology developed at the Massachusetts Institute of Technology's Lincoln Laboratory. These observations will profoundly improve scientists' understanding of processes driving high-impact storms.
Aug 2022 Kennedy Space Center	Falcon Heavy	Psyche/Janus (2nd)	NASA SMD	Psyche is a NASA interplanetary mission to visit the main belt asteroid "16 Psyche". The Spacecraft will take four years and one Mars flyby to reach the asteroid, which is comprised mostly of iron and nickel.
Sep 2022 Vandenberg Air Force Base	Atlas V	JPSS-2/LOFTID (2nd)	NASA SMD	JPSS-2 is a continuation of the JPSS series of satellites that will capture precise observations of the world's atmosphere, land and waters, and provide data that inform seven-day forecasts and extreme weather events.

Program Management & Commitments

Program Element	Provider
Commercial Launch Vehicle (CLV) Launch Services	Provider: ULS, Northrop Grumman Innovation Systems (NGIS) (formerly Orbital ATK), SpaceX, Rocket Lab USA, Virgin Orbit Lead Center: Kennedy Space Center (KSC) Performing Center(s): KSC Cost Share Partner(s): N/A

LAUNCH SERVICES

ACQUISITION STRATEGY

LSP's acquisition strategy was created for the original NASA NLS contracts for procuring CLV launch services from domestic commercial launch service suppliers. To meet the needs of science and technology customers who typically spend three to seven years developing a spacecraft mission, NASA created a contractual approach providing multiple competitive launch service options to cover small-, medium-, intermediate-, and heavy-sized missions. The follow-on contract mechanism, known as NLS II, has similar contract features. These features include not-to-exceed prices, indefinite-delivery-indefinite-quantity contract terms, and competitive firm-fixed-price launch service task order based acquisitions. The NLS II ordering period has been extended to June 30, 2025. To ensure active competition for NASA customers and encourage new launch capability development through these long-term contracts, NASA provides annual opportunities to U.S. industry to add new commercial launch service providers and/or launch vehicles to the contract.

LSP is also able to contract separately from the NLS contract mechanism if such an approach is necessary to meet a mission or customer need. For instance, the launch service for the Europa Clipper mission funded by NASA SMD is being competed outside and separate from the NLS II contract due to the special needs of that mission. In addition, VCLS awards for very small launch vehicles were conducted outside and separate from the NLS II contract to provide more flexibility to the new, small-class launch providers. The VADR contract will be an available contractual mechanism for NASA to acquire FAA licensed commercial launch services to place NASA-owned and NASA-sponsored payloads with a risk tolerance of Class D or higher risk tolerant payloads on trajectories to other planets, and/or spacecraft into orbit.

NASA has also made efforts to provide a complete launch service, including payload processing at the launch site. LSP uses firm-fixed-price indefinite-delivery-indefinite-quantity contracts for commercial payload processing capabilities on both the East and West coasts. The Payload Processing Facility (PPF) contracts are up for recompete. The East Coast Commercial Payload Processing Contract-4 (ECCPP-4) was awarded in April 2017 and the period of performance ends in April 2022. The West Coast Commercial Payload Processing Contract-3 (WCCPP-3) solicitation was cancelled. LSP is currently awarding mission specific PPF contracts for those on the West coast.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Venture Class Demonstration 2 (VCLS Demo 2)	Astra Space Inc. Relativity Space Inc. Firefly Black LLC	Alameda, California Long Beach, California Cedar Park, Texas
NASA Launch Services-II-U	ULS, LLC	Centennial, CO
NASA Launch Services-II-S	SpaceX	Hawthorne, CA
NASA Launch Services II-Blue	Blue Origin	Kennedy Space Center, FL

LAUNCH SERVICES

Element	Vendor	Location (of work performance)
NASA Launch Services-II-O	NGIS (formerly Orbital ATK Corporation)	Dulles, VA
East Coast Commercial Payload Processing-4	Astrotech Space Operations	Titusville, FL
West Coast Commercial Payload Processing-Landsat 9	Astrotech Space Operations	Vandenberg Air Force Base, CA
Integrated Processing Facility	Spaceport Systems International	Vandenberg Air Force Base, CA
Expendable Launch Vehicle Integrated Support (ELVIS) 2/3	a.i. Solutions, Inc.	Lanham, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Implementation Review (PIR)	Standing Review Board (SRB)	May 2014	Life Cycle Review	The SRB found LSP is a successful program with a strong technical and management team representing NASA's core competency, demonstrating exceptional performance with a 97.4 percent launch success record. The SRB recommended continuation of LSP operations as currently performed.	FY 2024*

**The FY 2024 milestone for LSP will be assessed by the Human Exploration and Operations Mission Directorate (HEOMD) Associate Administrator, and a determination will be made as to whether a PIR is required or if it can be delayed another five years. The FY 2024 milestone is also subject to change depending on LSP's manifest/launch schedule for that year.*

Historical Performance

LSP managed CLV Missions from inception through FY 2020:

Launch Vehicle Configuration	Provider	Number of Launches	Successful Launches	Unsuccessful Launches
Athena	Lockheed Martin/Alliant Techsystems	1	1	0
Atlas IIA	Lockheed Martin	5	5	0
Atlas IIAS	Lockheed Martin	1	1	0
Atlas V	Lockheed Martin	11	11	0
	ULS	8	8	0
Delta II	Boeing Launch Services	20	20	0
	ULS	4	4	0

LAUNCH SERVICES

Launch Vehicle Configuration	Provider	Number of Launches	Successful Launches	Unsuccessful Launches
Delta IV H	ULS	1	1	0
Falcon 9 v1.1	Space X Launch Services	1	1	0
Falcon 9 FT	Space X Launch Services	1	1	0
Pegasus Hybrid	Northrup Grumman (formerly OSC)	1	1	0
Pegasus XL	Northrup Grumman (formerly OSC)	4	4	0
Taurus XL	Northrup Grumman (formerly OSC)	2	0	2
Titan II	Lockheed Martin	3	3	0

ROCKET PROPULSION TEST

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**46.7**	**47.6**	**47.8**	**47.8**	**48.0**	**48.0**	**48.0**
Change from FY 2021			**0.2**				
Percentage change from FY 2021			**0.4%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Teams from NASA's Space Launch System (SLS) Program conducted a successful hot fire of the Artemis I core stage at NASA's Stennis Space Center on the B-2 Test Stand, which is maintained by the Rocket Propulsion Test program.

Developing and testing rocket propulsion systems is foundational to spaceflight. Whether the payload is a robotic science experiment or a crewed mission, the propulsion system used to launch it must be safe and reliable. A rigorous engine test program is a critical component of any rocket propulsion development activity.

NASA's Rocket Propulsion Test (RPT) program maintains and manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions. This test infrastructure includes facilities located across the U.S., and the program provides a single entry point for any user of NASA rocket test stands. RPT retains a skilled workforce capable of performing tests on all modern-day rockets and supporting complex rocket engine development. RPT evaluates customer test requirements and desired outcomes while minimizing test time and costs. It also streamlines facility usage and eliminates redundant capabilities by closing and consolidating NASA's rocket test facilities, as appropriate.

RPT is NASA's implementing authority for rocket propulsion testing. It approves and provides direction on test assignments, capital improvements, and facility modernization and refurbishment to reduce propulsion test costs. RPT integrates multi-site test activities, identifies and protects core capabilities, and develops advanced testing technologies.

The Agency has designated RPT as the NASA representative for the National Rocket Propulsion Test Alliance (NRPTA), an inter-agency collaboration with the Department of Defense (DoD), to facilitate efficient and effective use of the Federal Government's rocket propulsion test capabilities. The RPT Program Manager serves as a co-chair of the NRPTA Senior Steering Group and appoints NASA's alliance co-chair. The alliance co-chair position is a rotational appointment chosen from primary center representatives of RPT's management board.

For more information, go to: https://rpt.nasa.gov/

ROCKET PROPULSION TEST

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

Building on test results from previous years, RPT provided valuable propulsion data to the SLS and Orion programs as they prepare for Artemis I and Artemis II. These tests provided data to validate baseline designs, increase confidence in technical performance, reduce risks, and support launch readiness. RPT's FY 2020 work continued to position the programs to assess design changes that could affect performance and improve safety. RPT personnel executed hot fire testing of the SLS RS-25 engine for the Artemis missions on Stennis Space Center's (SSC) A-1 test stand and began testing the SLS core stage Green Run for Artemis I on the B-2 test stand. The Green Run test will help ensure mission success, and many aspects will be carried out for the first time, such as fueling and pressurizing the core stage. The test series culminates with firing up all four RS-25 engines to demonstrate the engines, tanks, fuel lines, valves, pressurization system, and software can all perform together just as they will on launch day. RPT also continued engine certification of the Aerojet Rocketdyne RS-68 liquid hydrogen/oxygen engine for the Delta IV launch vehicle on the B-1 test stand.

At Plum Brook Station (PBS) in Ohio, RPT completed all planned modifications of the In Space Power Facility (ISPF).

At White Sands Test Facility (WSTF) in New Mexico, RPT continued testing activities for the Orion European Space Agency (ESA) Service Module. RPT also continued providing propulsion test services to the Missile Defense Agency, Aerojet Rocketdyne, and U.S. Air Force.

RPT continued to maintain and modernize test facilities across the portfolio to support testing of future space vehicles in a simulated space environment and ambient conditions.

WORK IN PROGRESS IN FY 2021

RPT is providing propulsion data to validate baseline designs, increase confidence in technical performance, reduce risks, and ensure launch readiness in preparations for Artemis I and Artemis II, as well as supporting the Commercial Crew Program's (CCP) milestones. RPT personnel continue preparing for and conducting hot fire tests of the RS-25 engine on SSC’s A-1 test stand in support of the SLS program. On March 18, 2021, the core stage of the Space Launch System (SLS) fired its four RS-25 engines for 8 minutes and 19 seconds on the B-2 test stand at Stennis Space Center in Mississippi. The successful test, known as a hot fire, was a critical milestone ahead of the Agency’s Artemis I mission, which will send an uncrewed Orion spacecraft on a test flight around the Moon and back to Earth, paving the way for future Artemis missions with astronauts. RPT will continue to support engine certification of the Aerojet Rocketdyne RS-68 liquid hydrogen/oxygen engine for the Delta IV launch vehicle on the SSC B-1 test stand. Interstellar liquid oxygen/liquid hydrogen testing will continue on the SSC E-1 test stand's Cell 2.

At PBS, RPT will perform thermal vacuum testing for the Sierra Nevada Corp. (SNC) Dream Chaser Cargo System (DCCS) in the ISPF.

At WSTF, RPT will continue preparations for and testing of the Orion ESA Service Module (SM) and continue the CCP Boeing CST-100 SM thruster acceptance test program

ROCKET PROPULSION TEST

RPT facilities will continue evaluating and implementing high-risk/high-priority facility maintenance and modernization projects to assure propulsion test assets are available to support current and future propulsion test requirements. Additionally, the program will conduct an analysis of anticipated future propulsion test needs with the goal to strategically prepare availability of the portfolio of test stands at the four centers for NASA's future.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

RPT will support thermal vacuum testing for SNC Dream Chaser at the PBS ISPF. PBS is also looking at three high-probability hot fire projects in the ISPF, including the Plume Surface Interaction test, Dynetics test (projected to begin and end in FY 2022), and Blue Federal Ascent program (projected to start in the 4th quarter of FY 2022).

At Marshall Space Flight Center (MSFC), RPT will complete testing of rocket nozzles on test stand 115 and RS-25 engines on test stand 116.

At SSC, RPT will perform SLS RS-25 engine testing on test stand A-1 and, depending on engine demand, may perform RS-68 testing on the B-1 test stand.

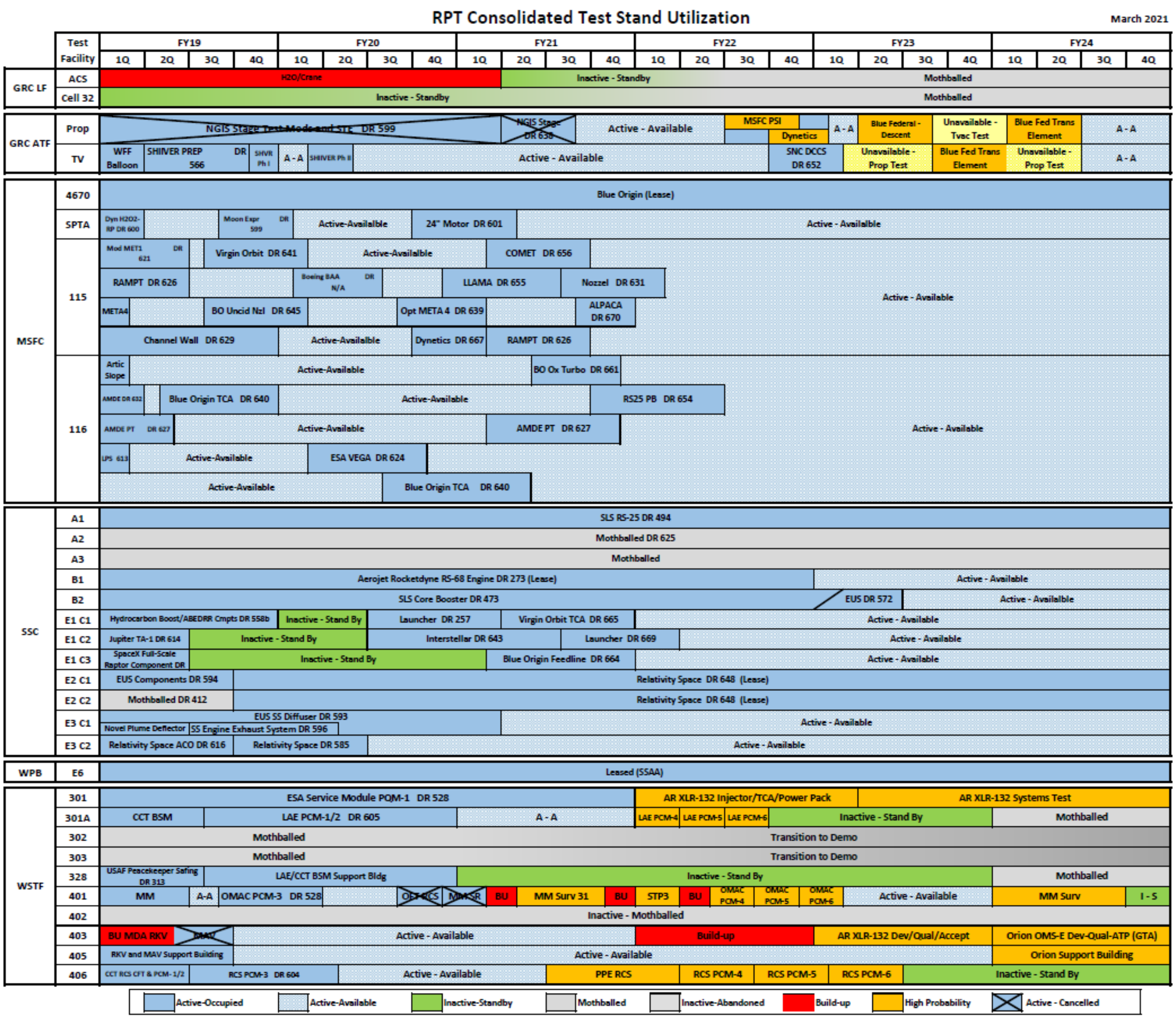
Several high-probability test opportunities are expected at WSTF. RPT is expected to test: the AR XLR-132 injector, Thrust Chamber Assembly, and its power pack unit on test stand 301; the Launch Abort Engine PCM and modules 4 – 6 of the Boeing CST-100 on test stand 301A; and the reaction control system (RCS) PCM 4 and RSC PCM 5 on test stand 401. In addition, on test stand 401, NASA will complete the DoD Minute Man effort and will prepare for Orbital Maneuvering and Attitude Control (OMAC) testing to support Boeing Commercial Crew.

Based on the future propulsion test needs study (FY 2021), RPT will begin planning and implementing the findings.

Program Schedule

The following chart shows past, current, and planned test campaigns at SSC, MSFC, Glenn Research Center (GRC), and WSTF rocket propulsion test facilities. The designations at the far left of the chart refer to the facility, the top of the chart shows time by quarter of fiscal and calendar year, and the key to the status of each facility is at the bottom.

Most test stands and facilities are scheduled 18 months in advance. Defining the scope of work, selecting test stands and fuel, and estimating labor and total cost to customers is a complex process that can take 18 to 36 months. RPT is working now with internal and external customers to design testing programs for FY 2022 and beyond.



ROCKET PROPULSION TEST

PROGRAM MANAGEMENT & COMMITMENTS

Program Element	Provider
RPT	Provider: RPT Lead Center: N/A Performing Center(s): SSC, JSC, GRC, MSFC, KSC, WFF Cost Share Partner(s): Various other NASA programs, DoD, and commercial partners

ACQUISITION STRATEGY

None.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None.

COMMUNICATIONS SERVICES PROGRAM

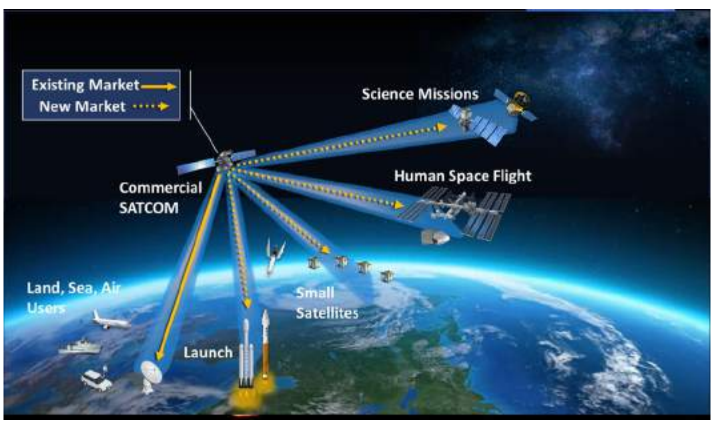
FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**2.7**	**23.4**	**42.0**	**51.2**	**58.9**	**58.9**	**58.9**
Change from FY 2021			**18.6**				
Percentage change from FY 2021			**79.5%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Upon establishment of the CSP in FY 2020, NASA transferred the Next Generation Capability funding line from SCaN to CSP.



The Communications Services Program will collaborate with industry to demonstrate commercially provided data relay services for NASA space missions.

The Communications Services Program (CSP) focuses on demonstrating the feasibility of commercially provided satellite communications (SATCOM) services to NASA missions. As an initial activity, CSP is pursuing demonstrations that will allow future NASA missions to use flight-qualified communications services. Ultimately, if CSP demonstrations are successful, near-Earth users will transition from using NASA-owned networks to commercially provided services.

The CSP effort is a component of the larger NASA strategy to migrate near-Earth missions from communications and navigation services provisioned by government-owned networks to commercial networks. This transition to commercial services, and particularly commercial SATCOM, is driven by both the state of current NASA network assets, by the National Space Policy, and by long-standing Federal procurement policies that direct the government to make use of, rather than duplicate, commercially-provided services. NASA will not replenish the Tracking and Data Relay Satellites as aging spacecraft assets are decommissioned. NASA will continue to support existing users, but seeks to transition future space-relay users to commercial providers, consistent with Federal policies intended to increase the cost-effectiveness of government operations and leverage investments that have already been made by the private sector.

The SCaN program has overarching Agency responsibility to ensure that operational NASA missions receive required communications and navigation support. CSP retains the responsibility to execute demonstrations of commercial SATCOM services and provide formal assessments and recommendations for service acquisition to the Agency. NASA will ensure that the transition to commercial services is managed in context with the gradual phase out of the existing NASA-owned network resources.

NASA has a diverse set of users and communications needs against which commercial capabilities will be evaluated, such as launch vehicle support, visiting vehicles (to ISS), human space flight, and science missions in Earth orbit - which range from flagship observatories to SmallSats and CubeSats. CSP intends to leverage the SATCOM capabilities that have been developed for terrestrial users, bringing the flexibility and functionality of service to the space domain. CSP will work with the commercial market to identify requirements and explore opportunities that are mutually beneficial to NASA and industry and will develop an acquisition model for incorporating commercial communications services into operations. NASA expects to partner with multiple commercial entities to demonstrate capabilities that best fulfill NASA's requirements while also being compatible with a larger commercial market, where NASA can be one of many customers. These partnerships will be designed to bolster American industry, significantly reduce the cost of communication services to NASA, and maximize interoperability between Government and commercial service providers while promoting a diverse commercial market.

CSP funding will support multiple partnerships between NASA and commercial SATCOM companies to develop and demonstrate capabilities that can meet NASA's needs and begin the initial planning for acquisition of commercial SATCOM services.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

In FY 2020, NASA began formulation activities for CSP and completed objectives for Phase 1 work, spanning analysis of alternatives and market research, industry and mission engagement, formulation efforts, and preparation for acquisition strategy approvals.

CSP assessment of alternatives and market research included a review of prior SCaN architecture studies spanning 2013 - 2019 as well as a critical evaluation of the NextSTEP-2 Space Relay Partnership and Services Studies in which industry awardees provided an in-depth perspective on possible commercial service offerings and architectures. CSP also completed independent evaluations of commercial networks, mission user needs projections and architecture concepts, as well as referencing similar work completed by the U.S. Air Force's Space and Missile Systems Center. CSP has continued to engage in dialogue with industry, building on what was initiated during the 2016 industry studies which focused on commercial satellite communications services. In parallel, CSP has engaged with the NASA mission community to ensure alignment between CSP efforts, the targeted commercial communications services, and NASA mission needs. The product of these efforts is a clear definition of the mission classes, services and scenarios targeted for demonstration.

The goals of CSP were released publicly as part of the Ka-band and International Communications Satellite Systems Conference in October 2019 which had broad commercial industry attendance. CSP progressed with establishing an organizational structure and a formulation team.

CSP worked collaboratively with SCaN and Goddard Space Flight Center (GSFC) to define and document the broader strategic plan for commercializing communications and navigation services to near-Earth missions. The executive level plan was subsequently reviewed and approved by HEOMD and

Agency leadership in Q3 FY 2020. Approval of the plan confirmed the CSP demonstration approach and its alignment with the larger plan.

CSP continued to develop the acquisition strategy for the planned commercial SATCOM demonstrations. CSP completed reviews of Power and Propulsion Element (PPE), Commercial Orbital Transportation Services (COTS), and Commercial Crew Lessons Learned to inform acquisition strategy development. Key lessons learned from these prior efforts included focusing on capabilities versus requirements and linking fixed price milestones to hardware or capability demonstrations, not approval of engineering reviews or documentation. CSP worked collaboratively across cognizant organizations in the development of the draft strategy, completing briefings with the Chief Procurement Officer, Chief Information Officer, General Counsel, Chief Financial Officer, Engineering Director, and Safety and Mission Assurance director in June 2020. The resulting initial acquisition strategy was reviewed by the Office of General Counsel in July 2020. CSP completed the pre-acquisition strategy briefing in August 2020 along with an initial draft announcement for proposals which was released for internal review.

WORK IN PROGRESS IN FY 2021

To date, CSP has completed critical steps toward releasing the SATCOM service demonstrations announcement and solicitation. Activities included: participation in a SCaN-hosted virtual industry event, which rolled out the larger NASA commercialization strategy for near-Earth communications; supporting the HEOMD pre-Acquisition Strategy Meeting (ASM); completion of the Formulation Authorization Document; and a successful ASM milestone in December 2020. CSP completed the Project Strategy Briefing for Earth Relay Services Acquisition/Part One Demonstration on March 1, 2021.

CSP is continuing to prepare solicitation materials. The solicitation will be developed and released to engage interested commercial providers in demonstrations which are expected to be completed over a multi-year period. NASA expects to demonstrate multiple capabilities through a diverse set of service providers. The end-to-end capabilities can address a singular service or series of services needed by a mission. Capability demonstrations that are applicable for different classes of NASA missions and suitable for other customers are desirable. The intent is to develop a demonstration portfolio of commercial capabilities that in the aggregate will address the future NASA mission needs for reliable, robust, and cost-effective communications and navigation services.

CSP released the draft announcement and hosted a successful virtual Industry day on May 11, 2021 with over 140 participants, followed by two days of industry one-on-ones. Drawing on planning and preparation that is already underway as well as feedback from Industry day, CSP will release the final announcement in Q3 FY 2021. Upon receipt of proposals, CSP will begin the evaluation process.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

CSP plans to evaluate submitted proposals and make multiple awards in Q1 FY 2022.

After demonstration contract award and kickoff, CSP will maintain surveillance of the awardees' progress through their demonstration plans and associated milestones. CSP will evaluate the success of the demonstrations based on the technical, business, security, and operations attributes. CSP will continue to engage with the mission community to review the progress and results of the demonstrations as part of achieving buy-in from stakeholders.

Program Schedule

The table below includes significant Communication Services program milestones in FY 2021 and FY 2022.

Date	Significant Event
Q1 FY 2021	Acquisition Strategy Meeting (Completed)
Q3 FY 2021	Draft Announcement Release
Q3 FY 2021	Industry Day
Q3 FY 2021	Request For Proposals
Q1 FY 2022	Demonstration Awards

Program Management & Commitments

Program Element	Provider
Communications Services	Provider: CSP Project Office Lead Center: GRC Performing Center(s): N/A Cost Share Partner(s): N/A

Acquisition Strategy

CSP has received, through the Acquisition Strategy Council, NASA concurrence to proceed with a funded Space Act Agreement acquisition approach for the demonstrations. NASA will define the future acquisition strategy for transitioning near-Earth NASA users to suitable commercially provided services, as informed by the demonstrations executed by CSP. This acquisition strategy could include commercial service contracts, hosted payloads, and/or public-private partnerships to obtain commercially provided satellite communications services.

MAJOR CONTRACTS/AWARDS

Awards are anticipated to be made in FY 2022. Details will be included in future justification documents.

INDEPENDENT REVIEWS

As project formulation is finalized in FY 2021 and NASA procedures are appropriately tailored, the need for and timing of independent reviews will be identified and included in future justification documents.

COMMERCIAL LEO DEVELOPMENT

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**15.0**	**17.0**	**101.1**	**186.1**	**186.1**	**186.1**	**186.1**
Change from FY 2021			**84.1**				
Percentage change from FY 2021			**494.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

NASA will partner with industry to develop and establish new commercial low-Earth orbit (LEO) destinations, culminating in NASA's participation as a customer in a robust space economy. Commercial LEO destination shown in this image is a notional rendering.

NASA seeks to maintain access to a low-Earth orbit (LEO) human-rated platform to continue the U.S. human presence – with both Government astronauts and private citizens – to support the utilization of space by U.S. citizens, companies, academia, and international partners, as well as to expand the American foothold in space. Guided by NASA's Strategic Goals and Objective 2.1 to "Lay the foundation for America to maintain a constant human presence in low-Earth orbit enabled by a commercial market," NASA is undertaking the Commercial LEO Development Program as a focused effort to develop a robust commercial space economy in LEO that supports good-paying jobs.

NASA's Commercial LEO Development Program is supporting the development of commercially-owned and operated LEO destinations from which NASA, along with other customers, can purchase services and stimulate the growth of commercial activities in LEO. As commercial LEO destinations become available, NASA intends to implement an orderly transition from current International Space Station (ISS) operations to these new commercial destinations. Transition of LEO operations to the private sector will yield efficiencies in the long term, enabling NASA to shift resources towards other objectives. With the introduction of commercial LEO destinations, NASA expects to realize efficiencies from the use of smaller, more modern and efficient platforms and a more commercial approach to meeting the Agency's needs in LEO. In the longer term, the gradual emergence of additional customers for commercial LEO destinations will offer the opportunity for additional savings.

To achieve the Commercial LEO Development Program's goals, NASA is committed to using the ISS and its capabilities to aid in the development of U.S. industry's ability to provide the necessary platforms and services in LEO. NASA is also committing to continued government utilization of LEO beyond the ISS for basic research and development, Earth and deep space observations, and astronaut training. NASA will support development of both the supply side of the future LEO economy (i.e., future platforms providing services for a fee) and the demand side (i.e., users of on-orbit services). NASA's commitment to growing the future LEO economy also includes providing government funding to private industry in the form of contracts and partnerships to ensure that future capabilities can fulfill government requirements.

NASA is pursuing several avenues to enable the supply side of the LEO economy. These include offering the use of an ISS berthing port to a private company to deploy a new commercial element on the ISS; supporting the development and use of free-flying commercial LEO destinations; and offering the use of the ISS for private astronaut missions. For the ISS to support the new commercial element, NASA will reconfigure the ISS port, provide new ISS utilities and resources to the port, integrate the commercial elements onto ISS, and recertify new docking port locations for Commercial Resupply Services and Commercial Crew Program vehicles. NASA’s expectation is that one or more of these development and demonstration efforts will prove commercially viable, allowing U.S. and international customers to purchase services in LEO while also providing NASA with the platforms and capabilities it requires in LEO.

Simultaneously, the Commercial LEO Development and ISS Programs are collaborating to develop and mature the demand side of the LEO economy. NASA issued a preliminary “LEO Demand Forecast” which describes NASA's long-term needs for microgravity services. The NASA budget also provides support for sustained demand focus areas such as industrial biomedicine and manufacturing in the form of ISS feasibility demonstrations and integration costs. Without NASA support, commercial entities pursuing these demand focus areas might lack sufficient microgravity facility access or the resources needed to overcome the significant initial investment required to become self-sufficient. These demand stimulation activities were previously funded by the Commercial LEO Development Program but will be funded by the ISS Program in FY 2022. Finally, NASA is making the ISS available to private entities to conduct activities such as marketing and advertising onboard on a fully reimbursable basis, which had previously not been allowed. Coupled with this is a pricing policy that delineates what services NASA is willing to offer, the limits on these services, and the price per unit.

NASA's Commercial LEO Development Budget request for FY 2022 supports and will advance the Nation’s goals in LEO and for deep space exploration by furthering the development and maturity of the commercial space market. This development will enable private industry to assume roles that have been traditionally Government-only by creating new opportunities for economic growth through new markets and industries in LEO and potentially yielding long-term cost savings to the Government by leveraging industry innovation and commercial market incentives.

EXPLANATION OF MAJOR CHANGES IN FY 2022

Demand stimulation content in the Commercial LEO Development Program is being transferred to the ISS Program.

COMMERCIAL LEO DEVELOPMENT

ACHIEVEMENTS IN FY 2020

A robust and competitive LEO economy will greatly accelerate progress in space. In August 2020, the Human Exploration and Operations Mission Directorate (HEOMD) established a Commercial LEO Development Program Office to lead this effort.

NASA began collaborations with the U.S. private industry to enable development of LEO capabilities. On January 27, 2020, NASA selected Axiom Space to provide a habitable commercial segment (port module), attached to the ISS Node 2 forward port. Contract award and initial development efforts commenced in March 2020, including the concept design review for the commercial segment. NASA participated in the System Requirements Review, as well as System Maturation Reviews for key elements (e.g., power, propulsion, and environmental life support systems). By the end of FY 2020, Axiom completed all milestones associated with the first two task orders on the contract, except one that closed in the first quarter of FY 2021.

NASA pursued opportunities to stimulate scalable and sustainable demand for LEO destinations through the award of contracts with companies seeking the opportunity to enhance the unique capabilities of the ISS, and utilize the ISS National Laboratory to develop and/or operate systems or facilities that may lead to a sustainable demand for a human-rated LEO platform. NASA selected proposals from four companies and awarded seven contracts to these companies seeking in-space manufacturing and regenerative medicine flight demonstrations. The selected companies were Apsidal, DSTAR Communications, Made In Space, Inc., and Space Tango. In addition, NASA selected an applied research proposal submitted by Bryce Space and Technology in response to the Agency's call to identify opportunities that could broadly foster the long-term growth of new and emerging markets for commercial activities in LEO.

NASA also began its initiative to accommodate new commercial activities on the ISS. This includes agreements to initiate training of private astronauts and planning for private astronaut missions to the ISS. Private astronaut missions will be privately funded, dedicated commercial spaceflights on a commercial launch vehicle to conduct approved commercial and marketing activities on the ISS, or in a commercial segment attached to the ISS. NASA released a Request for Information (RFI) soliciting feedback on the proposed liability framework for private astronaut missions. The input is being used to help inform and develop the best implementation approach to private astronaut missions and the liability terms.

WORK IN PROGRESS IN FY 2021

NASA continues efforts towards building and executing a targeted strategy for an "ecosystem of space commerce" that is sustainable, cost-effective, and safe. The current strategy builds on and applies the lessons learned from over a decade of work and experience with commercial companies. The Commercial LEO Development Program will focus attention on finalizing the strategy designed to guide future success and establish commercial partnerships to help achieve program goals.

Continuing work that began in FY 2020, the commercial segment provider, Axiom, will complete their design analysis, working towards the Preliminary Design Review (PDR) for the Axiom Segment and Axiom Node 1 (AxN1). Axiom is focusing on their Long Lead Structures Preliminary Design System Maturation Reviews (SMR) for the AxN1 and Axiom Habitation (AxH1) elements. In FY 2021, Axiom is also planning to complete AxN1 Structures Final Design SMR. Axiom is advertising that their first element will launch in late 2024. Equally critical to enabling the supply side of the LEO economy, NASA plans to finalize the acquisition strategy and make award(s) to enable partnerships for development and space flight demonstrations of free-flying commercial LEO destinations. NASA will also develop an overall commercial LEO destinations human-rating strategy as well as requirements. NASA seeks commercial LEO destinations that will provide a diverse portfolio of products and services that meet both NASA and non-NASA needs.

NASA established a commercial use and pricing policy for the ISS, enabling companies to reduce uncertainty and build business plans as they seek to perform commercial activities, including marketing. NASA plans to complete clarifying updates to this policy associated with commercial activities, including addressing the procurement of services for private astronaut mission providers. NASA will finalize requirements and documentation associated with private astronaut missions to document framework and concept of operations.

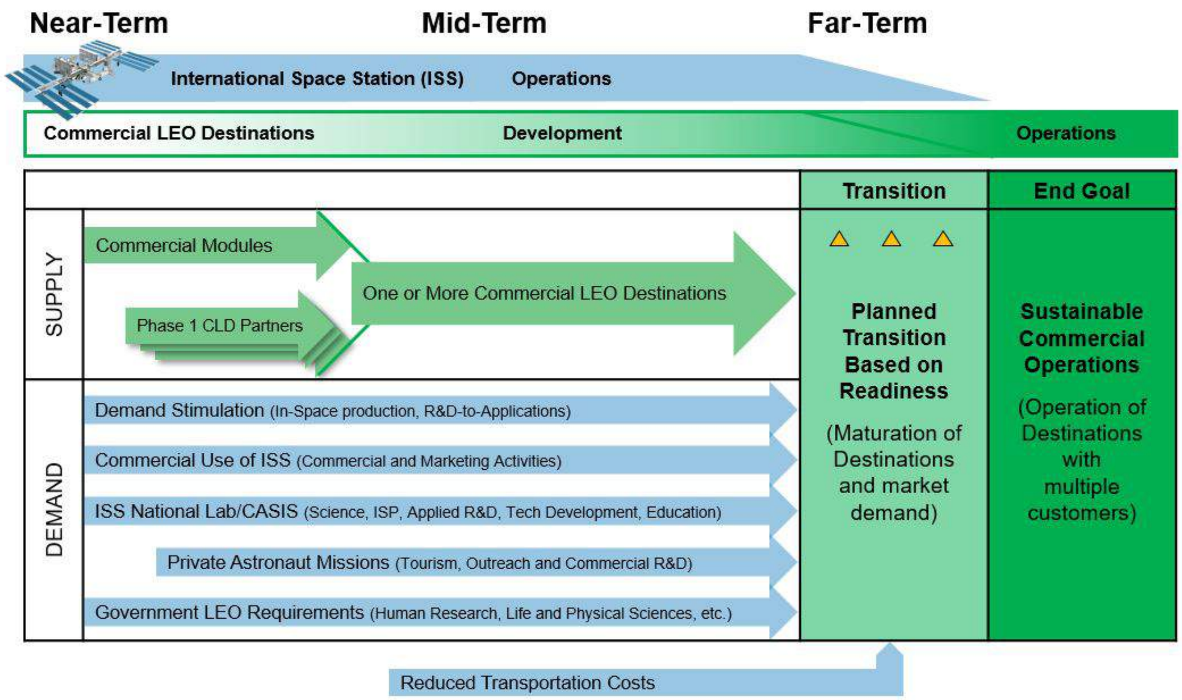
There are six in-space manufacturing contracts ongoing with the first flight demonstrations planned to begin in FY 2021 and continuing through calendar year 2023. NASA will develop and mature roadmaps and success criteria for each technology to assess performance of on-orbit demonstrations and inform the future down-select process. Bryce Space and Technology will submit to NASA their study on LEO Economy Barriers and a tangible action plan and complete their contract deliverable.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

NASA plans to continue to support the development of free-flying commercial LEO destinations that will lead to demonstrations. NASA will continue the development of the commercial segment that will attach to the ISS, including completing the critical design review for the first two commercial elements, the node and habitation modules. Funding in FY 2022 at the requested level is essential to facilitate the transition for U.S. human space flight activities in LEO from the current regime, which relies heavily on NASA sponsorship, to a regime where NASA is one of many customers by the end of the decade.

Program Schedule

The following chart depicts the near-term roadmap of planned Commercial LEO Development efforts.



Program Management & Commitments

Program Element	Provider
Commercial LEO Development Program Management	Lead Center: Johnson Space Center (JSC) Performing Center(s): JSC Cost Share Partner(s):TBD
Partner(s)	Provider: Axiom Space, Inc. Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): TBD

COMMERCIAL LEO DEVELOPMENT

Acquisition Strategy

NASA uses multiple acquisition tools for Commercial LEO Development. The established Next Space Technologies for Exploration Partnerships (NextSTEP-2) Broad Agency Announcement (BAA) contract vehicle was used for the Commercial Destinations for ISS contract to initiate development of the commercial segment. NASA plans to release a solicitation for free-flying commercial LEO destinations in FY 2021, using funded Space Act Agreements for the formulation and design. In parallel, NASA is employing the existing ISS Utilization NASA Research Announcement (NRA) to select and develop commercial concepts that will stimulate demand in the LEO economy. This NRA will also be used to solicit and evaluate proposals for private astronaut missions and for non-research and development commercial activities on the ISS.

Major Contracts/Awards

Element	Vendor	Location (of work performance)
Commercial Destination for International Space Station (CDISS)	Axiom Space, Inc.	Houston, TX

Independent Reviews

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Jan 2021	Provide independent guidance for the NASA Administrator	No new formal recommendations or findings	May 2021

SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Earth Science	1,971.8	2,000.0	**2,250.0**	2,343.5	2,398.3	2,573.0	2,702.3
Planetary Science	2,712.6	2,699.8	**3,200.0**	3,196.3	3,266.5	3,226.9	3,168.7
James Webb Space Telescope	423.0	414.7	**175.4**	172.5	172.0	172.0	172.0
Astrophysics	1,306.2	1,356.2	**1,400.2**	1,461.8	1,491.5	1,512.3	1,594.1
Heliophysics	724.5	751.0	**796.7**	803.3	816.6	833.6	858.5
Biological and Physical Sciences	5.0	79.1	**109.1**	118.1	128.0	137.9	147.8
Total Budget	**7,143.1**	**7,300.8**	**7,931.4**	**8,095.6**	**8,272.9**	**8,455.7**	**8,643.4**

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FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

SCIENCE

SCIENCE

Heliophysics

Biological and Physical Sciences

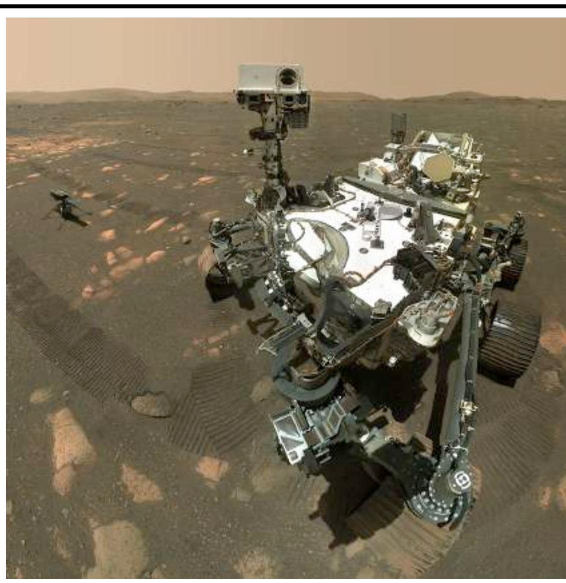
SCIENCE

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Earth Science	1,971.8	2,000.0	**2,250.0**	2,343.5	2,398.3	2,573.0	2,702.3
Planetary Science	2,712.6	2,699.8	**3,200.0**	3,196.3	3,266.5	3,226.9	3,168.7
James Webb Space Telescope	423.0	414.7	**175.4**	172.5	172.0	172.0	172.0
Astrophysics	1,306.2	1,356.2	**1,400.2**	1,461.8	1,491.5	1,512.3	1,594.1
Heliophysics	724.5	751.0	**796.7**	803.3	816.6	833.6	858.5
Biological and Physical Sciences	5.0	79.1	**109.1**	118.1	128.0	137.9	147.8
Total Budget	**7,143.1**	**7,300.8**	**7,931.4**	**8,095.6**	**8,272.9**	**8,455.7**	**8,643.4**
Change from FY 2021			**630.6**				
Percentage change from FY 2021			**8.6%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



NASA's Perseverance Mars rover took a selfie with the Ingenuity helicopter, seen here about 13 feet (3.9 meters) from the rover. The rover landed successfully on Mars on February 18, 2021 and has begun its search for signs of ancient microbial life.

Since NASA's inception, scientific discovery about our Earth, the Sun, the solar system, and the universe beyond has been an enduring purpose of the Agency as part of its three major strategic thrusts: discover, explore, and develop. NASA's Science Mission Directorate (SMD) conducts scientific exploration enabled by observatories that view Earth from space, observe and visit other bodies in the solar system, and gaze out into the galaxy and beyond. NASA's scientific exploration will also inform human exploration of the Moon, Mars, and the solar system, providing valuable scientific data for such human missions. NASA's science programs focus on three interdisciplinary objectives:

- Discovering the secrets of the universe;
- Searching for life elsewhere; and
- Protecting and improving life on Earth and in space.

NASA science programs address fundamental research about the universe and our place in it. How did the universe begin and evolve? How did our solar system originate? How and why is the Earth changing on all timescales? This fundamental research covers all areas of science and the intersections thereof when addressing the question, "Are we alone?" NASA's science programs also help protect and improve life on Earth through fundamental research that enables innovative and practical applications for decision-makers, including disaster response, natural resource management, and planetary defense. NASA also focuses on improving its operations and launching its science missions on schedule and on budget. Our discoveries continue to rewrite textbooks, inspire learners of all ages, and demonstrate U.S. leadership worldwide.

NASA uses the recommendations of the National Academies' decadal surveys as important inputs in planning and prioritizing the future of its science programs. For almost 50 years, decadal surveys have proven vital in establishing a broad consensus within the national science community on the state of science, the highest priority science questions we can address, and actions we can take to answer those questions. NASA uses these recommendations to prioritize future flight missions (including space observatories and probes) as well as technology development and proposals for theoretical and suborbital supporting research. Soon, NASA expects to receive decadal surveys for Astrophysics (2021), Planetary Science (2022), Heliophysics (2023), and Biological and Physical Sciences (2023). In determining the content of the Science portfolio, NASA also considers national priorities and policies, budgets, existing technological capabilities, partnership opportunities, and other programmatic factors.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The FY 2022 Budget provides $7.9 billion for Science and now includes the Biological and Physical Sciences Division, transferred to Science from the Human Exploration Mission Directorate in FY 2020. The Budget proposes significant increases in climate research, applications, and development within Earth Science, supports the initiation of four next generation Earth observing missions and initiates the Earth System Explorers Program. Funding for the Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) and Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder missions are also included in this request. These missions will continue to expand long-term observations of our living planet and advance our understanding of Earth's changing climate. The budget for Heliophysics supports increases for new mission selections in the Solar Terrestrial Probes program, formulation of the Geospace Dynamics Constellation mission, and additional investments in Heliophysics Technology which is proposed as a new program in FY 2022.

Within Astrophysics, the Budget includes funding for the Nancy Grace Roman Space Telescope, now in development and planned for launch in 2027. The Budget initiates a probe-class mission in anticipation of Decadal survey guidance, and proposes termination of the SOFIA mission, which costs over $80 million per year and has not proven to be as scientifically productive as other missions. The Budget proposes an increase in Planetary Science to support formulation activities for the Mars Sample Return (MSR) mission, with a targeted launch date as early as 2026. NASA established the MSR Program Office reporting directly to the Associate Administrator for Science, in recognition of the highly complex nature of the Mars Sample Return mission. The Budget shows a separate funding line for the MSR Program under the Planetary Science theme. The Planetary Science budget also funds important investments in the VIPER mission within the Lunar Exploration Program, as well as the Dragonfly mission, the Near Earth Objects Surveyor mission, and the Discovery Program, which provides flight opportunities for competed, PI managed, cost-capped missions.

NASA completed an analysis in late October 2020 confirming a significant incompatibility between the use of the Space Launch System (SLS) for the Europa Clipper mission and the existing Europa Clipper design. The Budget therefore supports the use of a Commercial Launch Vehicle for a launch in 2024. The Commercial Launch Vehicle will be obtained through a fully competitive selection and will not be limited to the launch vehicles listed in the NASA Launch Services II Contract.

Finally, many Science missions experienced delays and disruptions due to COVID-19 restrictions in FY 2020 and 2021, including facilities closures or limitations at NASA and contractor sites as well as supply chain issues. In some cases, additional funding has been added to mitigate these impacts and to ensure mission success. Detailed explanations are found in individual project sections below.

ACHIEVEMENTS IN FY 2020

SCIENCE RESULTS

NASA investments continue to generate productive science and meaningful results. In Planetary Science, data from NASA's Mercury Surface, Space Environment, Geochemistry and Ranging (MESSENGER) mission yielded surprising results, especially through expanded use of the topographic measurements from its laser altimeter. Detailed studies of Mercury's cratered surface—including using altimeter data to identify hidden basins—showed that half of Mercury's crater record is missing with the oldest craters obliterated by later events; quite different from the Earth's Moon, which has some craters nearly as old as the Moon itself. This research also supports the existence of only one population of impactors, in contrast to the theory of at least two populations including a late, heavy bombardment.

In Astrophysics, astronomers found the biggest explosion seen in the universe. This record-breaking eruption came from a black hole in a distant galaxy cluster. Astronomers made this discovery using X-ray data from NASA's Chandra X-ray Observatory and ESA's XMM-Newton as well as radio data from the Murchison Widefield Array (MWA) in Australia and the Giant Metrewave Radio Telescope in India. They detected the unrivaled outburst in the Ophiuchus galaxy cluster, which is about 390 million light years from Earth. Galaxy clusters are the largest structures in the Universe held together by gravity, containing thousands of individual galaxies, dark matter, and hot gas.

In Earth Science, researchers used Ice, Cloud and land Elevation Satellite 2 (ICESat-2) data to provide significant new insight into the behavior and trends of ice sheets. Researchers provided unified estimates of grounded and floating ice mass change from 2003 to 2019 from ICESat-2 data. Their analysis reveals patterns linked to the following climate processes: ice loss from coastal Greenland linked to increased surface melt, Antarctic ice shelves linked to increased ocean melting, Greenland and Antarctic outlet glaciers linked to dynamic response to ocean melting, and mass gains over ice sheet interiors linked to increased snow accumulation. Losses outpaced gains with grounded-ice loss from Greenland, at about 200 billion tons per year, and Antarctica, at about 118 billion tons per year, contributing 14 millimeters to sea level. Mass lost from West Antarctica's ice shelves accounted for more than 30 percent of that region's total. Quantifying changes in Earth's ice sheets and identifying the climate drivers are central to improving sea level projections.

In Heliophysics, the Magnetospheric Multiscale (MMS) mission recently discovered a new type of wave-particle interaction at work – low frequency waves. A density slope produces the low frequency waves that propagate through the electron reconnection region and accelerate particles there. This is likely triggering magnetic reconnection and the discovery was only possible with the extremely high-resolution MMS data. Most surprising has been the discovery that magnetic reconnection occurs in many more regions around the Earth than previously thought possible. MMS found reconnection at the bow shock, which is the interface between the Earth's magnetosphere and the solar wind and is analogous to the shock wave produced by a supersonic aircraft. The mission also found reconnection operating within plasma pile-up regions (i.e., dipolarization fronts) and within magnetic flux ropes, which are loops of magnetic field flung outward by reconnection events.

In Biological and Physical Science, the Rodent Research-12 study was completed on the International Space Station (ISS) in FY 2020. It investigated a mouse model with an immune system that closely parallels that of humans to understand how the immune system functioned in space after it was challenged by tetanus toxin. This study will provide a basis for developing measures designed to prevent compromised immune systems in space and help enable crew health during long-duration exploration missions.

NASA highlights these and many other scientific results in the pages that follow.

COST AND SCHEDULE PERFORMANCE

This budget reports recent cost and schedule delays in excess of Agency commitments on the NISAR, EMIT, GeoCarb and SWOT missions within Earth Science. Each of these missions has experienced significant disruptions due to the COVID-19 pandemic. Since 2011, when NASA implemented a requirement for most missions entering development to budget at the 70 percent confidence level, NASA has launched 24 Science missions subject to this requirement, with a total net budget underrun of 0.3 percent and 13 missions launched by NASA's original commitment date.

In the last 18 months, NASA successfully completed or launched three missions: Mars Rover 2020 (also known as Perseverance), Solar Orbiter Collaboration (SOC), and Sentinel-6 Michael Freilich (Sentinel-6 MF). The Mars Rover 2020 mission launched as planned in July 2020 and exceeded its development cost commitment by 21 percent. Both SOC and Sentinel-6 MF were launched by international partners. SOC launched in February 2020, 16 months later than planned and 26 percent under planned development costs. Sentinel-6 MF launched as planned in November 2020; development costs will be finalized after the launch of Sentinel-6B, planned for November 2026. All three missions are now conducting prime mission operations; Mars Rover 2020 (Perseverance) arrived on Mars in February 2021.

WORK IN PROGRESS IN FY 2021

NASA Science includes over 100 missions, most of which involve collaboration with international partners or other U.S. agencies. Work on over 45 missions in formulation and development continues, despite significant COVID-19 disruptions at NASA centers and contractor sites. In FY 2021 NASA launched the Sentinel-6 Michael Freilich mission, and will also launch the Landsat-9 mission. Operations of more than 60 other Science missions continue. Suborbital flights using aircraft, sounding rockets, and balloons were largely halted during 2020 due to COVID-19 related travel restrictions, but will restart in FY 2021 as local conditions improve. More than 3,000 competitively selected research awards will continue to scientists located at universities, independent research centers, NASA field centers, industry, and other Government agencies. NASA Science will expand several innovations within its competitive research programs including: Dual-Anonymous Peer Review (which has increased the diversity of talent in the NASA science ecosystem); and Blue Ribbon High-Risk/High-Impact review panel (which is designed to catalyze novel and potentially transformative research). In addition, several competitive research programs will be run with no due dates, increasing accessibility to NASA science funding.

By the end of FY 2021, NASA plans to make final selections from the four candidate Discovery missions, as well as initial selections for the next Astrophysics Small Explorers. NASA expects to receive the next Astrophysics Decadal Survey from the National Academies, which will guide Astrophysics mission planning for the decade spanning 2021-2031.

In FY 2021 NASA continued to be actively engaged in the development and utilization of SmallSats/CubeSats as a part of a balanced program of discovery. NASA will use SmallSats/CubeSats to perform technology demonstrations, train and develop the future workforce, and enable unique science observations. The Interstellar Mapping and Acceleration Probe (IMAP) mission has manifested four rideshare missions: Global Lyman-alpha Imagers of the Dynamic Exosphere (GLIDE), Lunar Trailblazer, Solar Cruiser, and Space Weather Follow On-Lagrange 1 (SWFO-L1). The Janus mission will take advantage of the Psyche mission launch to send two small spacecraft to two asteroid systems. Novel use of constellation mission architectures also enables new and unique methods of capturing science data. Multipoint science measurements are significantly more affordable using SmallSat/CubeSat constellations such as: Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of SmallSats (TROPICS), Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS), Polarimeter to Unify the Corona and Heliosphere (PUNCH), Escape and Plasma Acceleration and Dynamics Explorers (ESCAPADE), Janus, Polar Radiant Energy in the Far-InfraRed Experiment (PREFIRE), and Sun Radio Interferometer Space Experiment (SunRISE).

KEY ACHIEVEMENTS PLANNED FOR FY 2022

In FY 2022, after more than a decade of development and extensive environmental testing, NASA plans to launch the James Webb Space Telescope. Other planned FY 2022 launches include Lucy, Psyche, Double Asteroid Redirection Test (DART), X-ray Imaging and Spectroscopy Mission (XRISM), Imaging X-ray Polarimetry Explore (IXPE), and Euclid. Mission selections are planned from the Earth Venture Mission-3 Announcement of Opportunity (AO), as well as Astrophysics and Heliophysics Medium Explorer (MIDEX) selections. Within the Lunar Discovery & Exploration Program, the first two Commercial Lunar Payload Services deliveries will occur, delivering the first lunar science payloads to the surface of the Moon via this new commercial delivery model.

Anticipated growth of NASA’s science archives and advances in Artificial Intelligence (AI) and model-based methodologies for data analysis present unique opportunities for new scientific discovery and innovation. In FY 2022 NASA Science will coordinate and focus data systems investments in all five science divisions in order to drive adoption of novel data and computational technologies and systems and enable transformational open science. A new project within Earth Science, Open Sourced Science, will invest in cross-divisional capabilities and coordination.

NASA considers diversity and equity to be key strategic concepts in achieving scientific excellence. The Budget supports new initiatives within division research programs to expand the NASA community to better mirror the diversity of the United States. In FY 2022 NASA will invest funding in "bridge partnerships" with minority-serving institutions to provide paid research and engineering internships to students at participating institutions. The Budget also requests additional funding within the Science Activation project to advance equity and inclusion within the science education community. For example, new activities will focus on English language learners and indigenous communities, with special attention paid to advancing students into appropriate and relevant post-secondary educational institutions.

Themes

EARTH SCIENCE

From the vantage point of space, NASA satellites can view and study our home planet and its dynamic system of diverse components: the oceans, atmosphere, continents, ice sheets, and life. The Nation’s scientific community can thereby observe and track global-scale changes, connecting causes to effects. Scientists can study regional changes in their global context, as well as observe the role that human civilization plays as a force of change. NASA's Earth Science activities are an essential part of national and international efforts to understand change at all timescales and to use Earth observations and scientific understanding in service of society. Through its partnerships with other agencies that maintain forecasting and decision support systems, NASA helps to advance National capabilities to predict climate, weather, and natural hazards; manage resources; and inform the development of environmental policy.

In January 2018, the National Academies released the second Decadal Survey for Earth Science and Applications from Space, which provided recommendations for the next decade (2018 - 2027). The primary recommendations are included below, as well as current status:

- Complete the program of record, including maintaining the Venture Class program and completing missions currently in formulation and development. This budget supports the recommendation.
- Establish a "Continuity Measurement" strand as an addition to the existing Venture-class program to provide opportunity for the demonstration of low-cost sustained observations. This budget supports the recommendation within Venture class missions. The first Earth Venture mission, Libera, was selected in February 2020 and will maintain the 40-year data record of the balance between the solar radiation entering Earth's atmosphere and the amount absorbed, reflected, and emitted.
- Implement cost-capped medium- and large-size missions/observing systems to address the five "Designated" observables (Aerosols; Clouds, Convection, and Precipitation; Mass Change; Surface Biology and Geology; Surface Deformation and Change). This budget supports the implementation of four DO observing system/missions in the budget window, including Mission Concept Reviews for all four in FY 2022.
- Establish a new competed "Explorer" flight line to provide opportunities for cost-capped medium-size instruments and missions. This budget supports the establishment of the Earth System Explorer Program.
- Establish an "Incubator Program" to mature specific technologies for important – but presently immature – measurements. This budget supports the recommendation within the Earth Science Technology Program, in the Decadal Incubation project.

NASA asks the Earth Science Advisory Committee for input to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies.

PLANETARY SCIENCE

To answer questions about the solar system and the origins of life, NASA sends robotic space probes to the Moon, other planets and their moons, asteroids and comets, and the icy bodies beyond Neptune. In FY 2019, NASA began a new Lunar Discovery and Exploration program that is part of the Agency's exploration initiative. The program develops instruments and other payloads for missions to the lunar surface. In partnership with industry and with other NASA organizations, the new program will address exploration, science, and technology demonstration objectives as the Agency prepares for a sustained program of lunar exploration. NASA built the next Mars rover, which launched in July 2020 and arrived on Mars in February 2021. The Mars Rover 2020, also known as Perseverance, will address key questions about the potential for life on Mars and will cache samples for a future Mars Sample Return mission. In January 2019, the New Horizons spacecraft completed the first fly-by of a Kuiper Belt object. NASA is operating spacecraft at Mars, Jupiter, and the Moon, and the OSIRIS-REx spacecraft has captured a sample from the asteroid Bennu and is now returning the sample to Earth.

The primary recommendations of the National Academies' 2012 Decadal Survey for Planetary Science were:

- Continue Discovery solicitations, with the cost cap adjusted for inflation and a 24-month cadence. In the upcoming AOs, NASA will continue to impose a cost cap of $500 million FY 2019 constant dollars for phases A through D, not including the cost of the launch vehicle or the value of any non-NASA contributions, per the Decadal recommendation. This cost cap is equivalent to the $450 million FY 2015 in the previous AO, which led to the selection of the Lucy and Psyche missions. The out-year budget supports up to two new missions selected in spring of 2021 for launch no earlier than 2028.
- Continue New Frontiers with a $1 billion cost cap and select two new missions by 2022. This budget supports the recommended cost cap for the AO released in February 2017, which resulted in the 2019 selection of the Dragonfly mission to Saturn's moon Titan. The New Frontiers 5 AO will be released in 2024.
- Begin the two highest priority flagships: a Mars Astrobiology Explorer-Cacher and a Europa mission. This budget supports both the Mars Rover 2020 mission (launched July 30, 2020) that will address the highest priority Mars science objectives recommended by the Planetary Decadal Survey and the Europa Clipper project. The budget includes $653 million in FY 2022 toward development (along with international partners) of the Mars Sample Return mission, launching as early as 2026.
- Continue missions in development and flight, subject to senior review. This budget supports all missions selected for development, all missions in prime operations, and all extended missions.
- Increase research and analysis (R&A) spending by 5 percent above the FY 2011 budget level, and then 1.5 percent above inflation thereafter. This budget meets the recommendation.
- Increase Planetary Technology spending to six to eight percent of the total division budget, including completion of the advanced Stirling radioisotope generators. This budget meets the recommended goal for technology spending and includes funding for dynamic radioisotope power system development.
- Achieve a balanced program through a mix of Discovery, New Frontiers, and flagship missions and an appropriate balance among the many potential targets in the solar system. This budget achieves a balanced program by supporting the competed, Principal Investigator (PI)-led programs and two flagship missions (Mars Sample Return and Europa Clipper). It provides funding for the Icy Satellites Surface Technology project, including $5 million per year for technology efforts in support of a future Ocean Worlds lander mission.

NASA asks the Planetary Science Advisory Committee for input to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies.

ASTROPHYSICS

Space is the proving ground for many theories with breathtaking implications for our understanding of the physical universe, including the origin of the universe, black holes, dark matter and dark energy, and planets throughout the universe where life might exist. Having measured the age of the universe, the scientific community now seeks to explore further extremes: its birth, the edges of space and time near black holes, gravitational waves, and the mysterious dark energy filling the entire universe. Scientists have recently developed astronomical instrumentation and analysis methodologies sensitive enough to detect planets around other stars. With thousands of extrasolar planets now known, scientists are using current NASA missions in conjunction with ground-based telescopes to seek Earth-like planets in other solar systems.

The 2010 Decadal Survey in Astronomy and Astrophysics recommended a coordinated program of research, technology development, ground-based facilities, and space-based missions for implementation during 2012–2021. The primary recommendations were:

- Complete the ongoing program. The Astro 2010 Decadal Survey assumed continuation of the current program, which at that time assumed the launch of Webb in 2014; full operations of the Stratospheric Observatory for Infrared Astronomy (SOFIA) airborne observatory in 2012; and completion of three Explorer missions: the Nuclear Spectroscopic Telescope Array (NuSTAR) in 2012, the Gravity and Extreme Magnetism (GEMS) Explorer in 2014, and the U.S. contribution to the Japanese ASTRO-H mission in 2014. This budget fully supports launch of Webb in October 2021 and continued operations of NuSTAR (launched in 2012). NASA halted development of GEMS in 2012 due to cost overruns. NASA delivered the ASTRO-H instrument to Japan for launch in 2016. In response to the ASTRO-H spacecraft failure, this budget supports NASA's participation in the X-ray Imaging and Spectroscopy Mission (XRISM), Japan's planned recovery mission. This budget proposes termination of SOFIA given its high operating costs and low scientific productivity.
- Support the ongoing core research program to ensure a balanced program that optimizes overall scientific return. This budget fully supports the ongoing core research program and funds a balanced program of strategic and PI-led missions, research and analysis, suborbital projects, CubeSats, and technology development addressing the highest priorities in cosmic origins, exoplanet exploration, and physics of the cosmos.
- Launch the Nancy Grace Roman Space Telescope by 2020. This budget provides funding for the Nancy Grace Roman Space Telescope (formerly WFIRST) for a planned launch no earlier than 2026.
- Augment the Astrophysics Explorers Program to support the selection of four missions and four smaller missions of opportunity each decade. This budget fully supports the recommended cadence of new Astrophysics Explorers missions, with AOs in 2011, 2014, 2016, 2019, 2021, and 2024, and continues the small Pioneer-class Explorers.
- Launch the Laser Interferometer Space Antenna (LISA) by 2025. This budget supports studies and technology development leading toward a potential contribution to an ESA-led gravitational wave observatory for launch in the 2030s.
- Invest in Technology leading toward an international X-ray observatory in the 2020s. This budget supports a U.S. contribution to the ESA-led Athena advanced X-ray observatory for launch in the 2030s.
- Invest in a New Worlds technology development and precursor science program for a 2020s mission to image habitable rocky planets. This budget supports the technology development of coronagraphs, starshades, advanced mirrors, and precursor research programs required to realize potential missions that image and characterize habitable rocky exoplanets.
- Invest in technology development and precursor science for a 2020s mission to probe the epoch of inflation. This budget supports the development of technology and the conduct of precursor science

required for a potential future mission to probe the epoch of inflation at the immediate beginning of the universe.

- Increase funding for several targeted areas of supporting research and technology. This budget focuses investments on the science opportunities of CubeSats/SmallSats, taking advantage of the technological progress in the public and private sector toward meeting high-priority science goals. This budget also supports increased funding for research and analysis, including recommended investments in advanced technology development, theoretical and computational networks, suborbital programs, laboratory astrophysics, and technology for future ultraviolet/visible space telescopes.

NASA is continuing to address many of the Decadal Survey recommendations, though in some cases at a slower pace than anticipated. Adjustments to the Decadal Survey recommendations are primarily due to overly optimistic Decadal assumptions regarding future budgets, and challenges and delays to programs such as Webb. Other factors that could not be anticipated by the Decadal Survey include changing international partnership opportunities, emerging technologies that have changed what can be accomplished, and advances in our scientific understanding of the universe. The 2016 Midterm Assessment of decadal survey progress found that "NASA has maintained a balanced portfolio through the first half of the decade and, with the assumption of successful completion of an ambitious Explorer schedule, will do so during the second half of the decade as well." In 2019, NASA received the recommendations from the Senior Review of operating Astrophysics missions, which has informed the FY 2022 Budget request.

NASA asks the Astrophysics Advisory Committee for input to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies. NASA anticipates the National Academies will release the next Astrophysics Decadal Survey in 2021.

HELIOPHYSICS

The Sun, a typical small star midway through its life, governs our solar system. The Sun wields its influence through its gravity, radiation, solar wind, and magnetic fields, all of which interact with the Earth and its space environment. These processes are crucial for our understanding of the universe, and they relate directly to our ability to live in space as they produce space weather, which can affect human technological infrastructure and activities in space. Using a fleet of sensors on various spacecraft in Earth orbit and throughout the heliosphere, NASA seeks to understand the fundamental processes of how and why the Sun varies, how Earth and our solar system respond to the Sun, how the Sun and the solar system interact with the interstellar medium, and how human activities are affected by these processes. The science of heliophysics, including space weather, enables the predictions necessary to safeguard life and society on Earth and the outward journeys of human and robotic explorers.

The primary recommendations of the National Academies' 2013 Decadal Survey for Heliophysics were:

- Maintain and complete the current program. The Decadal Survey assumed launch of Van Allen Probes by 2012, Interface Region Imaging Spectrograph (IRIS) by 2013, Magnetospheric Multiscale (MMS) by 2014, Solar Orbiter Collaboration (SOC) by 2017, Parker Solar Probe by 2018, and continued current funding of the research program. Van Allen, IRIS, MMS, Parker Solar Probe, and the ESA-led Solar Orbiter Collaboration have all launched.
- Implement the DRIVE (Diversify, Realize, Integrate, Venture, Educate) initiative, including the incorporation of smaller spacecraft and an increase in the competed research program from 10 percent

to about 15 percent of the budget request. This budget request supports competed research budgets of between 13 and 15 percent and invests in the SMD-wide CubeSat/SmallSat initiative.

- Accelerate and expand the Heliophysics Explorer Program, resulting in an increase to the cadence of competed missions to one launch every two to three years. NASA launched IRIS in 2013, Global-Scale Observations of the Limb and Disk (GOLD) in 2018, and ICON in October 2019. The proposed out-year budgets, if realized, would enable launch of Atmospheric Waves Experiment (AWE) mission of opportunity in 2022, Polarimeter to Unify the Corona and Heliosphere (PUNCH) in 2023 and Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) no earlier than 2023. The budget also supports the launch by 2026 of one mission that will be selected through the 2019 MIDEX solicitation. NASA plans additional launches approximately every two years thereafter.
- Restructure Solar Terrestrial Probes (STP) as a moderate-scale, principal investigator-led flight program, and implement three mid-scale missions with an eventual recommended four-year cadence. This budget supports launch of the PI-led IMAP mission in 2025. NASA selected the GLIDE SmallSat mission from the most recent STP MO announcement of opportunity and will initiate a competitive selection for the Dynamical Neutral Atmosphere-Ionosphere Coupling (DYNAMIC) mission in FY 2022.
- Implement a large Living with a Star (LWS) mission to study Global Dynamic Coupling with a launch in 2024. In FY 2021 NASA began formulation of the Geospace Dynamics Constellation mission, with a targeted launch date no earlier than 2027.

The Decadal Survey also made recommendations related to space weather applications, addressed collectively to the relevant Government agencies. NASA has implemented the HERMES (Heliophysics Environmental & Radiation Measurement Experiment Suite) space weather instrument destined to operate on the Gateway and maintains funding for space weather applications research. NASA will continue collaborating with other agencies to improve space weather observation and forecasting capabilities.

NASA asks the Heliophysics Advisory Committee for input to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies.

BIOLOGICAL AND PHYSICAL SCIENCES

NASA pioneers research to understand how spaceflight affects living systems in space and to prepare for future human exploration missions far from Earth. The experiments NASA conducts on the International Space Station (ISS) and other platforms examine how astronauts, plants, and animals regulate and sustain their growth in space. NASA examines processes of metabolism, reproduction, and development and studies how organisms repair cellular damage and protect themselves from infection and disease in conditions of microgravity. In addition to providing useful information on how living organisms adapt to spaceflight, the discoveries NASA makes in space have enormous implications for life on Earth. NASA also conducts research to understand the fundamental laws of the universe, as well as determine how physical systems react in spaceflight environments. This research provides basic scientific knowledge and results leading to societal benefit, including contributions to the basic understanding underlying space exploration technologies such as power generation and storage, space propulsion, life support systems, and environmental monitoring and control. All have led to improved space systems or new products on Earth.

SCIENCE

The Decadal Survey on Biological and Physical Sciences Research in Space 2023-2032 will review the state of knowledge in the current and emerging areas of space-related biological and physical sciences research and generate consensus recommendations for a comprehensive vision and strategy for a decade of transformative science at the frontiers of biological and physical sciences research in space. The study report will help NASA define and align biological and physical sciences research to uniquely advance scientific knowledge, meet human and robotic exploration mission needs, and provide terrestrial benefits.

EARTH SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Earth Science Research	472.9	479.7	**537.5**	535.9	551.6	588.0	600.1
Earth Systematic Missions	858.9	780.5	**836.1**	1,004.8	988.8	1,068.7	1,120.0
Earth System Explorers	0.0	0.0	**6.6**	23.4	34.3	92.0	150.2
Earth System Science Pathfinder	273.6	316.1	**375.3**	273.9	282.1	238.0	225.2
Earth Science Data Systems	243.5	278.6	**330.7**	338.0	368.4	377.5	392.8
Earth Science Technology	69.6	82.2	**91.1**	93.3	95.9	108.1	110.2
Applied Sciences	53.3	62.9	**72.7**	74.2	77.3	100.8	103.7
Total Budget	**1,971.8**	**2,000.0**	**2,250.0**	**2,343.5**	**2,398.3**	**2,573.0**	**2,702.3**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

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Earth Science

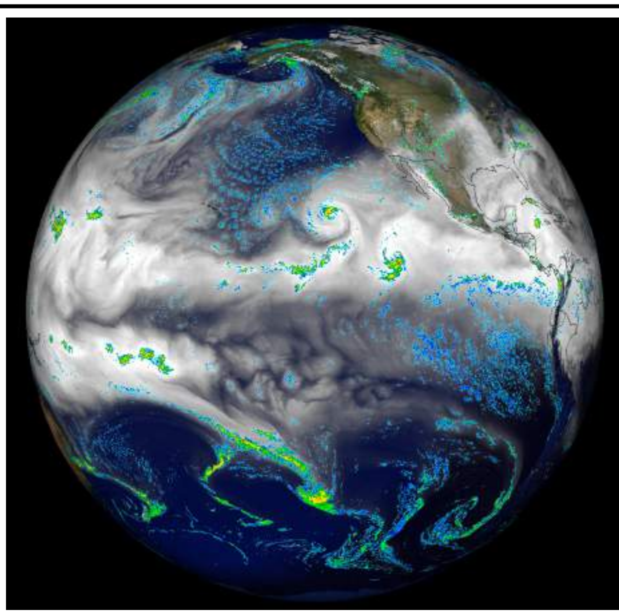
EARTH SCIENCE RESEARCH

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Earth Science Research and Analysis	321.2	344.4	**363.8**	359.9	365.6	384.7	393.2
Computing and Management	151.7	135.3	**173.6**	176.0	186.0	203.3	206.8
Total Budget	**472.9**	**479.7**	**537.5**	**535.9**	**551.6**	**588.0**	**600.1**
Change from FY 2021			**57.8**				
Percentage change from FY 2021			**12.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Goddard Earth Observing System (GEOS) ocean-air model simulation showing suspended rain, snow, and graupel in the atmosphere.

NASA's Earth Science Research program develops a scientific understanding of Earth and its response to natural or human-induced changes. Earth is a system, like the human body, comprised of diverse components interacting in complex ways. Understanding Earth's atmosphere, crust, water, ice, and life as a single, connected system is necessary to improve our predictions of climate, weather, and natural hazards. The Earth Science Research program addresses complex, interdisciplinary Earth science problems in pursuit of a comprehensive understanding of the Earth system. This strategy involves six interdisciplinary and interrelated science focus areas, including:

- Water and Energy Cycle: quantifying the key reservoirs and fluxes in the global water cycle, assessing water cycle change, and assessing water quality.
- Weather and Atmospheric Dynamics: enabling improved predictive capability for weather and extreme weather events.
- Earth Surface and Interior: characterizing the dynamics of the Earth's surface and interior and forming the scientific basis for the assessment and mitigation of natural hazards and response to rare and extreme events.

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- Climate Variability and Change: understanding the roles of ocean, atmosphere, land, and ice in the climate system and improving our ability to predict future changes.
- Atmospheric Composition: understanding and improving our predictive capability for changes in the ozone layer, Earth's radiation budget, and air quality associated with changes in atmospheric composition.
- Carbon Cycle and Ecosystems: quantifying, understanding, and predicting changes in Earth's ecosystems and biogeochemical cycles, including the global carbon cycle, land cover, and biodiversity.

NASA's Earth Science Research program pioneers the use of both space-borne and aircraft measurements in all these areas. The Earth Science Research program is critical to the advancement of the interagency U.S. Global Change Research Program (USGCRP), established in 1989 and mandated in the Global Change Research Act of 1990 to develop and coordinate "a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." The Earth Science Research program also makes extensive contributions to international science programs, such as the World Climate Research Program.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Budget request increases funding for Earth Science research to enhance NASA's ability to address important climate research priorities such as: coastal resilience and infrastructure, renewable energy, water availability (including subseasonal-to-seasonal modeling), as well as carbon monitoring and carbon cycle science. See more detailed information in the FY 2022 section below.

NASA renamed the "Fellowships and New Investigators" project to "Early Career Research" and it now includes both Future Investigators in NASA Earth and Space Science and Technology (FINESST) and the New Investigator Program (NIP).

ACHIEVEMENTS IN FY 2020

During the boreal winter/spring of 2019/2020, also known as the Northern Hemisphere winter/spring, the Arctic stratospheric polar vortex experienced an early onset and a sustained presence of the cold conditions conducive to the microphysical and chemical processes that result in chlorine-catalyzed ozone loss. These same processes give rise to the Antarctic "ozone hole." A NASA study used observations from the Microwave Limb Sounder (MLS) on NASA's Aura mission to show that during 2019/2020, the chemical composition of the Arctic polar vortex evolved in a more Antarctic-like manner than typical, leading to the lowest Arctic ozone values ever observed in the lower stratosphere.

A recent publication provided the first documentation of the structure of carbon dioxide and methane across frontal boundaries (i.e., the boundary between two different air masses which result in stormy weather) as a function of altitude, using measurements from the Atmospheric Carbon and Transport-America (ACT-America) 2016 summer field experiment. This study provides benchmark metrics of greenhouse gas weather to evaluate the atmospheric transport and carbon flux simulations needed to interpret long-term atmospheric carbon observations. Another paper showed that methane emissions from the oil and gas producing regions in the south-central United States are twice as large as estimated in current Environmental Protection Agency (EPA) emissions inventories, while agricultural methane emissions agree with EPA inventories. To distinguish between these two major methane sources, the researchers employed an innovative dual-tracer technique as well as ethane-to-methane emission ratios for the methane sources. They also demonstrated a new, weather-informed technique to solve for emissions from a large region.

A study characterizing the light penetration in coral reef and adjacent waters of Hawaii and Bermuda found that the suspended sediments on coral reef flats and in lagoons has the effect of decreasing the overall light penetration. The authors also found that reefs generate large amounts of dissolved organic matter which help protect them from UV radiation. These data provide some insight into reef water clarity and color and their importance to reef ecology. Light also impacts a variety of ecosystem functions, such as phytoplankton growth. Using data from the North Atlantic Aerosol and Marine Ecosystem Study, another study examined the important role of light on phytoplankton growth and zooplankton grazing rates. The results suggest that light could be a potential tool to predict the relative dynamics of phytoplankton growth and grazing losses, especially in large areas of the ocean.

A study leveraged a time series of Landsat satellite data to map deforestation, degradation, and natural disturbance in the Amazon rainforest from 1995 to 2017. They found that the area of disturbed forest in the Amazon is between 44 to 60 percent more than previously realized, indicating an unaccounted-for source of global carbon emissions and more pervasive damage to forest ecosystems in the Amazon. Another study used Landsat time series data (2000-2016) to map the drivers of mangrove forest loss, one of the most carbon dense ecosystems on the planet. The study estimated that 62 percent of global mangrove losses between 2000 and 2016 resulted from land-use change, primarily through conversion to aquaculture and agriculture. Up to 80 percent of these human-driven losses occurred within six Southeast Asian nations, reflecting the regional policy of enhancing aquaculture for export to support economic development.

Use of remote sensing in ecological studies found that sharks leverage swirling ocean vortices (i.e., mesoscale eddies) as a means of diving and foraging in deeper waters. Combining shark movement data gathered through satellite-transmitters and remotely sensed observations of sea surface height variation, researchers quantified specific shark–eddy interactions. This predator dives deep in warm, swirling water masses called warm-core (i.e., anticyclonic) eddies to forage in the deep ocean that contains the largest fish biomass on Earth.

California's Central Valley, one of the world's most productive agricultural regions and an area highly dependent on groundwater resources, experienced a drought from 2012 to 2015 that has been the subject of study for several publications utilizing GRACE and InSAR data. Researchers used both GRACE and Sentinel-1 InSAR data to monitor groundwater resources following the drought and found continued pumping-induced subsidence. They also found a close temporal correlation in subsidence events and groundwater anomaly variation from GRACE, demonstrating the utility of satellite geodesy in tracking groundwater storage change. Another study demonstrated that the California Central Valley aquifer system did not reach equilibrium during the drought and may be experiencing delayed compaction, adding to the amount of subsidence observed after the drought. Further studies looked at InSAR data from 2019 in the Central Valley to identify elastic (recoverable) and inelastic (permanent) deformation occurring in the aquifer to develop sustainable pumping practices. They found that, contrary to previous research, both seasonal and long-term multi-seasonal drawdown contain an elastic deformation component.

Extreme precipitation events have the potential to create catastrophic flooding, landslides, and infrastructure damage. Researchers diagnosed the spatial and temporal characteristics of such events

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using Integrated Multi-SatellitE Retrievals for GPM (IMERG) precipitation estimates to construct a record of extreme events that depict both the spatial extent and evolution of precipitation systems. They developed a classification approach that enables the accurate depiction of duration, areal coverage (i.e., a large area which is an expanse of space or a region of land), total volume, and propagation of each extreme event over its entire life cycle. Results from four years of IMERG statistics over the contiguous United States show that the most frequent extreme events have duration between three to six hours, an affected area of 1,000 – 50,000 square kilometers and a total precipitation volume of 106 –108 cubic meters. These events occur most frequently in the Northwest and Northeast U.S. in winter and spring, and the Southwest and Southeast in summer. Fall has the least number of extreme events and summer exhibits some of the heaviest and largest events.

Between 1992 and 2017, the Antarctic Ice Sheet (AIS) lost ice equivalent to 7.6 ± 3.9 millimeters of sea level rise. Ice shelves that provide a buttress by regulating ice flow from tributary glaciers mitigated AIS mass loss. However, meltwater ponding, which threatens ice-shelf stability, may initiate new fractures, or reactivate preexisting fractures. Through ground penetrating radar analysis over a buried lake in the grounding zone of an East Antarctic ice shelf, researchers presented the first field observations of a lake drainage event in Antarctica via vertical fractures. Concurrent with the lake drainage event, they observed a decrease in surface elevation and an increase in Sentinel-1 backscatter. They suggest that fractures, initiated or reactivated by lake drainage events in a grounding zone, will propagate with ice flow onto the ice shelf itself where they may have implications for its stability.

Research found abrupt decline in tropospheric nitrogen dioxide over China after the outbreak of COVID-19. The study showed reductions in satellite measurements of nitrogen dioxide (NO2) pollution over China before and after the Lunar New Year. The observed reduction in 2020 was approximately 20 percent larger than the typical holiday-related reduction and was primarily due to the changes in human behavior resulting from the outbreak of COVID-19. NO2 is a measure of economic activity, as NO2 is primarily emitted from fossil fuel consumption. The authors related this NO2 reduction to the imposition of provincial lockdowns and to the reporting of the first of COVID-19 case in each province that preceded the lockdowns. Both actions were associated with the same magnitude of reductions.

WORK IN PROGRESS IN FY 2021

With the additional $34.5 million appropriated in FY 2021, Earth Science research will continue through projects selected competitively from Release of Research Opportunities in Space and Earth Science (ROSES) 2019 and 2020. Notable research programs funded in FY 2021 are described below including the implementation of new awards from the most recent Interdisciplinary Science solicitation, based on remote sensing data and satellite observations, including suborbital sensors as appropriate. These investigations go beyond correlation of data sets and seek to understand the underlying causes of change through determining the specific physical, chemical, and/or biological processes involved. The selected projects involve traditionally disparate disciplines of the Earth sciences, and address at least one of the seven specific themes of emerging high priority research: Volcanoes in the Earth System; Interactions Between Sea Ice and the Atmosphere; Polar Ocean/Biology/Biogeochemical Coupling; The Life Cycle of Snow; Impacts of Urbanization on Local and Regional Hydrometeorology; Space-Enabled Archaeology: Using the Past to Inform the Present and Future; and Exploring the Microbial Biodiversity of the Atmosphere.

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The Remote Sensing Theory (RST) program will initiate selected projects to develop improved algorithmic and theoretical approaches for space-based remote sensing of the Earth in areas including theoretical algorithm advances, data fusion research, and advanced corrections research.

The Airborne Instrument Technology Transition (ITT) program will fully fund the first of two years for all recently selected projects. The program will also integrate existing instruments, developed under the NASA Instrument Incubator Program (IIP) or other similar development programs, onto platforms supported by the NASA Airborne Science Program. The selected projects will enhance four different instruments to be fully campaign ready and able to serve the NASA community. The projects involve remote sensing using a wide variety of remote sensing techniques and push the envelope to make new observation capabilities available to the scientific community.

NASA released the "Rapid Response and Novel Research in Earth Science" (RRNES) of ROSES 2020 as an opportunity to propose investigations which make innovative use of NASA satellite data to address regional or global environmental, economic, and/or societal impacts of the COVID-19 pandemic. Such widespread, rapid change in human activity is unprecedented and its effects are only just beginning to show. The research program, initiated support for the science community as it investigates the many changes this unique situation has brought to light. Through its RRNES initiative, the Agency is providing funding for selected, rapid-turnaround projects that make innovative use of satellite data and other NASA resources to address the different environmental, economic, and societal impacts of the pandemic. These projects will compete their work in FY 2021. Early selected investigations include: Exploring Uneven Gains in Urban Air Quality; Impact of Air Pollution Reduction on the Atmosphere; Air Pollution Links to Water Quality; and Shedding (Night) Light on Pandemic Economic Impacts.

NASA plans to make selections from the Modeling, Analysis and Prediction program solicitation in FY 2021. About 20 percent of these awards will focus on the area of Earth system prediction and predictability.

The New Investigator Program element (NIP) will initiate a new round of tasks beginning in FY 2021 with plans in place to support not only a larger set of investigators through than in the past, but also for approximately 20 percent larger tasks in order for the tasks to better support early career investigators. The NIP program solicitation is currently every three years, with applicants eligible for up to six years after their PhD, allowing all eligible investigators two opportunities to propose to this element.

In summer 2021, as part of Tracking Aerosol Convection interactions ExpeRiment (TRACER) Air Quality (AQ) campaign, NASA will deploy several assets (including aircraft and ground sensor units) to the Houston metropolitan region for a month to observe air quality and provide data to better understand the relationship between air pollution and health. NASA will conduct this effort in parallel with the Department of Energy led TRACER campaign. During TRACER-AQ, two of NASA's high-resolution ozone lidar instruments will collect information about the vertical distribution of this harmful pollutant. These observations are in collaboration with local and State stakeholders, providing measurements to better understand Houston's air quality and as a demonstration of some of the future capabilities of NASA's TEMPO geostationary air quality sensor.

NASA is coordinating planning with the European Space Agency (ESA) for a jointly organized field campaign to make measurements of the vertical profile of atmospheric winds using airborne and satellite data (with satellite data coming from ESA's Aeolus satellite). Both the ESA and the NASA campaigns will fly from Cabo Verde, off the west coast of Africa in summer 2021.

EARTH SCIENCE RESEARCH

KEY ACHIEVEMENTS PLANNED FOR FY 2022

In 2022, NASA plans to initiate new awards solicited in ROSES 2021. While most of the solicitations represent the periodic solicitations of ongoing R&A programs, several new initiatives are discussed below.

The NASA Physical Oceanography program element is preparing to conduct a dedicated Ocean Salinity Field Campaign in 2022-2023 to investigate the role of salinity in polar environments. NASA will integrate the observational field campaign with satellite observations and modeling studies in support of the salinity remote sensing missions and polar oceanography. The main scientific thrust of the campaign is to clarify the role of salinity in ocean-ice interactions and characterize potential salinity-ice feedback mechanisms in the rapidly changing Arctic ocean.

In FY 2022 NASA will plan the Arctic Radiation-Cloud-Aerosol-Surface-Interaction Experiment (ARCSIX) as an airborne investigation to take place during late spring/early summer with flights by two aircraft: a low flying in-situ sampling aircraft and a high flying remote sensing aircraft, flying over open water and sea ice in the Arctic Ocean. The overarching goal of ARCSIX is to quantify the contributions of surface properties, clouds, aerosol particles, and precipitation to the Arctic summer surface radiation budget and sea ice melt during the early melt season (proposed for May through mid-July 2023).

NASA plans to upgrade the Space Geodesy Satellite Laser Ranging stations. Upon completion of the upgrade, NASA expects improved accuracy for Precision Orbit Determination for missions such as ICESat-2 and GRACE-FO data products. The upgrade will also increase the accuracy of low-degree gravity field products in GRACE-FO, as well as strengthen confidence in the estimates of sea level rise rate and its acceleration such as those provided by Sentinel-6 Michael Freilich.

Scientific Computing plans to increase investment for cloud computing capabilities and facilities that will support sustainable growth. HECC plans to increase funding for technology refreshes to provide enhanced performance and productivity.

In the area of Coastal Resilience and Infrastructure, NASA is committed to understanding climate impacts and providing an important knowledge base that communities can use in preparing for changing climate conditions, providing an integrated, science-based approach to climate risk management. NASA plans to expand work associated with sea level rise, building off the current NASA Sea Level Change Team activity, strengthen partnerships with other Federal agencies (especially as coordinated through the U.S. Global Change Research Program initiative on coasts), and further integrate existing observations and models. There will also be enhanced emphasis on studies of water quality in coastal regions and analysis of the factors that affect it. Together, these will support the United States' involvement in the United Nations Decade of Ocean Science for Sustainable Development.

NASA will enhance renewable energy studies of atmospheric methane to allow better understanding of emissions using available satellite and airborne data together with atmospheric models. Integrated studies of both human-induced and naturally occurring emissions will help discriminate between the two types of sources.

NASA will continue to maintain a state-of-the-art seasonal prediction system for use in evaluating the impact of water availability, including subseasonal-to-seasonal modeling, and assimilate newly available satellite observations. The Agency will also evaluate additional sources of predictability in the Earth system through the expanded coupling of the Earth system model and assimilation components. Evaluation will highlight extreme precipitation events (e.g., atmospheric rivers) and the further

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development and utilization of ocean observations critical to the atmosphere-ocean connections that contribute to Earth System predictability.

Earth Science Research will use the full range of Earth observatory satellite and airborne observations for carbon monitoring and carbon cycle science, modeling/analysis capabilities, and commercial off-the-shelf technologies. The analysis will be used to produce and share well-characterized products (including atmosphere-surface fluxes and surface biomass products) that can be used for both scientific (e.g., carbon cycle budgets) and policy assessment purposes.

Program Elements

GLOBAL MODELING AND ASSIMILATION OFFICE

The Global Modeling and Assimilation Office creates global climate and Earth system component models using data from Earth science satellites and aircraft. Investigators can then use these products worldwide to further their research.

AIRBORNE SCIENCE

The Airborne Science project is responsible for providing aircraft systems to further science and advance the use of satellite data. NASA uses these assets worldwide in campaigns to investigate extreme weather events, observe Earth system processes, obtain data for Earth science modeling activities, and calibrate instruments flying aboard Earth science spacecraft. NASA Airborne Science platforms support mission definition and development activities. These activities include:

- Conducting instrument development flights;
- Gathering ice sheet observations as gap fillers between missions (e.g., Operation IceBridge);
- Serving as technology test beds for Instrument Incubator Program missions;
- Serving as the observation platforms for research campaigns, such as those competitively selected under the suborbital portion of Earth Venture; and
- Calibrating and validating space-based measurements and retrieval algorithms.

OZONE TRENDS SCIENCE

The Ozone Trends Science project produces a consistent, calibrated ozone record used for trend analyses and other studies.

INTERDISCIPLINARY SCIENCE

Interdisciplinary Science includes science investigations as well as calibration and validation activities that ensure the utility of space-based measurements. In addition, this project supports focused fieldwork (e.g., airborne campaigns) and specific facility instruments which fieldwork depends on.

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EARTH SCIENCE RESEARCH AND ANALYSIS

Earth Science Research and Analysis is the core of the research program and funds the analysis and interpretation of data from NASA's satellites. This project funds the scientific activity needed to establish a rigorous foundation for the satellites' data and their use in computational models.

EARLY CAREER RESEARCH

The Early Career Research project (formally named Fellowships and New Investigators) supports graduate and early career research in the areas of Earth system research and applied science.

SPACE GEODESY

Geodesy is the science of measuring Earth's shape, gravity, orientation, and rotation and how these properties change over time. The Space Geodesy Project (SGP) encompasses the development, operation, and maintenance of a global network of space geodetic technique instruments, a data transport and collection system, data analysis, and the public dissemination of data products required to maintain a stable terrestrial reference system. SGP provides the data and analysis essential for fully realizing the measurement potential of the current and coming generation of Earth Observing spacecraft.

EARTH SCIENCE DIRECTED RESEARCH AND TECHNOLOGY

The Earth Science Directed Research and Technology project funds the civil service staff who work on emerging Earth Science flight projects, instruments, and research.

GLOBAL LEARNING AND OBSERVATIONS TO BENEFIT THE ENVIRONMENT

Global Learning and Observations to Benefit the Environment (GLOBE) is a worldwide hands-on primary and secondary school-based project that promotes collaboration among students, teachers, and scientists to conduct inquiry-based investigations about our environment. NASA works in close partnership with NOAA and the National Science Foundation to study the dynamics of Earth's environment, focused on atmosphere, hydrosphere, pedosphere (i.e., soil), and biosphere. Students take measurements, analyze data, and participate in research in collaboration with scientists. NASA initiated a citizen science component, called GLOBE Observer, in 2016 that makes four protocols available for use by anyone in a GLOBE country.

For more information, go to: http://www.globe.gov

SCIENTIFIC COMPUTING

The Scientific Computing project funds NASA's Earth Science Discover supercomputing system, high-end storage, network, software engineering, and user interface projects at NASA Goddard Space Flight Center (GSFC), including climate assessment modeling and data analysis. Scientific Computing supports Earth system science modeling activities based on data collected by Earth science spacecraft. The system is separate from the High-End Computing Capability program at NASA Ames Research

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Center, so it can be close to the satellite data archives at GSFC. The proximity to the data and the focus on satellite data assimilation makes the Discover cluster unique in its ability to analyze large volumes of satellite data quickly. The system currently has approximately 100,000 computer processor cores.

HIGH END COMPUTING CAPABILITY

High End Computing Capability (HECC) focuses on the Endeavour, Merope, Pleiades, Electra, and Aitken supercomputer systems and the associated network connectivity, data storage, data analysis, visualization, and application software support. It serves the supercomputing needs of all NASA mission directorates and NASA-supported principal investigators at universities. The funding supports the operation, maintenance, upgrade, and expansion of NASA's supercomputing capability. These four supercomputer systems, with approximately 865,000 computer processor cores, support NASA's aeronautics, human exploration, and science missions. For example, the systems are being used to perform first-of-a-kind simulations helping engineers reduce risk from acoustic vibrations generated by Orion's Launch Abort System motor. The systems also run simulations created with unprecedented resolution helping scientists understand how galaxies co-evolve with extensive reservoirs of gas around them.

DIRECTORATE SUPPORT

The Directorate Support project funds the NASA Science Mission Directorate's institutional and crosscutting activities including: National Academies studies, proposal peer review processes, printing and graphics, information technology, the NASA Postdoctoral Fellowship program, working group support, independent assessment studies, procurement support for the award and administration of all grants, and other administrative tasks.

Program Schedule

Date	Significant Event
Q1 FY 2021	ROSES-2020 selection within six to nine months of receipt of proposals
Q2 FY 2021	ROSES-2021 solicitation release
Q1 FY 2022	ROSES-2021 selection within six to nine months of receipt of proposals
Q2 FY 2022	ROSES-2022 solicitation release
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation release
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation release
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation release

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Date	Significant Event
Q1 FY 2026	ROSES-2025 selection within six to nine months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation release

Program Management & Commitments

Program Element	Provider
Global Modeling and Assimilation Office	Provider: Various Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): N/A
Airborne Science	Provider: Various Lead Center: HQ Performing Center(s): AFRC, ARC, WFF, JSC, LaRC Cost Share Partner(s): N/A
Scientific Computing	Provider: GSFC Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): N/A
Ozone Trends Science	Provider: Various Lead Center: HQ Performing Center(s): LaRC, GSFC Cost Share Partner(s): USGCRP and SOST agencies
Interdisciplinary Science	Provider: Various Lead Center: HQ Performing Center(s): HQ, JPL, GSFC, ARC, AFRC, GRC, LaRC, MSFC, JSC Cost Share Partner(s): USGCRP and SOST agencies
Earth Science Research and Analysis	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): USGCRP and SOST agencies
High-End Computing Capability	Provider: ARC Lead Center: HQ Performing Center(s): ARC Cost Share Partner(s): N/A

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Program Element	Provider
Directorate Support	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): N/A
Early Career Research	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): N/A
Space Geodesy	Provider: Various Lead Center: GSFC Performing Center(s): GSFC, JPL Cost Share Partners: N/A
Global Learning and Observations to Benefit the Environment	Provider: University Corporation for Atmospheric Research Lead Center: HQ Performing Center(s): HQ, GSFC Cost Share Partner(s): N/A

Acquisition Strategy

NASA implements the Earth Science Research program via competitively selected research awards. NASA releases research solicitations each year in the ROSES NASA Research Announcements. All proposals in response to NASA ROSES are peer reviewed and selected based on defined criteria. The program competitively awards funds to investigators from academia, the private sector, NASA centers, and other Government agencies.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Earth Science Advisory Committee	2020	To review progress towards Earth Science objectives in the NASA Strategic Plan	All six science focus areas remained on track towards the achieving both Earth Science annual performance goals	2021; annually

EARTH SYSTEMATIC MISSIONS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Surface Water and Ocean Topography Mission (SWOT)	98.2	63.9	**32.8**	47.5	10.5	10.6	6.5
NASA-ISRO Synthetic Aperture Radar (NISAR)	201.6	75.5	**73.3**	58.6	28.9	24.2	15.7
Landsat 9	37.9	86.5	**2.8**	2.9	3.0	3.0	3.1
Sentinel-6	13.4	8.0	**22.8**	40.3	63.9	55.2	25.6
PACE	131.0	145.1	**119.4**	100.3	67.0	20.1	12.0
Other Missions and Data Analysis	376.8	401.6	**585.0**	755.2	815.6	955.5	1,057.2
Total Budget	**858.9**	**780.5**	**836.1**	**1,004.8**	**988.8**	**1,068.7**	**1,120.0**
Change from FY 2021			**55.6**				
Percentage change from FY 2021			**7.1%**				

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Technicians are shown preparing the Landsat 9 observatory for electromagnetic testing. On top of the spacecraft are the Operational Land Imager 2 and the Thermal Infrared Sensor 2 instruments. Also shown is the thermal insulating blanketing.

The Earth Systematic Missions (ESM) program includes a broad range of multi-disciplinary science investigations aimed at understanding the Earth system and its response to natural and human-induced forces and changes. Understanding these forces will help determine how to predict future changes and mitigate or adapt to these changes.

The ESM program develops Earth-observing satellite missions, manages the operation of these missions once on-orbit, and produces mission data products to support the research and applications communities.

Interagency and international partnerships are central elements of the ESM program. More than half of the projects in development under ESM have an international or interagency contribution, and several on-orbit missions provide data products in near real-time for use by the United States and international meteorological agencies and disaster responders.

EARTH SYSTEMATIC MISSIONS

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Budget request includes funding to accelerate the development of four Designated Observable missions (recommended in the 2017 Decadal Survey), each of which will provide important climate science observations. The request also accommodates an increase in the lifecycle cost for the NISAR mission; NASA expects this mission to exceed its baseline for development cost and schedule. See the NISAR sections for additional details. Based on a recent assessment, NASA has concluded that the SWOT project will exceed its Agency Baseline Commitment for schedule (i.e., Launch Readiness Date) of April 2022 by more than six months. A notification to Congress will be issued soon. See the SWOT section for additional details. The request includes funding for the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) and the Climate Absolute Radiance and Refractivity Observatory Pathfinder (CLARREO Pathfinder) missions. The budget will also support sustained observations to provide ongoing situational awareness of the changing climate and earth system, to support climate change prediction and implementation of adaption and mitigation measures.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	136.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	136.8
Development/Implementation	414.4	98.2	63.9	**32.8**	29.8	0.0	0.0	0.0	0.0	639.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	17.7	10.5	10.6	6.5	1.4	46.7
2021 MPAR LCC Estimate	**551.2**	**98.2**	**63.9**	**32.8**	**47.5**	**10.5**	**10.6**	**6.5**	**1.4**	**822.4**
Total Budget	**551.2**	**98.2**	**63.9**	**32.8**	**47.5**	**10.5**	**10.6**	**6.5**	**1.4**	**822.4**
Change from FY 2021				**-31.1**						
Percentage change from FY 2021				**-48.7%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The 2021 MPAR LCC Estimate reflects the Fiscal Year 2021 Quarter 2 Financial Report, which is current as of March 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since March 2021.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

An artist's concept shows the Surface Water Ocean Topography (SWOT) satellite, which entered the implementation phase in May 2016. SWOT will make high-resolution, wide-swath altimetric measurements of the world's oceans and fresh water bodies to understand their circulation, surface topography, and storage. This multi-disciplinary, cooperative international mission will produce science and data products that will allow for fundamental advances in understanding the global water cycle.

PROJECT PURPOSE

The Surface Water and Ocean Topography (SWOT) mission will improve our understanding of the world's oceans and terrestrial surface waters. The mission will make high-resolution measurements of ocean circulation, its kinetic energy, and its dissipation, through broad swath altimetry. These measurements will improve ocean circulation models and predictions of weather and climate. The mission will also revolutionize knowledge of the surface water inventory on the continents by making precise measurements of water levels in millions of lakes and water bodies and the discharge of all major rivers. This will allow for deeper understanding of the natural water cycle and potentially better water management.

The 2007 and 2017 National Academies decadal surveys endorsed SWOT. The mission will complement the Jason oceanography missions, as well as other NASA missions currently in operation and development to measure the global water cycle: Sentinel-6, Global Precipitation Measurement, Soil Moisture Active Passive, and Gravity Recovery and Climate Experiment Follow-On.

SWOT is a collaborative mission with the Centre National d'Études Spatiales (CNES), Canadian Space Agency (CSA), and United Kingdom Space Agency (UKSA).

EXPLANATION OF MAJOR CHANGES IN FY 2022

Based on a recent assessment, NASA has concluded that the SWOT project will exceed its Agency Baseline Commitment for schedule (i.e., Launch Readiness Date) of April 2022 by more than six months. A notification to Congress will be issued soon. The project experienced a significant slowdown during FY 2020 and FY 2021 due to COVID-19, particularly for the critical path instrument, payload, and observatory Integration and Test (I&T) activities. Most of the delay is due to stoppages, disruptions, and inefficiencies of in-lab work at CNES and the Jet Propulsion Laboratory (JPL). Additionally, schedule delays arose due to technical challenges and unexpected integration and test complexities. NASA will report on the revised mission budget and schedule plans in accordance with Section 103 of P.L. 109-155 by November 2021. The budget includes an increase to the SWOT life cycle cost of $67.5 million to cover COVID-19 impacts and schedule delays.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

PROJECT PARAMETERS

SWOT will provide broad-swath sea surface heights and terrestrial water heights for at least 90 percent of the globe using a dual-antenna Ka-band Radar Interferometer (KaRIn). The SWOT payload will also include a precision orbit determination system consisting of Global Positioning System-Payload (GPSP), Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) receivers, and a Laser Retro-reflector Assembly (LRA). In addition, SWOT carries a Nadir Altimeter and a radiometer for tropospheric path delay corrections. NASA will provide a radiometer designed to determine tropospheric water vapor content, the GPSP system to complement DORIS for precise positioning of the satellite, and a backscattering laser for precise calibration of the other instruments. The CSA will provide a key component of the radar instrument – a set of Extended Interaction Klystrons (EIKs). CNES will provide radar Radio-Frequency Unit (RFU), the Poseidon-3C Ku-/C-band altimeter, and a DORIS precise orbit determination system. UKSA will provide commercial applications that will strengthen the international collaborations of the mission. SWOT's prime mission is three years.

ACHIEVEMENTS IN FY 2020

The SWOT project completed integration and initiated testing of the KaRIn instrument, including the CNES-supplied RFU and CSA-supplied EIKs. The SWOT project completed integration and testing of the nadir payload module including the Advanced Microwave Radiometer-C (AMR-C) and LRA.

WORK IN PROGRESS IN FY 2021

The SWOT project will complete the KaRIn instrument testing and integrate the KaRIn and nadir payload modules into an Integrated Payload Module (IPM). The project completed a System Integration Review (SIR) leading to a successful KDP-D review. The project will then complete the testing of the testing of the IPM and ship the IPM to Thales (CNES spacecraft contractor) for integration with the spacecraft and to support observatory-level integration and testing at Thales.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The SWOT project will integrate the IPM with the CNES provided spacecraft and conduct observatory-level integration and testing, in preparation for launch and operations.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
KDP-C	May 2016	May 2016
CDR	Feb 2018	May 2018
KDP-D	Oct 2019	Apr 2021
Launch	Apr 2022	Jun 2023
Start Phase E	Oct 2022	Dec 2023
End of Prime Mission	Oct 2025	Dec 2026

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	571.5	>70%	2021	639.0	12%	Launch Readiness Date (LRD)	Apr 2022	Jun 2023	+14

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**571.5**	**639.0**	**+67.5**
Aircraft/Spacecraft	0	0	0
Payloads	181.6	352.5	+170.9
Systems I&T	4.9	10.2	+5.3
Launch Vehicle	131.3	107.8	-23.5
Ground Systems	34.7	30.8	-3.9
Science/Technology	46.7	49.8	+3.1
Other Direct Project Costs	172.3	87.9	-84.4

Project Management & Commitments

The Earth Systematic Missions program at JPL has program management responsibility for SWOT, and NASA assigned project management responsibility to JPL. SWOT is a partnership mission between NASA, CNES, CSA, and UKSA.

Element	Description	Provider Details	Change from Baseline
KaRIn	Makes swath measurements of sea surface topography and lake and river heights	Provider: NASA, CNES, CSA, UKSA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): CNES (RFU), CSA (EIK), UKSA (Duplexer)	N/A
AMR	Provides wet tropospheric delay correction of KaRIn	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
GPSP	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
LRA	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
X-band Telecom	Provides downlink of science data	Provider: L-3, Tesat Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Nadir Altimeter	Measures Jason-heritage ocean surface topography at nadir	Provider: CNES Lead Center: None Performing Center(s): None Cost Share Partner(s): CNES	N/A
DORIS	Provides orbit determination	Provider: CNES Lead Center: None Performing Center(s): None Cost Share Partner(s): CNES	N/A
Spacecraft Bus	Provides instrument platform	Provider: CNES Lead Center: None Performing Center(s): None Cost Share Partner(s): CNES	N/A
Launch Vehicle	Delivers spacecraft to orbit	Provider: SpaceX Lead Center: KSC Performing Center(s): None Cost Share Partner(s): N/A	N/A

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Travel, shipment logistics, and work protocols change and/or escalate at JPL and/or France due to the COVID-19 pandemic, Then: Completion and delivery of the IPM may be delayed and/or the observatory I&T in France delayed per the project re-plan resulting in impacts to schedule and cost reserves.	The project is developing and implementing mitigation measures in coordination with CNES and Thales to: increase schedule margins by advancing the completion and delivery of the IPM to enable a timely start of observatory I&T; setting up a core resident team in France to avoid travel logistics issues; setting up remote operations capabilities for some operations; cross-training teams; and proactively preparing a team safety and training plan.

Acquisition Strategy

The acquisition strategy for SWOT leveraged Jason heritage by using JPL legacy instrument designs (AMR, GPSP, and LRA) and in-house build with a combination of sole source and competitive procurements. The KaRIn leverages the Earth Science Technology Office investments and is an in-house development. The X-band Telecom was a competitive procurement. NASA selected SpaceX to provide a Falcon 9 launch vehicle through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
X-band Telecom	L3 for modulator, Tesat for traveling wave tube amplifiers	San Diego, CA Backnang, Germany
Launch Vehicle	SpaceX	Los Angeles, CA

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Strategic Review Board (SRB)	May 2014	Systems Requirement Review (SRR) / Mission Definition Review (MDR)	Successful	Apr 2016
Performance	SRB	Apr 2016	Preliminary Design Review (PDR)	Successful	Feb 2018
Performance	SRB	May 2018	Critical Design Reviews (CDR)	Successful	Mar 2021
Performance	SRB	Mar 2021	System Integration Review (SIR)	Successful	Jan 2023
Performance	SRB	Jan 2023	Operational Readiness Review (ORR)	TBD	N/A

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

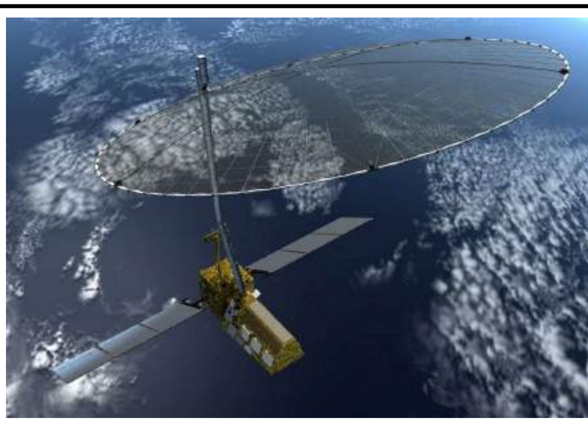
Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	117.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	117.0
Development/Implementation	415.0	190.6	71.0	**64.8**	32.9	0.0	0.0	0.0	0.0	774.3
Operations/Close-out	0.0	0.0	0.0	**0.0**	16.7	25.9	21.1	14.9	1.3	79.9
2021 MPAR LCC Estimate	**532.0**	**190.6**	**71.0**	**64.8**	**49.6**	**25.9**	**21.1**	**14.9**	**1.3**	**971.2**
Total Budget	**542.0**	**201.6**	**75.5**	**73.3**	**58.6**	**28.9**	**24.2**	**15.7**	**1.3**	**1,021.2**
Change from FY 2021				**-2.2**						
Percentage change from FY 2021				**-2.9%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



The NISAR satellite (depicted here) is a joint mission between NASA and the Indian Space Research Organization (ISRO) and will be the first radar imaging satellite to use dual frequencies. NISAR will observe and take measurements of some of the planet's most complex processes, including ecosystem disturbances, ice-sheet collapse, and natural hazards.

PROJECT PURPOSE

The NASA-ISRO Synthetic Aperture Radar (NISAR) mission will provide an unprecedented, detailed view of the Earth using advanced radar imaging and a dual frequency (L-band and S-band) Synthetic Aperture Radar (SAR). NISAR will be NASA's first dual frequency radar imaging satellite and will observe and measure some of the Earth's most complex processes, including ecosystem disturbances, ice sheet collapse, and natural hazards (e.g., earthquakes, tsunamis, volcanoes, and landslides). The mission will reveal information about the evolution and state of Earth's crust, broaden scientific understanding of our planet's changing processes and their effect on Earth's changing climate, and aid future resource and hazard management.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Both the 2007 and 2017 Earth Science Decadal Surveys endorsed the NISAR science objectives. NISAR is a collaborative mission with the Indian Space Research Organization (ISRO).

EXPLANATION OF MAJOR CHANGES IN FY 2022

The budget provides an additional $104 million to support lifecycle cost increases associated with the delayed S-band SAR (S-SAR) delivery and COVID impacts to the mission. The updated NISAR lifecycle cost exceeds the Agency development estimate of $661 million by more than 15 percent and the baseline launch readiness date (LRD) of September 2022 by more than six months. NASA has notified Congress of this likely delay in accordance with Section 103 of P.L. 109-155 and plans to report on the revised mission budget and schedule by July 2021. The new mission cost and schedule estimates are shown in the sections below.

PROJECT PARAMETERS

NISAR consists of a dual frequency (L-band and S-band) SAR. NASA will provide the L-band SAR (L-SAR), the engineering payload, the payload integration, and payload operations. ISRO will provide S-SAR, the spacecraft bus, the launch vehicle, observatory integration and testing, and spacecraft operations. NISAR has a prime mission of three years.

NISAR will implement enhanced data acquisition and data downlink capability as well as a global soil moisture product for agricultural, forest, and modeling efforts, as recommended by the interagency Satellite Needs Working Group (SNWG) process (a function of the U.S. Group on Earth Observations). The SNWG identified multiple other agencies that would benefit from NISAR systematically collecting data over all of North America in Quad-pol 40-megahertz mode, thus requiring additional data acquisition and downlink capability. NASA will track the cost of these additional capabilities outside of the Agency Baseline Commitment for cost, as the scope enhancements were approved after mission confirmation.

ACHIEVEMENTS IN FY 2020

The Standing Review Board (SRB) successfully completed an interim technical and programmatic review of the NISAR project in January 2020. The project completed the integration and testing of the dynamic test module. The project received all flight hardware for the L-SAR and the 12-meter reflector. Integration and testing of the L-SAR has continued at the Jet Propulsion Laboratory (JPL), while maintaining “safe at work” protocols. S-SAR integration and testing have continued in parallel at ISRO.

WORK IN PROGRESS IN FY 2021

The project is making progress in building, integrating, and testing of the L-SAR and the engineering payload. The project received the S-SAR band from ISRO and will start system integration and testing of the combined L-SAR and S-SAR. The project completed the system integration review in October 2020.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

The project held the Key Decision Point (KDP)-D review in March 2021 and will begin its observatory integration and testing phase of development.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The project will continue system integration and testing of the entire payload (L-SAR and S-SAR) along with the reflector and boom assembly in FY 2022. The project will deliver the payload with reflector and boom assembly along with the engineering payload to ISRO for integration with the ISRO-provided spacecraft bus.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
Key Decision Point (KDP-C)	Aug 2016	Aug 2016
Critical Design Reviews (CDR)	Oct 2018	Oct 2018
Key Decision Point (KDP-D)	Dec 2019	Mar 2021
Payload delivery to ISRO	Feb 2021	Mar 2022
Launch Readiness Date (LRD)	Sep 2022	Sep 2023

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	661.0	>70%	2021	774.3	+17%	LRD	Sep 2022	Sep 2023	+12

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**661.0**	**774.3**	**+113.3**
Aircraft/Spacecraft	77.1	127.6	+50.5
Payloads	211.1	323.3	+112.2
Systems I&T	23.0	43.3	+20.3
Launch Vehicle	0.6	0.2	-0.4
Ground Systems	72.6	89.7	+17.1
Science/Technology	28.2	33.1	+4.9
Other Direct Project Costs	248.4	157.1	-91.3

Project Management & Commitments

The Earth Systematic Missions program at NASA Goddard Space Flight Center (GSFC) has program management responsibility for NISAR. NASA assigned project management responsibility to JPL. NISAR is a partnership between NASA and ISRO.

Element	Description	Provider Details	Change from Baseline
L-SAR	Radar imaging payload	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
S-SAR	Radar imaging payload	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Spacecraft	Provides platform for the payload	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A
Launch Vehicle	Geosynchronous Satellite Launch Vehicle (GSLV); delivers observatory to orbit	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A

Project Risks

Risk Statement	Mitigation
If: The Reflector Deployment operations is not successful, Then: The observatory will not function as planned.	The critical functionality is exercised and tested during System Integration and Test activities and risk is retired before launch.
If: The Boom Deployment operation is not successful, Then: The observatory will not function as planned.	The critical functionality is exercised and tested during System Integration and Test activities and risk is retired before launch.

Acquisition Strategy

The design and build of L-SAR radar will be an in-house build at JPL with competed subcontracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Solid State Recorder	Airbus	Germany
Reflector Antenna	Astro Aerospace	California

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Strategic Review Board (SRB)	Dec 2014	Systems Requirement Review (SRR) / Mission Design Review (MDR)	Successful	Jun 2016
Performance	SRB	Jun 2016	Preliminary Design Review (PDR)	Successful	Oct 2018
Performance	SRB	Oct 2018	Critical Design Reviews (CDR)	Successful	Oct 2020
Performance	SRB	Oct 2020	System Integration Review (SIR)	Successful	Nov 2022
Performance	SRB	Nov 2022	Operational Readiness Review (ORR)	TBD	N/A

LANDSAT 9

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	234.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	234.8
Development/Implementation	393.5	37.9	85.2	**0.0**	0.0	0.0	0.0	0.0	71.0	587.7
Operations/Close-out	0.0	0.0	1.3	**2.8**	2.9	3.0	3.0	3.1	0.0	16.1
2021 MPAR LCC Estimate	**628.3**	**37.9**	**86.5**	**2.8**	**2.9**	**3.0**	**3.0**	**3.1**	**71.0**	**838.5**
Total Budget	**628.3**	**37.9**	**86.5**	**2.8**	**2.9**	**3.0**	**3.0**	**3.1**	**0.0**	**767.5**
Change from FY 2021				**-83.7**						
Percentage change from FY 2021				**-96.8%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The 2021 MPAR LCC Estimate reflects the Fiscal Year 2021 Quarter 2 Financial Report, which is current as of March 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since March 2021.

The Landsat 9 mission is a partnership between NASA and the U.S. Geological Survey. Landsat 9 (depicted above) will continue the Landsat program's critical role in monitoring, understanding, and managing the land resources needed to sustain human life.

PROJECT PURPOSE

The Landsat 9 mission will extend the record of multi-spectral, moderate resolution Landsat quality data and meet operational and scientific requirements for observing land use and land change.

Landsat 9 is a collaboration between NASA and the U.S. Geological Survey (USGS) and is a cornerstone of our nation's multi-satellite, multi-decadal, Sustainable Land Imaging (SLI) program. SLI is a NASA-Department of the Interior (DOI)/USGS partnership to develop, launch, and operate a spaceborne system and provide researchers and users with high quality, global,

LANDSAT 9

Formulation	Development	Operations

continuous land imaging measurements that are compatible with the existing 47-year Landsat record and will evolve through investing in and introducing new sensor and system technologies.

The Landsat data series, initiated in 1972, is the longest continuous record of changes in Earth's surface as seen from space and the only U.S. satellite system designed and operated to make repeated observations of the global land surface at moderate resolution. Landsat data is available at no cost to users, providing a unique resource for people who work in agriculture, geology, forestry, regional planning, education, mapping, and climate research.

EXPLANATION OF MAJOR CHANGES IN FY 2022

Due to efficient project management and cost performance, NASA expects to underrun the Agency life cycle cost commitment for Landsat 9. Therefore, the budget is reduced by $71 million; final development costs will be reported after launch.

PROJECT PARAMETERS

Landsat 9 has two science instruments: the Operational Land Imager 2 (OLI-2) and the Thermal Infrared Sensor 2 (TIRS-2). Landsat 9 is designed to provide 16-day continuous coverage of the global land mass with spatial resolutions of 15 meters for panchromatic light, 30 meters for visible and near-infrared and shortwave infrared light, and 120 meters for infrared light. In concert with other land-imaging satellites, including the currently operating Landsat 8 and Sentinel-2 satellites, Landsat 9 will contribute to improved coverage for users. NASA will build, launch, and perform the initial checkout and commissioning of the satellite. USGS will develop the ground system, operate the Landsat 9 observatory, and process, archive, and freely distribute the mission's data.

ACHIEVEMENTS IN FY 2020

The Landsat 9 project completed its System Integration Review (SIR) and Key Decision Point D (KDP-D) review in FY 2020. The project completed the spacecraft assembly, including the integration of the OLI-2 and TIRS-2 instruments, and initiated environmental testing of the integrated Landsat 9 observatory.

WORK IN PROGRESS IN FY 2021

The Landsat 9 project will complete its observatory testing, Operational Readiness Review (ORR), Key Decision Point E (KDP-E) review, delivery to the launch site, and launch in FY 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The project will complete early operations and handover of the observatory to USGS in FY 2022.

LANDSAT 9

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

The November 2021 launch estimate reflects the Agency Baseline Commitment made at the KDP-C review in December 2017. Currently, NASA is on-track to launch Landsat 9 on September 16, 2021.

Milestone	Confirmation Baseline Date	FY 2022 PB Request
KDP-C	Dec 2017	Dec 2017
Critical Design Review	Apr 2018	Apr 2018
System Integration Review	Aug 2019	Mar 2020
KDP-D	Dec 2019	Apr 2020
Operational Readiness Review	Sep 2020	Jun 2021
Launch	Nov 2021	Nov 2021
Handover to USGS	Mar 2022	Mar 2022

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2018	634.2	>70%	2021	587.7	-7%	LRD	Nov 2021	Nov 2021	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

LANDSAT 9

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**634.2**	**587.7**	**-46.5**
Aircraft/Spacecraft	98.1	119.8	+21.7
Payloads	107.6	110.2	+2.6
Systems I&T	0	0.7	+0.7
Launch Vehicle	154.4	149.2	-5.2
Ground Systems	17.2	28.3	+11.1
Science/Technology	9.2	9.3	+.1
Other Direct Project Costs	247.7	170.0	-77.7

Project Management & Commitments

The Earth Systematic Missions (ESM) program at Goddard Space Flight Center (GSFC) has program management responsibility for Landsat 9. NASA assigned project management responsibility to GSFC. The Landsat 9 mission is a partnership between NASA and USGS.

Element	Description	Provider Details	Change from Formulation Agreement
Operational Land Imager 2	Provide moderate resolution, multi-channel, wide-swath visible imaging of the Earth's surface, consistent with previous Landsat missions.	Provider: Ball Aerospace Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Thermal Infrared Sensor 2	Provide moderate resolution thermal infrared imaging of the Earth’s surface, consistent with previous Landsat missions.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

LANDSAT 9

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Spacecraft	Provide a platform with performance commensurate with OLI-2 and TIRS-2 requirements	Provider: Northrop Grumman Space Systems (NGSS) Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Provide launch services for the Landsat 9 Observatory	Provider: United Launch Services LLC Lead Center: GSFC Performing Center: Kennedy Space Center (KSC) Cost Share Partner(s): N/A	N/A
Ground System	Collect, process, archive, and freely distribute Landsat data	Provider: General Dynamics Mission Systems (GDMS) Lead Center: USGS Earth Resources Observation and Science (EROS) Center Performing Center(s): USGS EROS Cost Share Partner(s): USGS	N/A
Mission Operations Element	Provide software and system with capabilities for command and control, mission scheduling, long-term trending, and flight dynamics analysis	Provider: General Dynamics Mission Systems (GDMS) Lead Center: USGS EROS Performing Center(s): USGS EROS Cost Share Partner(s): USGS	N/A

Project Risks

Risk Statement	Mitigation
If: Development and testing of mission operations and ground readiness products are not ready to support launch, Then: Shipment of the Observatory to the launch site could be delayed.	The Landsat 9 project management team, GSFC, and Science Mission Directorate management are evaluating the pre-ship and launch criteria for mission and ground readiness activities; improving and adding simulator remote capabilities; and ensuring that the development and testing schedule is as efficient as possible and that time is allocated to simulators based on priorities. Staffing is being augmented and adjusted to ensure timely completion of critical path activities to avoid shipping and launch delays.

LANDSAT 9

Formulation	Development	Operations

Acquisition Strategy

The acquisition strategy for Landsat 9 is the same strategy used for Landsat 8, formerly known as the Landsat Data Continuity Mission (LDCM). NASA selected Ball Aerospace to provide the OLI-2 instrument through a sole source procurement. NASA selected NGSS (formerly Orbital ATK) to provide the Landsat 9 spacecraft through the GSFC Rapid Spacecraft Development Office selection process. NASA assigned the TIRS-2 instrument as a directed development to GSFC. NASA selected United Launch Services LLC to provide an Atlas V launch vehicle through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
OLI-2	Ball Aerospace	Boulder, Colorado
TIRS-2	GSFC	Greenbelt, Maryland
Spacecraft	Northrop Grumman Space Systems	Gilbert, Arizona
Launch Vehicle	United Launch Services LLC	Decatur, Alabama

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Strategic Review Board (SRB)	Jun 2016	System Requirements Review (SRR)	Successful	Sep 2017
Performance	SRB	Sep 2017	Preliminary Design Review (PDR)	Successful	Apr 2018
Performance	SRB	Apr 2018	Critical Design Review (CDR)	Successful	Jan 2020
Performance	SRB	Mar 2020	System Integration Review (SIR)	Successful	Jun 2021
Performance	SRB	Jun 2021	Operational Readiness Review (ORR)	TBD	N/A

SENTINEL-6

Formulation	Development	Operations

FY 2022 Budget

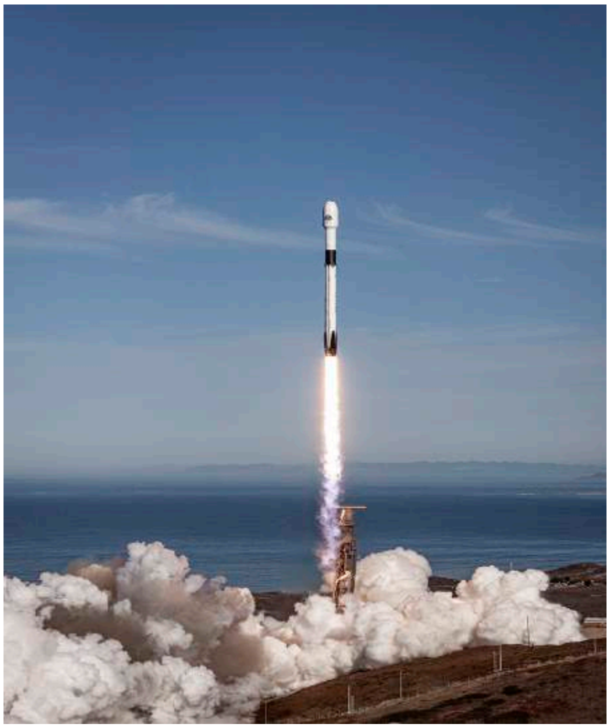
Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	15.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	15.5
Development/Implementation	201.3	13.4	7.5	**13.6**	34.1	60.4	49.0	23.1	0.0	402.3
Operations/Close-out	0.0	0.0	0.5	**9.2**	6.2	3.5	6.2	2.5	39.4	67.5
2021 MPAR LCC Estimate	**216.7**	**13.4**	**8.0**	**22.8**	**40.3**	**63.9**	**55.2**	**25.6**	**39.4**	**485.2**
Total Budget	**216.7**	**13.4**	**8.0**	**22.8**	**40.3**	**63.9**	**55.2**	**25.6**	**39.4**	**485.2**
Change from FY 2021				**14.8**						
Percentage change from FY 2021				**185.0%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

SENTINEL-6

Formulation	Development	Operations



The U.S.-European Sentinel-6 Michael Freilich ocean-monitoring satellite successfully launched from Vandenberg Air Force Base on a Falcon 9 rocket on November 21, 2020. Continuing the legacy of the Jason series missions, Sentinel-6/Jason-CS (Continuity of Service) will extend the records of sea level into their fourth decade, collecting accurate measurements of sea surface height for more than 90 percent of the world's oceans, and providing crucial information for operational oceanography, marine meteorology, and climate studies. Credit: SpaceX

PROJECT PURPOSE

The Sentinel-6 mission will provide continuity of ocean topography measurements beyond the Topography Experiment (TOPEX)/Poseidon (launched in 1992), Jason-1 (2001), Ocean Surface Topography Mission/Jason-2 (2008), and Jason-3 (2016) missions. The Sentinel-6 mission consists of two satellites, Sentinel-6 Michael Freilich and Sentinel-6B, that will launch approximately five years apart (2021 for Sentinel-6 Michael Freilich and 2026 for Sentinel-6B) to extend measurement continuity for at least another decade. This mission will serve both the operational user community and the scientific community by enabling the continuation of multi-decadal ocean topography measurements for ocean circulation and climate studies.

As a secondary mission objective, Sentinel-6 will characterize atmospheric temperature and humidity profiles by measuring bending angles of Global Navigation Satellite System (GNSS) signals occulted by the Earth's atmosphere. The project will process these measurement products on Earth within a few hours of acquisition on-board the satellite and make them available for incorporation into National Weather Service models to support weather forecasting capabilities.

Sentinel-6 is a collaborative mission with the National Oceanic and Atmospheric Administration (NOAA), the European Space Agency (ESA), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

SENTINEL-6

Formulation	Development	Operations

PROJECT PARAMETERS

NASA will provide the launch vehicle and launch services as well as a set of three instruments for each of the Sentinel-6 spacecraft. These two sets of instruments are Advanced Microwave Radiometer-Climate Quality (AMR-C), the GNSS-Radio Occultation (GNSS-RO) receiver, and the Laser Reflector Array (LRA). Additionally, NASA will provide support for instrument integration and testing on the satellites, mission operations support for the NASA-developed instruments, an operational AMR-C science data processor for EUMETSAT, near real-time and offline data processing for GNSS-RO data, and mission data product archiving and distribution. The Sentinel-6 Michael Freilich and Sentinel-6B observatories have a five-and-a-half-year prime mission.

ACHIEVEMENTS IN FY 2020

The Sentinel-6 project completed the Sentinel-6 Michael Freilich Operational Readiness Review (ORR) and completed observatory-level integration and testing. The Sentinel-6 project completed the development and testing of the Sentinel-6B NASA instrument payload, delivered it to the ESA spacecraft integrator (Airbus), and completed mechanical integration to the spacecraft.

WORK IN PROGRESS IN FY 2021

NASA launched the Sentinel-6 Michael Freilich spacecraft on November 21, 2020 and subsequently began the commissioning phase. The Sentinel-6MF satellite bus and all science payload instruments have been functionally activated, checked out, and all systems are nominal. Sentinel-6MF has achieved its final operational orbit to facilitate cross-calibration and validation with Jason-3. The Sentinel-6 project will complete electrical integration of the Sentinel-6B payload to the spacecraft and support observatory-level integration and testing. NASA will initiate the Sentinel-6B launch service acquisition process through its Launch Services Program.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The Sentinel-6 project in coordination with its partners will complete the verification of all Sentinel-6 Michael Freilich data products and their dissemination to users. The Sentinel-6 project will support the Storage Review for the Sentinel-6B spacecraft following completion of observatory-level integration and testing at Airbus and the IABG environmental test facility. NASA will complete the Sentinel-6B launch service acquisition process through its Launch Services Program.

SENTINEL-6

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
Key Decision Point (KDP-C)	Apr 2017	Apr 2017
CDR	Oct 2017	Oct 2017
Sentinel-6 Michael Freilich U.S. Payload delivery to ESA	Mar 2020	Mar 2020
Sentinel-6B U.S. Payload delivery to ESA	Oct 2020	Oct 2020
Launch (Sentinel-6 Michael Freilich)	Nov 2021	Nov 2020
Start Phase E (Sentinel-6 Michael Freilich)	Feb 2022	Feb 2021
End Prime Mission (Sentinel-6 Michael Freilich)	Aug 2027	Aug 2026
Launch (Sentinel-6B)	Nov 2026	Nov 2026
Start Phase E (Sentinel-6B)	Feb 2027	Feb 2027
End Prime Mission (Sentinel-6B)	Aug 2032	Aug 2032

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	465.9	>70%	2021	402.3	-14%	LRD of Sentinel-6 Michael Freilich	Nov 2021	Nov 2020	-12

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

SENTINEL-6

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**465.9**	**402.3**	**-63.6**
Aircraft/Spacecraft	0	0	0
Payloads	65.8	76.2	+10.4
Systems I&T	8.8	6.9	-1.9
Launch Vehicle	280.7	248.1	-32.6
Ground Systems	9.7	13.8	+4.1
Science/Technology	4.4	18.3	+13.9
Other Direct Project Costs	96.5	39.0	-57.5

Project Management & Commitments

The Earth Systematic Missions Program at Goddard Space Flight Center (GSFC) has program management responsibility for Sentinel-6. NASA assigned project management responsibility to the Jet Propulsion Laboratory (JPL). Sentinel-6 is a partnership with NOAA, ESA, and EUMETSAT.

Element	Description	Provider Details	Change from Baseline
AMR-C	Provides high spatial resolution wet tropospheric path delay corrections for the ESA-supplied Ku/C-Band Altimeter	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
GNSS-RO	Supports secondary mission objectives for weather modeling and forecasting	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A

SENTINEL-6

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
LRA	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Ku/C-Band Altimeter	Measures Jason-heritage ocean surface topography at nadir	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)	Provides orbit determination	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Spacecraft Bus	Provides instrument platform	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Launch Vehicle	Delivers spacecraft to orbit	Provider: NASA Lead Center: JPL Performing Center(s): Kennedy Space Center (KSC) Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The launch environments for the Sentinel-6B spacecraft are different than for Sentinel-6 Michael Freilich due to changes in the selected launch vehicle, Then: The project will need to do additional testing or analysis to ensure compatibility of the spacecraft with the launch vehicle.	NASA will require the qualification test levels used for the Sentinel-6 Michael Freilich spacecraft as a spacecraft-specific requirement during the Sentinel-6B launch service acquisition process. The Launch Services Program will monitor the development of new candidate launch vehicles and evolution of existing launch vehicles to ensure compliance with the known Sentinel-6 spacecraft capabilities.

SENTINEL-6

Formulation	Development	Operations

Acquisition Strategy

Sentinel-6 leverages Jason heritage by using JPL legacy instrument designs (e.g., AMR-C, GNSS-RO, and LRA) and an in-house build with a combination of sole source and competitive procurements. NASA selected SpaceX to provide a Falcon 9 launch vehicle through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
GNSS-RO Electronics	MOOG	Golden, CO
AMR-C Antenna	Northrop Grumman Innovation Systems	San Diego, CA
LRA	ITE	Laurel, MD
Launch Services	SpaceX	Los Angeles, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2017	Critical Design Reviews (CDR)	Successful	Apr 2019
Performance	SRB	Apr 2019	Project System Integration Review (P-SIR)	Successful	Sep 2021
Performance	SRB	Sep 2020	Sentinel-6 Michael Freilich ORR	Successful	Aug 2026
Performance	SRB	Aug 2026	Sentinel-6B ORR	TBD	N/A

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	260.3	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	260.3
Development/Implementation	108.9	131.0	145.1	**119.4**	87.7	40.2	0.0	0.0	0.0	632.4
Operations/Close-out	0.0	0.0	0.0	**0.0**	12.6	26.8	20.1	12.0	0.0	71.4
2021 MPAR LCC Estimate	**369.2**	**131.0**	**145.1**	**119.4**	**100.3**	**67.0**	**20.1**	**12.0**	**0.0**	**964.1**
Total Budget	**369.2**	**131.0**	**145.1**	**119.4**	**100.3**	**67.0**	**20.1**	**12.0**	**0.0**	**964.1**
Change from FY 2021				**-25.7**						
Percentage change from FY 2021				**-17.7%**						

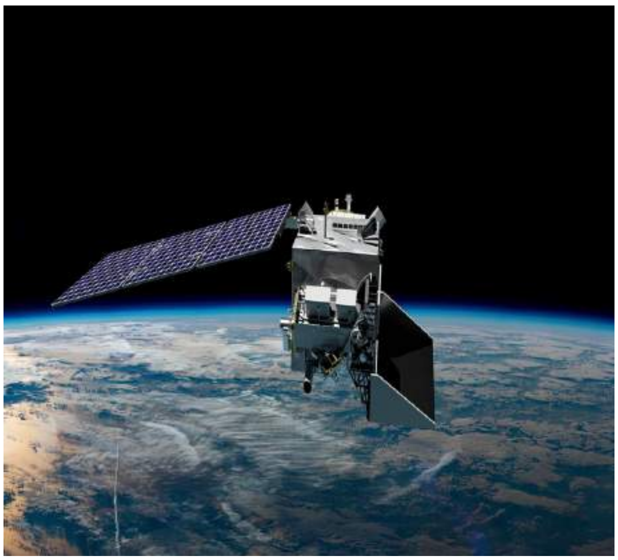
FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The 2021 MPAR LCC Estimate reflects the Fiscal Year 2021 Quarter 2 Financial Report, which is current as of March 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since March 2021.

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations



PACE (depicted here) will advance the assessment of ocean health by measuring the distribution of phytoplankton, tiny plants and algae that sustain the marine food web. It will also continue systematic records of key atmospheric variables associated with air quality and Earth's climate.

PROJECT PURPOSE

The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission will improve our understanding of how the ocean and atmosphere exchange carbon dioxide. In addition, it will reveal how aerosols might fuel phytoplankton growth in the surface ocean. PACE's unprecedented spectral coverage will provide the first-ever global measurements designed to identify phytoplankton community composition. This will significantly improve our ability to understand Earth's changing marine ecosystems, manage natural resources (e.g., fisheries), and identify harmful algal blooms.

PACE's primary sensor, the Ocean Color Instrument (OCI), is a highly advanced optical spectrometer that will be used to measure properties of light over portions of the electromagnetic spectrum. The interaction of sunlight with substances or particles present in seawater such as chlorophyll, a green pigment found in most phytoplankton species, determine the color of the ocean. By monitoring global phytoplankton distribution and abundance with unprecedented detail, OCI will help us improve our understanding of the complex systems that drive ocean ecology.

PACE is planned to include two contributed polarimeters to measure how the oscillation of sunlight within a geometric plane - known as its polarization - changes by passing through clouds, aerosols, and the ocean. Measuring polarization states of UV-to-shortwave light at various angles provides detailed information on the atmosphere and ocean (e.g., particle size and composition).

EXPLANATION OF MAJOR CHANGES IN FY 2022

NASA increased the PACE budget by $74 million over the KDP-C baseline to mitigate impacts due to COVID-19 restrictions. The project is currently undergoing a re-plan, which is anticipated to be completed by Summer 2021; therefore, the dates contained in the sections below are subject to change.

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

PROJECT PARAMETERS

PACE is a design-to-cost mission, and NASA approved the baseline cost, mission requirements, and mission architecture at confirmation. The NASA Goddard Space Flight Center (GSFC) is responsible for the design and fabrication of the spacecraft, development of the ocean color instrument, and development of the mission operations center. GSFC will collect, process, archive, and distribute PACE data. OCI will consist of a cross-track rotating telescope, thermal radiators, along with half-angle mirror and solar calibration mechanisms. OCI's tilt mechanism will help avoid sun glint and single science detector design will inhibit image striping. Its signal-to-noise ratios will rival or exceed previous ocean color instruments. OCI will have two-day global coverage at a 60-degree instrument view angle.

The Hyper-angular Rainbow Polarimeter 2 (HARP-2) is a wide-swath imaging polarimeter capable of characterizing atmospheric aerosols for the purposes of sensor atmospheric correction and atmospheric science. The Spectro-Polarimeter for Exploration (SPEXOne) provides atmospheric aerosol and cloud data at high temporal and spatial resolution.

PACE is NASA Class C mission with a notional launch date in the 2023-2024 timeframe and a minimum mission duration of three years. Nominal spacecraft altitude is 676.5 kilometers (420 miles) with an inclination of 98-degrees. PACE will launch on a Space-X Falcon 9.

ACHIEVEMENTS IN FY 2020

The PACE team successfully completed a comprehensive Mission Integrated Baseline Review in November 2019. The OCI team successfully completed the Critical Design Review (CDR) in December 2019 and completed a comprehensive system-level thermal vacuum test of the instrument engineering test unit. In addition, the PACE team completed CDRs for the ground system, the spacecraft, and the overall mission in February 2020. The PACE project worked with the NASA Launch Services Program (LSP) to award the launch services contract to SpaceX in February 2020. In March 2020, GSFC directed the team to stop on-site work due to COVID-19, but software development for the flight and ground elements continued remotely. In July 2020, the OCI systems and science teams held a detailed data review of the OCI thermal vacuum testing with the standing review board. In August 2020, the team restarted the critical path work on the instrument and spacecraft on-site at GSFC.

WORK IN PROGRESS IN FY 2021

The PACE team has made good progress in FY 2021 with work continuing to occur on-site at GSFC. The spacecraft structure is completed and in test; the solar array substrate was built and shipped to the solar cell vendor; and the propulsion module is being built. For OCI, the shortwave infrared (SWIR) detection assembly flight unit completed environmental testing and the flight Loop Heat Pipe pump bodies and radiators are in environmental testing. The SPEXOne Polarimter Pre-Ship Review (PSR) and shipment occurred in March 2021. Spacecraft Integration and Testing (I&T) will begin in July 2021, and OCI I&T will begin in August 2021.

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The PACE team plans to conduct the OCI Pre-Environmental Review (PER) in December 2021. The spacecraft delivery to Observatory Integration and Testing (I&T) is scheduled for April 2022. The Mission Systems Integration Review (MSIR) is planned for August 2022.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
KDP-B	Jul 2017	Jul 2017
KDP-C	Aug 2019	Aug 2019
KDP-D	Aug 2021	Oct 2022
Launch (or equivalent)	Jan 2024	Jan 2024
End Prime Mission	Apr 2027	Apr 2027

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2020	558.0	>70%	2021	632.4	+13%	LRD	Jan 2024	Jan 2024	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**558.0**	**632.4**	**+74.4**
Aircraft/Spacecraft	103.6	101.4	-2.2
Payloads	79.2	113.2	+34.0
Systems I&T	18.8	18.8	0
Launch Vehicle	105.0	80.4	-24.6
Ground Systems	19.3	19.5	+.2
Science/Technology	50.0	49.7	-.3
Other Direct Project Costs	182.1	249.4	+67.3

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Polarimeter (HARP-2) - Contribution	Measures how the oscillation of sunlight changes by passing through clouds, aerosols, and the ocean	Provider: University of Maryland Baltimore County (UMBC) Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): UMBC	N/A
Polarimeter (SPEXOne) - Contribution	Measures how the oscillation of sunlight changes by passing through clouds, aerosols, and the ocean.	Provider: Netherlands Institute for Space Research (SRON) Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): SRON	N/A

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Ocean Color Instrument	Highly advanced optical spectrometer that will be used to measure properties of light over portions of the electromagnetic spectrum	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Spacecraft	Provides a platform for instruments	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Provides launch services for the PACE Observatory	Provider: SpaceX Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mission Operations and Ground system	Provides software and system with capabilities for command and control, mission scheduling, long-term trending, and flight dynamics analysis. Collects, processes, archives, and distributes PACE data	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The proto-flight optical module fails vibration testing, Then: A re-alignment and design modification of the flight optical module will be necessary.	The hyperspectral to Main Optical Sub-Bench (MOSB) vibration test and post metrology has been completed. The project is working to complete the MOB-to-MOSB interface test. Successful results of this test will complete all mitigation steps.

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

Risk Statement	Mitigation
If: Current OCI gain stability and noise margin is not adequate, Then: OCI will exhibit decreased capability.	Interface tests have been inserted into the test program to assess expected flight system performance.

Acquisition Strategy

The spacecraft and OCI instrument will be built in-house at GSFC. UMBC will contribute the HARP-2 polarimeter. The Netherlands Institute for Space Research will contribute the SPEXOne polarimeter. The PACE Project worked with the NASA Launch Services Program (LSP) to award the launch services contract to SpaceX in February 2020.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Launch Vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Mar 2019	Preliminary Design Review (PDR)	Pass	Jan 2020
Performance	SRB	Jan 2020	Critical Design Review (CDR)	Pass	Aug 2022
Performance	SRB	Aug 2022	Systems Integration Review (SIR)	TBD	Sep 2023
Performance	SRB	Sep 2023	Operations Readiness Review (ORR)	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Earth Systematic Missions (ESM) Research	24.1	24.9	**25.7**	28.8	32.0	39.5	40.1
Ocean Surface Topography Science Team (OSTST)	5.8	5.8	**5.9**	6.0	6.2	6.2	6.3
Earth Observations Systems (EOS) Research	11.0	10.7	**10.7**	10.7	10.7	10.7	11.0
Sage III	4.8	4.6	**4.6**	4.7	4.8	4.8	4.8
Radiation Budget Instrument (RBI)	0.7	8.1	**0.0**	0.0	0.0	0.0	0.0
Sustainable Land Imaging	10.9	28.7	**56.0**	100.8	129.2	129.2	132.5
Earth from ISS	1.7	1.6	**1.7**	1.7	1.5	0.9	0.0
Total Solar Irradiance Sensor-2 (TSIS-2)	26.5	18.0	**66.2**	31.6	13.8	7.3	4.5
Earth Radiation Budget Science	13.8	14.0	**14.3**	14.7	15.1	15.1	15.5
Ozone Mapping and Profiler Suite (OMPS)	7.0	7.4	**4.9**	3.2	2.5	1.5	1.4
Total Solar Irradiance Sensor-1 (TSIS-1)	4.3	4.9	**4.7**	4.8	4.9	4.9	4.9
CLARREO Pathfinder	26.0	24.5	**18.5**	23.4	15.5	5.7	2.8
Decadal Survey and Future Missions	17.6	55.0	**137.8**	298.2	408.2	558.6	686.0
Earth Science Program Management	44.0	48.1	**58.8**	52.9	52.5	54.0	54.9
Precipitation Science Team	6.3	6.4	**6.5**	6.6	6.8	6.8	7.0
Ocean Winds Science Team	3.0	3.0	**3.1**	3.2	3.3	3.3	3.3
Land Cover Science Project Office	1.3	1.3	**1.3**	1.4	1.4	1.4	1.4
Ocean Salinity Science Team	7.4	7.5	**7.6**	7.8	8.0	8.0	8.2
Soil Moisture Active and Passive (SMAP)	11.3	6.9	**12.5**	13.0	13.4	13.8	13.7
Deep Space Climate Observatory	1.7	1.7	**1.7**	1.7	1.7	1.7	1.7
Global Precipitation Measurement (GPM)	20.4	21.2	**21.4**	21.5	22.1	22.1	22.6
Ocean Surface Topography Mission (OSTM)	2.3	2.0	**0.0**	0.0	0.0	0.0	0.0
Suomi National Polar-Orbiting Partnership (Sumoi NPP)	3.6	3.7	**3.8**	3.9	4.0	4.0	4.1
Terra	31.1	22.0	**29.5**	30.0	9.0	9.0	0.0
Aqua	31.5	26.1	**32.2**	33.1	11.7	11.7	0.0
Aura	21.8	19.0	**23.1**	23.0	8.2	6.3	0.0
SORCE	3.2	0.0	**0.0**	0.0	0.0	0.0	0.0
ICESat-2	19.6	20.5	**21.5**	17.3	17.7	17.7	18.4
GRACE Follow-On	14.1	4.0	**11.1**	11.2	11.5	11.5	12.0
Total Budget	**376.8**	**401.6**	**585.0**	**755.2**	**815.6**	**955.5**	**1,057.2**
Change from FY 2021			**183.4**				
Percentage change from FY 2021			**45.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the

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Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Earth Systematic Missions Other Missions and Data Analysis includes operating missions and their science teams and competed research projects. Mission science teams define the scientific requirements for their missions and generate algorithms used to process the data into useful data products. The research projects execute competitively selected investigations related to specific mission measurements.

Also included are Sustainable Land Imaging activities, as well as smaller missions in formulation and development, such as the Ozone Mapping and Profiler Suite Limb Sounder and Total and Spectral solar Irradiance Sensor-2.

Mission Planning and Other Projects

EARTH SYSTEMATIC MISSIONS (ESM) RESEARCH

ESM Research funds various science teams for the Earth Systematic missions. These science teams are composed of competitively selected individual investigators who analyze data from the missions to address related science questions.

Recent Achievements

Researchers used Ice, Cloud and land Elevation Satellite 2 (ICESat-2) data to provide significant new insight into the behavior and trends of ice sheets. Researchers provided unified estimates of grounded and floating ice mass change from 2003 to 2019 from ICESat-2 data. Their analysis reveals patterns linked to the following climate processes: ice loss from coastal Greenland linked to increased surface melt, Antarctic ice shelves linked to increased ocean melting, Greenland and Antarctic outlet glaciers linked to dynamic response to ocean melting, and mass gains over ice sheet interiors linked to increased snow accumulation. Losses outpaced gains with grounded-ice loss from Greenland, at about 200 billion tons per year, and Antarctica, at about 118 billion tons per year, contributing 14 millimeters to sea level. Mass lost from West Antarctica’s ice shelves accounted for more than 30 percent of that region’s total. Quantifying changes in Earth’s ice sheets and identifying the climate drivers are central to improving sea level projections.

A recent publication advances soil moisture retrieval with Gravity Recovery and Climate Experiment (GRACE), SMAP, and L-band Synthetic Aperture Radar (SAR). First, a study in the Journal of Hydrology presented a new approach to retrieving Surface Soil Moisture (SSM) data from the NASA GRACE mission. The GRACE SSM data is found to be in reasonable agreement with in-situ data and highly correlated with retrievals from the NASA SMAP and European Space Agency's (ESA) Soil Moisture and Ocean Salinity missions, especially over wet regions under the assumption that net water flux is well approximated by the change in terrestrial water storage over time. This approach is

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particularly useful for areas, such as heavily vegetated regions, which are difficult to monitor using conventional microwave data sources.

NASA scientists showed that U.S. Department of Agriculture National Agricultural Statistics Survey (NASS) visual assessments of soil moisture conditions correlate well with soil moisture retrievals from the NASA SMAP mission. This consistency allows for combining the two different types of data to produce a value-added assessment, which enables cropland soil moisture mapping and state-level statistics. Moreover, it enables daily assessment rather than weekly. The results signify that the SMAP soil moisture retrievals are relatable to soil moisture estimation conducted in agricultural crop by land managers and farmers.

OCEAN SURFACE TOPOGRAPHY SCIENCE TEAM (OSTST)

OSTST uses scientific data from the Ocean Surface Topography Mission and Jason radar altimetry satellites, together with data from international altimetry satellites such as ESA's Sentinel-3a, to measure global sea surface height. Data from tide gauges and a handful of calibration stations such as the Harvest oil platform help validate the satellite data.

Recent Achievements

OSTST produced global maps of the ocean salinity with unprecedented coverage, accuracy, and resolution, boosting oceanographic research and scientific applications. New salinity maps improve our ability to study large-scale ocean processes, including tropical instability waves and Rossby waves; predict various climate phenomena including El Niño; understand how the water cycle influences ocean circulation; and gain insights into recent amplification of the Earth’s hydrological cycle that produce flood and drought events. New satellite salinity maps are becoming key in monitoring ocean carbon cycle, enabling the development of the first space-based product for ocean-surface total alkalinity that is important to research in ocean acidification and air-sea flux of carbon dioxide products. Recent studies also demonstrate the use of satellite salinity as a new resource to monitor hurricanes and ocean’s response to tropical storms.

EARTH OBSERVATION SYSTEMS (EOS) RESEARCH

EOS Research funds science for the EOS missions, currently Terra, Aqua, Aura, and ICESat missions. The project competitively selects individual investigators to undertake research projects that analyze data from specific missions. Overall, most selected activities focus on science data analyses; however, some funded activities continue algorithm improvement and validation for the EOS mission instrument data products.

Recent Achievements

India’s ceramic industry is an important source of anthropogenic sulfur dioxide (SO2) emissions not accounted for in common emissions inventories but estimated from Aura's Ozone Monitoring Instrument (OMI) SO2 data. Using data from OMI, scientists revealed a large SO2 pollution “hotspot” over Morbi, Gujarat, India, attributing it to the ceramic industries in the area, and they estimated an upward pollution trend of approximately 300 percent between 2009 and 2016. Legislators use these new OMI emissions estimates to monitor the impact of policy regulations to close Morbi-based ceramic units that are running on coal gasifiers.

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The Atmospheric Infrared Sounder (AIRS) on NASA's Aqua satellite gathers infrared energy emitted from Earth's surface and atmosphere globally, every day. Its data provides 3D measurements of temperature and water vapor through the atmospheric column along with a host of trace gases and surface and cloud properties. Weather prediction centers use AIRS data around the world to improve their forecasts. They also use it to assess climate models and in applications ranging from volcanic plume detection to drought forecasting. On July 20, 2020, NASA released the AIRS Version 7 of the L2 and L3 data products to the public. The Version 7 data products represent a significant improvement over the previous Version 6 products, especially with the AIRS "infrared-only" products. Notable improvements include: improved consistency between day and night water vapor; improved total column ozone; improved temperature products; improved AIRS IR-only retrievals, especially in the high latitude regions; improvement in the stochastic cloud clearing neural network; removal of ambiguity in surface classification in the infrared-only (IR-only) retrieval algorithm.

NASA scientists developed an algorithm to fuse multiple instrument radiance observations. The goal of this work is to produce a homogeneous, gridded, radiance data set over several decades that converts high resolution AIRS, Cross-track Infrared Sounder (CrIS) and Infrared Atmospheric Sounding Interferometer (IASI) radiances to a common spectral response, and to use these climate-quality data to answer several fundamental climate questions. Science topics include: the magnitude of water-vapor feedback as observed over several decades, trends in cloud longwave fraction and radiative forcing, and trends in both air and surface temperature. This homogeneous radiance dataset provides measurements similar to the long-wave CLARREO mission, but with much higher space/time sampling.

SUSTAINABLE LAND IMAGING (SLI)

The SLI program enables the development of a multi-decade, space-borne system that will provide U.S. users with high quality global land-imaging measurements. These measurements will be compatible with the existing Landsat record and will address near and long-term issues of continuity risk. They will also evolve flexibly and responsibly through investment and introduction of new sensor and system technologies. Under the SLI framework, NASA will maintain responsibility for developing, launching, and initial checkout of space systems. The U.S. Geological Survey (USGS) will be responsible for collecting and documenting user needs, developing the associated ground systems, operating the on-orbit spacecraft, and collecting, calibrating, archiving, processing, and distributing SLI system data to users.

Through the implementation of SLI technology activities, NASA will enable new SLI measurement technologies, capabilities, and architectures. The Sustainable Land Imaging-Technology (SLI-T) program aims to: demonstrate improved, innovative, full-instrument concepts for potential infusion into the architecture and design of the next generation of Landsat missions; and develop technologies at the component and/or breadboard-level that have long-term potential to improve future land imaging instruments and systems significantly through substantial architecture changes. NASA will solicit instrument and subsystem development activities in coordination with the Landsat science community.

SLI funding also supports the development of the next generation of Landsat observing system approaches, Landsat Next. In order to minimize the risk of gaps while taking advantage of cost savings and capability enhancements resulting from the technology development activity outlined above, the Administration will make key strategic decisions for Landsat Next as part of the FY 2023 budget process.

Additional SLI activities support efforts to minimize costs and maximize the overall utility for U.S. users by responsibly engaging with international partners to ensure access to high-quality data and fusion of

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those measurements with those from the U.S. Landsat missions. NASA and USGS conducted pre-launch cross-calibration investigations with the European developers of the Sentinel-2A/B land imaging system, ensuring uniform calibration of both Landsat 8 and Sentinel-2A/B instruments to the same standards. The USGS, supported by NASA and other agencies, is serving as the primary U.S. Government point of contact to ensure access to and archiving of Sentinel-2 data products for U.S. research and operational users.

Recent Achievements

The six SLI-T grants NASA awarded under a competitive solicitation in 2015 continued to make substantial progress in FY 2020, and the SLI Architecture Study Team extensively referenced the results from these projects. Additionally, two projects completed aircraft demonstrations of new instruments in FY 2020, and analysis of the data from the test flights is ongoing with the aim to release publicly. All but one of the 2015 grants ended in December 2020.

The six new grants NASA awarded in July 2020 support technology development activities aimed specifically at demonstrating improved, innovative, full-instrument concepts for potential infusion into the architecture and design of missions beyond Landsat Next. Development and technical maturation at the component and/or breadboard-level of technologies have long-term potential to significantly improve future land imaging instruments and systems through substantial architecture changes.

The NASA/USGS SLI Architecture Study Team (AST) completed its final report in December 2019, which provided several potential roadmap options for a Landsat Next observing system. Based on the SLI AST report, NASA authorized pre-Phase A activities for Landsat Next in April 2020. Pre-Phase A activities for the project consist of an overarching trade study that will inform the observing system concept.

CLARREO PATHFINDER (CPF)

CPF will measure sunlight reflected by the Earth and Moon and improve the accuracy of these measurements by five to ten times compared to current best sensors. Higher accuracy means greater certainty in the measurements, which will make it possible to detect Earth's subtle climate change trends decades sooner than otherwise possible.

Recent Achievements

In FY 2020, the CPF project successfully completed its Critical Design Review (CDR) virtually. The project continues to work with the International Space Station (ISS) on the thermal cold-case modeling and the approach to payload survival heaters. The Technical University of Denmark (DTU) completed a successful pre-ship review for their star tracker in September 2020. Teledyne delivered one flight detector to the University of Colorado's Laboratory for Atmospheric and Space Physics (LASP). They are on contract to also deliver a flight spare. Moog, Inc. conducted a successful pre-ship review prior to the delivery of the HySICS pointing system actuators, which were approved for shipment to LASP.

TOTAL SOLAR IRRADIANCE SENSOR-2 (TSIS-2)

The TSIS-2 instrument will maintain and extend the 41-year measurement record of total solar irradiance and spectral solar irradiance beyond 2023 provided by TSIS-1 and earlier missions. Researchers have used the solar irradiance data to understand how the solar energy affects the Earth system over an 11-year

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cycle and longer time scale. NASA is implementing TSIS-2 by leveraging the available spare parts from the TSIS-1 mission to the greatest degree possible. NASA will implement TSIS-2 as a Class D payload and as a free flyer. The mission will operate for no less than three years. Formulation began in FY 2019.

Recent Achievements

In FY 2020, the TSIS-2 project awarded a contract to develop the spacecraft and ground communication network. After a successful review of the instrument effort, NASA authorized the University of Colorado's Laboratory for Atmospheric and Space Physics (LASP) to proceed with development of both TSIS-2 instruments.

EARTH RADIATION BUDGET SCIENCE (ERBS)

The ERBS project produces climate data records of Earth’s radiation budget and the associated cloud, aerosol, and surface properties. The project utilizes data from the multiple radiation budget instruments in orbit and ancillary measurements to produce integrated, self-consistent data products over the entire suite of radiation budget instruments. The data products utilize coincident imager measurements and Clouds and the Earth's Radiant Energy System (CERES) instrument broadband radiative fluxes from Terra, Aqua, Suomi National Polar-orbiting Partnership, NOAA-20 and operational geostationary satellite observations. In total, scientists have used 30 instruments on 24 spacecraft thus far to produce an accurate and temporally consistent description of the radiation budget, not only at the top of the atmosphere but also at the surface and within the atmosphere. The ERBS project is the only project worldwide whose prime objective is to produce global, climate-quality ERB data from dedicated ERB satellite instruments.

Recent Achievements

In FY 2020, the scientific community extensively used CERES data products to publish scientific papers related to earth’s energy imbalance, climate feedback, aerosol radiative forcing, atmospheric and oceanic energy transports, polar climate, and climate model evaluation. The CERES global flux data products support monitoring of ground-based solar panel operations and crop modeling. The ERBS team generated data products from all six CERES instruments and continued to perform inter-comparison campaigns between the Terra, Aqua, Suomi-NPP, NOAA-20 instruments, as well as additional campaigns with the Geostationary Earth Radiation Budget instruments. After careful operational planning, the ERBS team placed one of the CERES instruments on Terra in a programmable azimuth plane mode to maximize the number of observations over the Multidisciplinary Drifting Observatory for the Study of Arctic Climate site. The ERBS team released a new data product that will significantly advance climate model evaluation and cloud feedback research. To improve communication of mission science results to the public, the team also completed a re-design of the CERES webpage.

OZONE MAPPING AND PROFILER SUITE LIMB SOUNDER (OMPS-L)

The advanced Ozone Mapping and Profiler Suite (OMPS) tracks the health of the ozone layer and measures the concentration of ozone in the Earth’s atmosphere. OMPS is a three-part instrument, a nadir mapper that maps global ozone with about 50-km ground-resolution, a nadir profiler that will measure the vertical distribution of ozone in the stratosphere, and a limb profiler that will measure ozone in the lower stratosphere and troposphere with high vertical resolution. The entire OMPS suite currently operates on the Suomi NPP spacecraft. To ensure data continuity, a copy of this suite will fly on NOAA’s Joint Polar Satellite System-2 (JPSS-2) mission, planned for launch in FY 2023. NASA is responsible for providing

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the OMPS-Limb profiler for integration on the OMPS instrument. The project budget also supports OMPS-Limb profilers for JPSS-3 and JPSS-4.

Recent Achievements

In FY 2020, OMPS Limb shipped to Northrup Grumman for integration, JPSS-3 Limb testing commenced, and the team completed spectral, stray light, irradiance, and polarization tests, with no reported issues.

DECADAL SURVEY AND FUTURE MISSIONS

In January 2018, the National Academies released a new Earth Science Decadal Survey, entitled "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space." This Decadal Survey recommended completing missions that were already in formulation and development. Additional observation capabilities including the following "designated observable" (DO) scientific areas: Aerosols; Clouds, Convection, and Precipitation; Mass Change; Surface Biology and Geology; and Surface Deformation and Change. Along with the DOs, the Decadal Survey called for a new, competed program element, termed "Earth System Explorers," that would address other "targeted observables."

In October 2018, NASA initiated studies to develop concepts for missions/observing systems to address the five DO priorities. These missions/observing systems will constitute a new Earth System Observatory and will be implemented as cost-constrained projects. In FY 2021, NASA will initiate the pre-formulation phase for four DO missions addressing: Aerosols; Clouds, Convection, and Precipitation; Mass Change; Surface Biology and Geology. The fifth, targeting Surface Deformation and Change, will remain in the study phase to incorporate lessons learned from the related NASA-ISRO Synthetic Aperture Radar (NISAR) mission. The four DO missions will complete their Mission Concept Reviews in FY 2022. The Mass Change mission will target a launch in FY 2027, while the Surface Biology and Geology mission will target a launch in FY 2028. NASA will implement two missions to address Aerosols and Clouds, Convection and Precipitation, with the first scheduled to launch to an inclined orbit in FY 2028 and the second to launch into a polar orbit in FY 2030.

Funding within this project will also support sustained observations that may not be designated in the 2017 Decadal Survey, but that provide ongoing study of the changing climate and earth system to support climate change prediction and implementation of adaption and mitigation measures. NASA will work with international and commercial partners to achieve efficient, effective and timely missions.

Recent Achievements

In FY 2020, the pre-formulation studies to address the DO priorities identified in the Decadal Survey continued to assess potential observing system architectures for the areas noted above. A series of focused discussion sessions was organized to address cross-cutting issues for all of the DO studies, including the role of international partnerships, challenges and opportunities associated with constellation-based observing systems, accelerating science and applications return, mission assurance and risk assessment, and open science/open data systems. Throughout the studies, and in the guidance for the pre-formulation phase, NASA has emphasized the need to achieve the recommended science objectives within the identified budgets through innovative development approaches, technology development, and robust cost and schedule risk management.

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EARTH SCIENCE PROGRAM MANAGEMENT

The Earth Science Program Management budget supports critical flight project management functions executed by the ESM program offices at NASA Goddard Space Flight Center (GSFC) and the Jet Propulsion Laboratory (JPL), and the Earth System Science Pathfinder Program Office at NASA Langley Research Center (LaRC). This budget supports:

- The GSFC conjunction assessment risk analysis function, which determines maneuvers required to avoid potential collisions between spacecraft and to avoid debris;
- The technical and management support for the international Committee on Earth Observation Satellites, which coordinates civil space-borne observations of Earth. Participating agencies strive to enhance international coordination and data exchange and to optimize societal benefit;
- Senior Review Board teams, who conduct independent reviews of the various flight projects in Earth Science; and
- Earth Science division communications and public engagement activities.

PRECIPITATION SCIENCE TEAM

The Precipitation Science Team carries out investigations of precipitation using measurements from, but not limited to, the Tropical Rainfall Measuring Mission (TRMM) mission, which ended in 2015, the Global Precipitation Measurement (GPM) mission, which launched in February 2014, and GPM mission constellation partner spacecraft. GPM mission constellation partners include NOAA, Department of Defense, Centre National d'Études Spatiales (CNES), Japan Aerospace Exploration Agency (JAXA), and Exploitation of Meteorological Satellites (EUMETSAT). This program supports scientific investigations in three research categories:

- Development, evaluation, and validation of TRMM and GPM retrieval algorithms;
- Development of methodologies for improved application of satellite measurements; and
- Use of satellite and ground measurements for physical process studies to gain a better understanding of the global water cycle, climate, and weather and concomitant improvements in numerical models on cloud resolving to climate scales.

Recent Achievements

Team members continued to use airborne and ground observations from GPM field campaigns and long-term fixed ground sites to develop advanced algorithms in cold-season precipitation over steep mountains and for warm-season convective storms. One study evaluated retrievals of rainfall and raindrop sizes against measurements from NASA field campaigns and another validated the GPM surface snowfall algorithm against ground-based radar. Researchers also extended estimates of atmospheric heating (the heat released by conversion of water vapor to liquid or water to ice, and vice versa) from tropical regions to mid latitudes by developing new databases for midlatitude cyclones. In a unique study, researchers used GPM Dual-frequency Precipitation Radar (DPR) surface returns to infer different vegetation zones in Mongolia and showed that the region experienced extensive changes in grassland and desert areas during the study years.

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OCEAN WINDS SCIENCE TEAM

The Ocean Winds Science Team uses scientific data received from the QuikSCAT satellite, RapidScat instrument, and other international missions, which measure ocean surface winds by sensing ripples caused by winds at the ocean's surface. From this data, scientists can compute wind speed and direction thus acquiring global observations of surface wind velocity each day. Wind data from ships and buoys serve to calibrate the satellite data.

Recent Achievements

Recent improvements in products have facilitated applications closer to coasts, addressing important societal needs. The study for air-sea interaction at finer resolution is revealing roles in which winds, currents, and waves interact to more strongly couple the upper ocean with the lower atmosphere. NASA and the Department of Defense are making launch preparations for the Compact Ocean Wind Vector Radiometer that will improve algorithm development. The study for air sea interaction at finer resolution is revealing roles in which winds, currents, and waves interact to more strongly couple the upper ocean with the lower atmosphere.

LAND COVER PROJECT SCIENCE OFFICE (LCPSO)

The LCPSO maintains over 40 years of calibration records for the Landsat 1 through Landsat 8 series of satellites. The office also provides community software tools to make it easier for users to work with this data. In collaboration with USGS, LCPSO supports cross-calibration of the Landsat record with other international sensors, provision of preprocessed data sets for land-cover change analysis and facilitates use of international data sets for improved land cover monitoring.

Recent Achievements

This year the LCPSO completed work on the global Harmonized Landsat/Sentinel-2 (HLS) global surface reflectance product, which combines observations from the U.S. Landsat and European Union Sentinel-2 satellite series. In collaboration with the Earth Science Data Systems Program, the Interagency Implementation and Advanced Concepts Team (IMPACT) team is generating global HLS products and distributing them via the Land Processes distributed active archive center. The LCPSO also began a new initiative to archive and distribute land cover map products generated by efforts previously funded by the NASA Land Cover/Land Use Change program element. This rich set of satellite-based land cover information had not previously been easily accessible to researchers or the general public. In collaboration with USGS, the LCPSO continued to support algorithm validation and refinement for the Landsat surface reflectance and surface temperature products.

OCEAN SALINITY SCIENCE TEAM (OSST)

The OSST supports the development and construction of surface salinity products from L-Band microwave radiometers such as Aquarius, SMAP, and data sets of opportunity such as ESA's Soil Moisture and Ocean Salinity (SMOS) mission. The team also seeks to understand upper-ocean processes that impact variability of surface salinity in order to improve interpretation of the space-based salinity products. The team is working on a SMAP salinity product that is consistent with the Aquarius salinity product, which ended in June 2015.

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Recent Achievements

OSST produced global maps of the ocean salinity with unprecedented coverage, accuracy, and resolution, boosting oceanographic research and scientific applications. New salinity maps improve our ability to study large-scale ocean processes, including tropical instability waves and Rossby waves; predict various climate phenomena including El Niño; understand how the water cycle influences ocean circulation; and gain insights into recent amplification of the Earth's hydrological cycle that produce flood and drought events. New satellite salinity maps are becoming key in monitoring the ocean carbon cycle, enabling the development of the first space-based product for ocean-surface total alkalinity that is important to research in ocean acidification and air-sea flux of carbon dioxide products.

Operating Missions

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

The ICESat-2 mission measures global elevation to provide an important multi-year record needed to determine sea ice thickness and ice sheet mass change. It also provides topography and vegetation data around the globe. These additional data products support estimates of biomass and carbon in aboveground vegetation in conjunction with related missions, measurements of ocean topography, inland water body elevation such as lakes and rivers, and cloud properties. The ICESat-2 observatory has one instrument, the Advanced Topographic Laser Altimeter System (ATLAS), which measures the round-trip time of laser light from the observatory to Earth and back as the basis for the mission's elevation measurements. Launched on September 15, 2018, ICESat-2 will remain in prime mission operations through December 2021.

Recent Achievements

The ICESat-2 observatory and ATLAS instrument continue to operate nominally and have provided more than two trillion new elevation measurements since data collection began on October 14, 2018. NASA made ICESat-2 data available to the public on May 28, 2019, via the National Snow and Ice Data Center. To date, over 2,400 users have downloaded over 8.4 million data files. The initial science results from ICESat-2 have demonstrated that the elevation data is accurate to less than 3 centimeters vertically, the location is known to less than 6 meters horizontally, and that measurements from ICESat-2 are of comparable quality to measurements from low-flying aircraft. The data show the ongoing ice loss from the Greenland and Antarctic ice sheets, and that the ice shelves of Antarctica may be losing more ice than previously thought. In addition, analysis has shown that the green laser light of ICESat-2 can penetrate up to 15 meters (nearly 50 feet) of water, enabling shallow water bathymetry measurements from space. To date, more than 50 peer-reviewed publications in the scientific literature used ICESAT-2 data.

GRACE FOLLOW-ON

The Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) mission provides continuity of month-to-month mass change observations and high-resolution global models of Earth's gravity field, as in the original GRACE mission (launched in 2002). The GRACE-FO mission allows scientists to gain

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new insights into the dynamic processes of Earth's water cycle, including variations in water storage over land, the mass of glaciers and ice sheets, and sea level and ocean currents. GRACE-FO also maps large earthquakes and tectonic processes. Data from the mission, in combination with other existing sources of data, greatly improves scientific understanding of how Earth's water cycle evolves. GRACE-FO data is vital to ensuring there is a minimal gap in mass change measurements following the decommissioning of the original GRACE mission in 2017. GRACE-FO is a partnership with the German Research Centre for Geosciences (GFZ). Launched on May 22, 2018, GRACE-FO will remain in prime mission operations through November 2023.

Recent Achievements

GRACE-FO continues in prime mission operations. As of October 2020, the mission added 25 monthly Global Mass Change datasets to the more than 15 years of monthly mass change maps archived by GRACE. The GRACE-FO science data system team has been able to deliver these data to NASA's Physical Oceanography distributed active archive center, ahead of schedule (on average 35 days vs the 60-day requirement), enabling scientists and resource managers worldwide to provide timely analysis of weather and climate-related events, and to accurately and efficiently monitor long-term changes in our Earth's ice sheets and glaciers, underground water storage, and crustal deformation due to major earthquakes. The GRACE-FO team is producing a near real-time data stream with a latency of approximately three days to aid in the management of drought and water resources in the United States.

SOIL MOISTURE ACTIVE AND PASSIVE (SMAP)

The SMAP mission, launched in January 2015, provides a capability for global mapping of soil moisture with unprecedented accuracy, resolution, and coverage. The SMAP measurement system consists of a radiometer (passive) instrument and a synthetic aperture radar (active) instrument operating with multiple polarizations in the L-band range. Although the active radar instrument failed in July 2015, the radiometer is operating nominally, and continues to provide global mapping of soil moisture with accuracy, resolution, and coverage that exceeds the capability of other on-orbit systems. The SMAP project team has developed a blended data product that combines SMAP radiometer measurements with the European Copernicus Program's Sentinel-1 active radar measurements. This operational product provides soil moisture information with higher spatial resolution whenever the two systems have coincident measurements.

SMAP is currently in extended operations.

Recent Achievements

NASA accepted the 2020 Earth Science Senior Review endorsement of the SMAP mission to continue extended operations through 2023.

In FY 2020, SMAP made significant improvements to its soil moisture and vegetation water content products obtained from a dual-channel algorithm. U.S. Federal agencies continue to increase their use of SMAP soil moisture data to meet or improve operational requirements. The U.S. Air Force's 557th Weather Wing began using SMAP soil moisture data in November 2019 and the transition to the use of updated SMAP radiometer products is underway. Similarly, the U. S. Navy's Fleet Numerical Meteorology and Oceanography Center is currently assessing the value of SMAP data to support operational forecast needs, such as ship navigation. Since April 2020, the U. S. Department of Agriculture (USDA) Foreign Agriculture Service has included SMAP in their operational systems to support analysis

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of international crop yields and food shortages. With assistance from NASA researchers and the SMAP project, the USDA National Agriculture Statistics Service (NASS) also developed an automated SMAP data ingest system and is evaluating its domestic assessment of water needs for crop growth. In addition, knowledge of SMAP soil moisture prior to snowfall has benefited the estimation of water storage in the snowpack from NOAA operational airborne gamma radiation surveys, contributing to improvement in snowmelt flood predictions, as well as the accuracy of the NOAA SNOw Data Assimilation System by removing a known source of error.

GLOBAL PRECIPITATION MEASUREMENT (GPM)

The GPM mission, launched in February 2014, advances the measurement of global precipitation through the combined use of active and passive remote-sensing techniques. Tracking storms as they move within the tropics and higher latitudes, GPM provides a three-dimensional view of their structural and microphysical properties and provides estimates of storm rainfall accumulations for major storm events. The GPM Microwave Imager (GMI) measures energy from different types of precipitation within clouds to estimate heavy to light rain and to detect falling snow. The Dual-frequency Precipitation Radar (DPR) provides three-dimensional information about precipitation particles, including their size distributions and associated rainfall rates, derived from reflected energy at two radar wavelengths at different heights within the cloud system. GPM is a joint mission with JAXA.

GPM is currently in extended operations.

Recent Achievements

NASA accepted the 2020 Earth Science Senior Review endorsement for the GPM mission to continue extended operations through 2023.

In FY 2020, the GPM project coordinated with SpaceX to eliminate possible conjunctions with planned launches releasing satellites near the GPM orbit altitude and set in place two Operational Agreements with Planet Labs and Spaceflight Industries to eliminate close approaches while in close proximity. Scientists updated algorithms for rainfall retrievals from the radar, the microwave imager, and from a combination of the two sensors (known as the combined algorithm) and developed advanced approaches for combining data from other satellites in the constellation into a merged precipitation product. The precipitation processing systems generated initial precipitation retrievals from DPR that take advantage of the widening of the scan of one of the radar bands implemented in May 2018, allowing for potentially more accurate rainfall estimates. The GPM ground validation team participated in the IMPACTS airborne mission, which is a cross-cutting mission (the National Weather Service is involved) to improve knowledge and prediction of East Coast and Midwest winter storms. The GPM applications team held a Weather and Air Quality Forecasting Workshop that brought together experts from six operational forecasting centers and the academic community to support cross-cutting goals to advance prediction, obtain key feedback on how GPM data is brought into forecast models, discuss future plans, and identify needs and gaps with satellite products looking forward to NASA's next generation of missions. The team also collected information on GPM data use from over 5,000 users to understand better what products are most useful to which stakeholder groups in the government, academia, and private sector.

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SUOMI NATIONAL POLAR-ORBITING PARTNERSHIP (SUOMI NPP)

The Suomi NPP mission, launched in October 2011, is a partnership between NASA and NOAA. The five instruments on Suomi NPP provide visible and infrared multi-spectral global imagery, atmospheric temperature and moisture profiles, total ozone and stratospheric ozone profiles, and measurements of Earth's radiation balance. In addition to a wide range of applications studies, the NASA science focus areas served by Suomi NPP include atmospheric composition, climate variability and change, carbon cycle, ecosystems, water and energy cycles, and weather. Several primary Suomi-NPP products have demonstrated their capabilities to provide critical continuity and near-real-time data, extending the EOS observation long time-series in monitoring changes in land, ocean, and atmosphere as well as Earth's radiation budget. NASA built and launched Suomi NPP. NOAA operates the spacecraft and instruments. NASA and NOAA continue to collaborate to ensure meeting the shared objectives of both agencies.

Suomi NPP is currently in extended operations.

Recent Achievements

In FY 2020, the NASA Suomi NPP team continued to add to the data records from Earth Observing System missions, enabling scientists to build multi-satellite, multidecadal (greater than 30 years) time series with high accuracy and long-term stability suitable for studies of Earth systems science. Aided by the enhanced 3D ozone distribution mapping capability provided by the Ozone Mapping and Profiler Suite (OMPS) Limb Profiler (LP), scientists found that lower stratospheric ozone concentration dropped to extremely low levels in October 2020, in conjunction with the formation of a large and deep Antarctic ozone hole. To help monitor the impacts of the ongoing global pandemic in 2020, Suomi NPP products contributed to the key socio-economic indicators in the tri-agency (ESA/NASA/JAXA) COVID-19 dashboard. For example, the observations of Earth at night in NASA's Black Marble product combined Visible Infrared Imaging Radiometer Suite (VIIRS) with ISS astronaut photography to track variations in energy use, migration, and transportation, in response to social distancing and lockdown measures. The VIIRS aerosol and OMPS SO2 products also helped to assess the impact of COVID-19 on air pollution. In addition, the VIIRS datasets continued to provide timely information during disaster events such as wildfires from Australia (in January) and California and Colorado (in September). For example, scientists used the data products for aerosol, fire counts, and burned areas to monitor and assess, in near real-time, the effects of massive fire events on air quality, as well as wildfire location and extent. The OMPS LP aerosol profile data provided complementary information on the aerosol height for these smoke plumes.

TERRA

Terra, launched in December 1999, is one of the Earth Observing System (EOS) flagship missions. It enables a wide range of interdisciplinary studies of atmospheric composition, carbon cycle, ecosystems, biogeochemistry, climate variability and change, water and energy cycles, and weather. The Terra mission has provided more than 20 years of continuous data collection, including fundamental observations of the Earth's climate system, high-impact events, and adding value to other satellite missions and field campaigns. The spacecraft platform and five sensors are all fully functional, with the exception of the shortwave infrared bands in the Advanced Space-borne Thermal Emission and Reflection Radiometer instrument. Terra is a joint mission with Japan and Canada.

Terra is currently in extended operations.

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Recent Achievements

NASA accepted the 2020 Earth Science Senior Review endorsement of the Terra mission to continue extended operations through 2023.

In FY 2020, the Terra mission entered its 21st year. With a healthy suite of instrument and spacecraft systems, careful stewardship of spacecraft resources (fuel, batteries, data storage), and maintenance of instrument calibrations throughout the mission, Terra continued to provide a unique, long-term climate and environmental record not available from any other satellite platform.

The Terra project delivered over 90 million high-resolution Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) topographic data sets from its global archive, highlighting both the accessibility and demand for this recently updated product. Multiple Federal and international agencies used Terra's land and atmospheric products for volcanic ash monitoring, weather forecasting, forest fire monitoring, carbon management, and global crop assessment. In FY 2020, the mission’s long-term record was crucial to understanding changes in concentrations of atmospheric particulates (dust and haze) and other air pollutants in the United States and globally as a result of pandemic mitigation efforts. Together, Terra’s five instruments continued to play a key role in understanding fire location and intensity, burn areas and revegetation, and injection and transport of aerosols and carbon monoxide in the atmosphere, especially important for the unprecedented 2020 wildfires in Australia and the United States. The mission's measurements of sea-surface temperature and sea-ice boundary conditions contributed to ongoing evaluations of the performance of state-of-the-art global climate models.

AQUA

Aqua, launched in May 2002, is one of the EOS flagship missions. Aqua improves our understanding of Earth’s water cycle and the intricacies of the climate system by monitoring atmospheric, land, ocean, and ice variables. It was the first satellite launched into what has become the afternoon constellation of satellites, known as the A-Train, and remains the anchor satellite of that constellation. Four of Aqua’s Earth observing instruments – the Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit, Clouds and the Earth’s Radiant Energy System (CERES), and the Moderate Resolution Imaging Spectroradiometer (MODIS) – continue to collect valuable data about the Earth’s atmosphere, oceans, land, ice, and overall energy budget. The science community widely uses these data and in practical applications ranging from improved weather forecasting to monitoring forest fires, crop yields, volcanic ash plumes, and ice-infested waters. Aqua is a joint mission with Japan and Brazil.

Aqua is currently in extended operations.

Recent Achievements

NASA accepted the 2020 Earth Science Senior Review endorsement of the Aqua mission to continue extended operations through 2023.

In FY 2020, researchers published over 2,000 peer-reviewed articles incorporating Aqua data, including articles that quantify the downward trend in atmospheric methane in all latitude zones, using AIRS data; quantify the effect of solar panel installations on local surface reflection of solar radiation in areas of the southwestern United States, using MODIS data; and test how well state-of-the-art climate models represent observed changes in the Earth’s radiation budget, using CERES data.

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The AIRS team worked with the National Weather Service to combine AIRS observations and wind-trajectory models to improve the prediction of extreme storms over the United States.

MODIS data revealed an increase in foliage around the planet over the last two decades that includes greening in the United States, Mexico, and especially India and eastern China, in part due to extensive tree-planting programs.

Research using CERES data showed that a complete disappearance of Arctic sea ice would contribute an additional heating (relative to a 1979 baseline) equal to the effect of one trillion tons of carbon dioxide emissions.

AIRS data also contributed to monitoring the effects of COVID-19 on atmospheric pollution, and MODIS data provided important monitoring of the highly destructive August 2020 Complex Fire in California, the largest fire by area on record in the state, and numerous other wildfires in the western states of California, Oregon, Washington, and Colorado.

AURA

Aura, launched in July 2004, is one of the EOS flagship missions. Aura advances the understanding of changes in the Earth's radiation balance, air quality, and the ozone layer that result from changes in atmospheric composition, climate variability, and weather by measuring atmospheric chemical composition, tropospheric/stratospheric exchange of energy and chemicals, chemistry-climate interactions, and air quality. Aura is also part of the A-Train. Two of Aura’s four instruments are operational: the Microwave Limb Sounder and the Ozone Monitoring Instrument. Additional measurements include clouds, aerosols, solar spectral irradiance, and water vapor. Aura is a joint mission with the Netherlands, Finland, and the United Kingdom.

Aura is currently in extended operations.

Recent Achievements

NASA accepted the 2020 Earth Science Senior Review endorsement of the Aura mission to continue extended operations through 2023.

More than 16 years into its mission, Aura continued to witness unprecedented phenomena in FY 2020. Despite the rich record of middle atmosphere observations from the Aura Microwave Limb Sounder and other sensors, two events offered unusual opportunities to observe the stratosphere: the Australian fires that injected a vast amount of pollution into the lower stratosphere and the unusually small Antarctic ozone hole in late 2019 that redefined the envelope of observable behavior for Aura. Both phenomena have strong linkages to the poorly understood variability in stratospheric circulation. Aura's ozone monitoring instrument observed the unprecedented and sustained decrease in air pollution around the world associated with the COVID-19 pandemic in FY 2020, through its measurements of nitrogen dioxide and sulfur dioxide, two pollutants released in the combustion of fossil fuels. Climate scientists used the nitrogen dioxide measurements as a proxy for co-emitted carbon dioxide, a potent greenhouse gas. Intelligence agencies can use such data to assess the true impact of the pandemic on global economies as they are largely fueled by fossil fuels. Health professionals are using the data to gauge the effectiveness (e.g., reduction in emissions from traffic and industry) of lockdown efforts to contain or slow the pandemic. The long and stable pollution records from the ozone monitoring instrument provide a baseline for data comparisons with this past year. The International Ozone Monitoring Instrument Team received the prestigious 2020 American Meteorological Society Special Award, "for providing a stellar

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example of international collaboration to produce novel satellite observations that have transformed atmospheric chemistry research, especially air quality and health applications."

STRATOSPHERIC AEROSOL AND GAS EXPERIMENT III (SAGE-III)

SAGE-III, launched in February 2017, operates on the ISS, and provides global, long-term measurements of key components of Earth's atmosphere. The most important of these are the vertical distribution of aerosols and ozone from the upper troposphere through the stratosphere. In addition, SAGE-III provides unique measurements of temperature in the stratosphere and mesosphere and profiles of trace gases, such as water vapor and nitrogen dioxide, which play significant roles in atmospheric radiative and chemical processes. These measurements are vital inputs to the global scientific community for improved understanding of climate and human-induced ozone trends.

SAGE-III completed its prime mission in July 2020 and is now in extended operations.

Recent Achievements

NASA accepted the 2020 Earth Science Senior Review endorsement of the SAGE-III mission for continued extended operations through 2023.

The SAGE-III project continued to demonstrate improvements in operational efficiency for payload commanding and science data collection. In 2019 and 2020, the SAGE-III instrument observed the global impact of stratospheric aerosol loading from the devastating bushfires in Australia that produced record-setting quantities of smoke lofted into the stratosphere. SAGE-III also recorded the seasonal and yearly variations of ozone and other trace gases during an unusually brief reversal of the Equatorial stratospheric winds that influence the global distribution of these gases. The project continued to communicate with the international science community on the variations of stratospheric aerosol and ozone captured in the SAGE-III data products freely released to the public on a monthly schedule.

EARTH FROM ISS

NASA's ISS program sponsored the development of several earth science instruments for the ISS. The Earth from ISS project ensures the appropriate processing of data and its availability to the earth science research community from the data collected by these instruments. This project invests in algorithm development, data production and distribution, as well as data analysis and modeling for the currently planned ISS earth science payloads.

The ISS Lightning Imaging Sensor (LIS) makes space-based global lightning observations, using the backup flight spare for the instrument that operated for 17 years on the Tropical Rainfall Measuring Mission. LIS provides a great opportunity to not only extend the TRMM record of tropical lightning measurements, but also to expand coverage to the higher latitudes missed by the previous mission. LIS observations continue to support the global scientific research community, across a wide range of disciplines that include weather and extreme storms, climate studies, atmospheric chemistry, and lightning physics. Researchers use LIS to help calibrate and validate the observations from the new Geostationary Lightning Mapper operating on NOAA's newest geostationary weather satellite, GOES-16.

LIS is currently in extended operations.

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Recent Achievements

NASA accepted the 2020 Earth Science Senior Review endorsement for the LIS mission to continue extended operations through 2023.

LIS successfully completed three years on orbit in FY 2020. A major research journal published initial scientific results, demonstrating high accuracy as well as consistency with the long-term TRMM lightning record. The LIS instrument released quality-controlled (QC) data spanning the entire mission through late 2020. The QC dataset represents a significant improvement for science and applications end users. Comparisons of LIS observations with those of the Geostationary Lightning Mappers on NOAA's GOES-16/17 weather satellites continued to help cross-validate both systems.

TOTAL SOLAR IRRADIANCE SENSOR-1 (TSIS-1)

Launched in December 2017, TSIS-1 is currently in its prime operating mission, providing absolute measurements of total solar irradiance (TSI) and spectral solar irradiance (SSI) important for accurate scientific models of climate change and solar variability. TSIS-1 is comprised of two instruments, the Total Irradiance Monitor (TIM) and the Spectral Irradiance Monitor (SIM), which are the most accurate solar irradiance instruments in the world, allowing scientists to better understand solar variability at both short and long-time scales. The Laboratory for Atmospheric and Space Physics (LASP) built a highly sensitive thermal pointing system that the project uses to accommodate the instruments on the ISS.

Recent Achievements

The TSIS-1 instruments on the ISS continue to track daily TSI and SSI variations with unprecedented accuracy and precision. In FY 2020, the TIM extended the TSI record to 41 years and observed a small increase in TSI since December 2019 as the Sun entered Solar Cycle 25. The SIM reduced SSI uncertainties from Solar Radiation and Climate Experiment (SORCE, 2003-2020) by an order of magnitude in the visible (VIS) and more in the near infrared (NIR). Measuring the incoming solar energy at different spectral wavelengths provides critical elements for understanding how the Earth’s atmosphere and surface absorb that energy.

DEEP SPACE CLIMATE OBSERVATORY (DSCOVR)

DSCOVR, which launched in February 2015, is a multi-agency (NOAA, United States Air Force, and NASA) mission with the primary goal of making unique space weather measurements from the Lagrange point L1. Lagrange point L1 is on the direct line between Earth and the Sun and provides about a 45-minute early warning for adverse space weather events. NASA provided the two Earth-observing instruments, the Earth Poly-Chromatic Imaging Camera (EPIC) and the National Institute of Standards and Technology Advanced Radiometer (NISTAR), to the DSCOVR satellite. NASA-processed EPIC and NISTAR data has been publicly available since June 2015 and includes color images of the full sunlit disk of the Earth; maps of ozone, clouds, aerosols, and vegetation; and measurements of sulfur dioxide from volcanic eruptions.

The DSCOVR NASA provided instruments are currently in extended operations.

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Recent Achievements

NASA accepted the 2020 Earth Science Senior Review endorsement of the DSCOVR mission to continue extended operations through 2023.

In FY 2020, the NASA DSCOVR project further improved the geolocation algorithm, which improved the science quality of derived Earth-viewing EPIC products. Work began on new EPIC data products covering ocean chlorophyll and glint from cloud ice crystals and surface water. The near-real-time true color images of the Earth generated by EPIC remained highly popular with the public, especially during major storms. For example, EPIC observed the California wildfires and the time dependence of smoke plumes over both land and oceans, as well as the passage of the Moon behind Earth on October 2, 2020. The project also improved the NISTAR data in-flight calibration based on the observed stability of the cavity radiometers. The stability of NISTAR enables the use of a single calibration number for the duration of the mission, thereby improving the science quality of NISTAR shortwave data.

EARTH SYSTEM EXPLORERS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**0.0**	**0.0**	**6.6**	**23.4**	**34.3**	**92.0**	**150.2**
Change from FY 2021			**6.6**				
Percentage change from FY 2021			**100.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

NASA’s Earth System Explorers program provides competitive opportunities for medium-sized instruments and missions that address specific science and applications needs identified in the 2017 National Academies’ report "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space."

NASA's Earth System Explorers (illustrated above) will continue the tradition of the first U.S. satellite Explorer 1, launched in 1958.

These Principal Investigator (PI)-led projects will employ innovative, streamlined, and efficient management approaches to constrain design, development, and operations costs. Distinct from Earth Venture instruments and missions, Earth System Explorers will focus on one or more of the seven identified targeted observables, important to our understanding of Earth system science:

- Atmospheric winds
- Greenhouse gases
- Ice elevation
- Ocean surface winds and currents
- Ozone and trace gases
- Snow depth and snow water equivalent
- Terrestrial ecosystem structure

EXPLANATION OF MAJOR CHANGES IN FY 2022

Earth System Explorers is a new program to be initiated in FY 2022.

EARTH SYSTEM EXPLORERS

ACHIEVEMENTS IN FY 2020

None.

WORK IN PROGRESS IN FY 2021

None.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

NASA will develop an Announcement of Opportunity for one or more Earth System Explorers for release in FY 2022.

Program Elements

EARTH SYSTEM EXPLORERS FUTURE MISSIONS

Earth System Explorers Future Mission funding supports the selection of new missions through Announcement of Opportunity (AO) solicitations every three years to support the goal of launching three missions within a decade. This funding supports proposals selected during Step 1 of the proposal process to conduct Phase A formulation studies. Selected proposals will move to Step 2 for full mission implementation.

EARTH SYSTEM EXPLORERS PROGRAM MANAGEMENT

Earth System Explorers Program Management provides for the development of AO solicitations and the technical, management, and cost evaluations of proposals received in response to the AO solicitations. It also supports management of missions conducting formulation studies and missions in implementation, per the two-step selection process.

Program Schedule

Date	Significant Event
Q1 FY 2022	AO release
Q1 FY 2023	Selection of candidates to move into Step 1 within nine months of receipt of proposals
Q1 FY 2024	Select proposals for Step 2 after 9-14 months

EARTH SYSTEM EXPLORERS

Program Management & Commitments

Program Element	Provider
Earth System Explorers Program Management	Provider: TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

NASA will issue Announcement of Opportunity (AO) solicitations for Earth System Explorers every three years to support the goal of launching three missions within a decade. NASA will select all Earth System Explorers through full and open competition using a two-step proposal process.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None.

EARTH SYSTEM SCIENCE PATHFINDER

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Venture Class Missions	222.5	263.6	**326.9**	225.4	242.1	198.1	184.7
Other Missions and Data Analysis	51.1	52.5	**48.4**	48.4	39.9	39.9	40.5
Total Budget	**273.6**	**316.1**	**375.3**	**273.9**	**282.1**	**238.0**	**225.2**
Change from FY 2021			**59.2**				
Percentage change from FY 2021			**18.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

NASA's ECOSTRESS instrument, on board the International Space Station, imaged the water use and loss (evapotranspiration) in San Juan, Argentina on December 2, 2020. ECOSTRESS measured the temperature of the surface and produced data for the amount of water being used by plants. Blue colors indicate high water use (e.g., in the agricultural fields and mountains), and beige colors indicate dry conditions (e.g., in the surrounding desert).

The Earth System Science Pathfinder (ESSP) program provides regular competitively selected Earth science research opportunities that accommodate new and emerging scientific priorities and measurement capabilities. This results in a series of relatively low-cost, small-sized investigations and missions. Principal investigators lead these focused projects that contribute to studies of the atmosphere, oceans, land surface, polar ice regions, or solid Earth.

ESSP projects include space missions, remote sensing instruments for space-based missions of opportunity, and extended duration airborne-science missions. The ESSP program also supports the conduct of science research utilizing data from these missions. ESSP projects may involve partnerships with other U.S. agencies and/or international organizations. This portfolio of missions and investigations provides opportunity for investment in innovative Earth science that enhances NASA's capability for better understanding the current state of the Earth system.

EXPLANATION OF MAJOR CHANGES IN FY 2022

This budget reflects the movement of the Commercial SmallSat Data Acquisition (CSDA) project from the ESSP program to the Earth Science Data Systems program. Cost growth of greater than 10 percent is expected within the Earth Surface Mineral Dust Source Investigation (EMIT) and GeoCarb missions. Details are found in the Venture Class section of this document.

VENTURE CLASS MISSIONS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**222.5**	**263.6**	**326.9**	**225.4**	**242.1**	**198.1**	**184.7**
Change from FY 2021			**63.3**				
Percentage change from FY 2021			**24.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

TROPICS will make measurements over the tropical latitudes to observe the thermodynamics and precipitation structures of Tropical Cyclones (TCs). These measurements and the increased temporal resolution provided by the six-CubeSat constellation (one shown in image) will enable better understanding of the TC lifecycles and the environmental factors that affect the intensification of TCs.

NASA's Earth Venture Class Missions provide frequent flight opportunities for high-quality, low-cost earth science investigations that can be developed and flown in five years or less. NASA selects the investigations through open competitions to ensure broad community involvement and encourages innovative approaches. Successful investigations enhance our capability to understand the current state of the Earth system and enable continual improvement in the prediction of future changes. Solicitations include both space-borne and airborne/suborbital opportunities.

NASA established Venture Class Missions in response to recommendations in the 2007 National Academies' report, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond." The 2017 National Academies' report, "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space," also endorses the Venture Class Missions.

The Earth Venture Class Missions include four components:

- Earth Venture Suborbital (EVS) investigations, which are sustained suborbital-science investigations. NASA releases EVS solicitations every four years with a budget of approximately $133 million in FY 2022 dollars, and selects multiple investigations within each call, individually cost-capped at no more than $30 million.

VENTURE CLASS MISSIONS

- Earth Venture Missions (EVM) are small space-based missions. NASA releases EVM solicitations every four years at a cost cap of approximately $190 million in FY 2022 dollars.
- Earth Venture Instruments (EVI) are missions of opportunity hosted on space-borne platforms. NASA releases EVI solicitations every three years at a cost cap of approximately $108 million in FY 2022 dollars.
- Earth Venture Continuity (EVC) will fly on-orbit demonstrations of affordable measurement approaches for maintaining the long-term record of important Earth science measurements. NASA will release EVC solicitations every three years at a cost cap of approximately $166 million in FY 2022 dollars.

The cadence of solicitations for EVI and EVC investigations will alternate every 18 months, releasing each approximately every three years. The cadence of EVS and EVM solicitation is independent of other Earth Venture solicitations.

EXPLANATION OF MAJOR CHANGES IN FY 2022

NASA established a new project for Libera (from the Earth Venture Continuity-1 selection) and augmented the budget for hosting the Tropospheric Emissions: Monitoring of Pollution (TEMPO) instrument onboard the Intelsat 40e mission.

Pursuant to Section 521 of P.L. 113-235, NASA notified Congress via the FY 2021 Operating Plan in March 2021 that the Earth Surface Mineral Dust Source Investigation (EMIT) instrument has experienced total cost growth of greater than 10 percent. Due to COVID-19, the Jet Propulsion Laboratory (JPL) stood down all onsite work on EMIT starting mid-March 2020. EMIT experienced additional shutdowns due to the California wildfires and lost a total of three months. With continued safe-at-work protocols in place, EMIT is experiencing additional inefficiencies, which will cause a slip of instrument delivery by a total of five months, and incur a corresponding cost increase. NASA revised the Agency cost estimate to $112.6 million. The baseline launch readiness date for EMIT remains as October 2022.

Based on a recent assessment, the budget includes a $117 million lifecycle cost increase for the GeoCarb mission to mitigate COVID impacts and to accommodate changes to hosting/launch plans. A notification to Congress will be issued soon. Due to COVID-19, the California wildfires, loss of SES Government Solutions Company as a hosting option, and instrument technical challenges, the Lockheed Martin facility stood down all onsite work on GeoCarb starting mid-March 2020 and lost several months of onsite work. With continued safe-at-work protocols in place, the project is experiencing additional inefficiencies, which will cause a slip of instrument delivery by a total of 14 months, from January 2022 to March 2023, and incur a corresponding cost increase. NASA is assessing the impacts to the Agency cost estimate and baseline launch readiness date for GeoCarb and expects to finalize revised estimates no later than Q3 FY 2021.

VENTURE CLASS MISSIONS

Program Element

VENTURE CLASS FUTURE MISSIONS

Earth Venture Class Future Mission funding supports the selection of new missions through Announcement of Opportunity (AO) solicitations at intervals of every four years for EVS and EVM; EVI and EVC will alternate every 18 months, each released approximately every three years. NASA released EVM-3 AO in November 2020 and plans to release a solicitation for EVI-6 in FY 2021.

CYCLONE GLOBAL NAVIGATION SATELLITE SYSTEM (CYGNSS) (EVM-1, SELECTED IN 2012)

CYGNSS data enables scientists to probe from space key air-sea interaction processes that take place near the inner core of the storms and play large roles in the genesis and intensification of hurricanes. The CYGNSS measurements also provide information to the hurricane forecast community, potentially enabling better modeling to predict the strength of hurricanes as they develop. CYGNSS also makes measurements over land that are used to image flood inundation, wetland extent, and surface soil moisture.

CYGNSS's eight micro-satellite observatories receive both direct and reflected signals from Global Positioning System (GPS) satellites. The direct GPS signals pinpoint CYGNSS observatory positions and track fluctuations in GPS power, while the reflected signals are indicative of ocean surface roughness. Scientists use both measurements to derive the critical measurement of wind speed over ocean and water properties over land. CYGNSS launched in December 2016 and entered its extended mission phase in March 2019.

Recent Achievements

NASA accepted the 2020 Earth Science Senior Review endorsement of CYGNSS to continue extended operations through 2023.

The NOAA Center for Satellite Applications and Research began producing a version of the CYGNSS ocean-wind data product to assess its utility for use in their operational numerical weather prediction models. Furthermore, global climate and ocean circulation studies leveraged CYGNSS's ability to determine precisely the distance from the satellite to the surface over the ocean to produce measurements of sea level. Over land, researchers used CYGNSS's ability to image inland water bodies with high resolution to determine river flow rates during extreme flooding events and to map wetland flooding under heavy-tropical vegetation during and after the monsoon season to support global models of methane production. Through a collaboration with the United Nations Food and Agriculture Organization, CYGNSS measurements of soil moisture under heavy vegetation were used to support locust eradication efforts in East Africa.

Planned Future Achievements

Over ocean, activities will focus on the development and optimization of data assimilation schemes to use CYGNSS measurements of surface wind speed in both global numerical weather prediction models and

VENTURE CLASS MISSIONS

hurricane forecast models. Over land, the initial soil moisture and inland waterbody algorithms will be subject to focused validation studies to improve the characterization of their performance. Ground-based validation sites are being set up in Colorado and New Mexico, with a third site planned for the Southeast United States. A sustained airborne validation effort is also in development through a partnership between NASA, the New Zealand Space Agency, and the Air New Zealand (ANZ) commercial carrier. A domestic ANZ aircraft, with an airborne version of the CYGNSS sensor, will operate continuously to provide CYGNSS underflight validation measurements.

TROPOSPHERIC EMISSIONS: MONITORING OF POLLUTION (TEMPO) (EVI-1, SELECTED IN 2012)

The TEMPO instrument will measure atmospheric pollution covering most of North America. A commercial communications satellite will host the instrument and launch in 2023. On an hourly basis, TEMPO will measure atmospheric pollution from Mexico City to the Canadian tar/oil sands and from the Atlantic to the Pacific. TEMPO will provide measurements that include the key elements of air pollution chemistry (e.g., ozone, nitrogen dioxide) in the lowest part of the atmosphere. Measurements from geostationary orbit will capture the inherent high variability in the daily cycle of emissions and chemistry. Measuring across both time and space will create a revolutionary dataset that provides understanding and improves prediction of air quality and climate forcing.

Maxar Technologies of Westminster, Colorado will provide satellite integration, launch, and data transmission services for TEMPO.

Recent Achievements

Through the U.S. Air Force Hosted Payload Solutions (HoPS) contract, NASA awarded the hosting services contract for TEMPO in FY 2019 to Maxar Technologies, who partnered with Intelsat in FY 2020 to host the instrument on the Intelsat 40e satellite. The TEMPO project subsequently held a successful Spacecraft System Requirements Review (SRR), Host Requirements Review, Spacecraft Preliminary Design Review (PDR), and Spacecraft Accommodations Review (SCAR). In April 2021, TEMPO held a successful KDP-C to formally establish the Agency Baseline Commitment.

Planned Future Achievements

In FY 2021, the TEMPO project will hold the Spacecraft Critical Design Review (CDR) and the instrument pre-ship review, prior to shipping the TEMPO instrument to the host facilities to begin performance testing. The project will complete environmental testing in FY 2022 and conduct the Operations Readiness Review (ORR).

ECOSYSTEM SPACEBORNE THERMAL RADIOMETER EXPERIMENT ON SPACE STATION (ECOSTRESS) (EVI-2, SELECTED IN 2014)

ECOSTRESS, launched in June 2018, to observe changes in global vegetation from the ISS. The sensors give scientists new ways to see how changes in climate or land use affect forests and ecosystems. ECOSTRESS uses a high-resolution thermal infrared radiometer to measure plant evapotranspiration and the loss of water from growing leaves and evaporation from the soil. This data reveals how ecosystems change with climate and provide a critical link between the water cycle and effectiveness of plant growth, both natural and agricultural. ECOSTRESS is currently in extended operations.

VENTURE CLASS MISSIONS

Recent Achievements

NASA accepts the 2020 Earth Science Senior Review endorsement of the ECOSTRESS mission to continue extended operations through 2021.

NASA collects over 136,000 ECOSTRESS scenes (images that are 400km by 400 km in size) and achieves an acquisition rate that is more than double the proposed acquisition rate. The data show variations in plant water use and plant stress over different regions, together with differences in plant water uptake over the daily cycle. Companies incorporate ECOSTRESS data into systems used by farmers to optimize irrigation schedules for crops throughout the world. Large cities, such as Los Angeles, are using ECOSTRESS data for heat island assessment and mitigation strategies, and scientists are using the data to detect droughts throughout the world.

Planned Future Achievements

The project will continue extended operations through 2021, with a possible further extension to 2023, provided the instrument remains healthy and the site on the International Space Station is available. An expanded science team will use the ECOSTRESS data for a variety of studies in agriculture, forestry, geology, and the environment.

GLOBAL ECOSYSTEM DYNAMICS INVESTIGATION (GEDI) LIDAR (EVI-2, SELECTED IN 2014)

GEDI is a geodetic-class laser ranging system that provides three-dimensional measurements of the Earth's forests from the ISS. GEDI measures the height of the Earth's temperate and tropical forests and their vertical structure. This data will help scientists to determine, for the first time, how much carbon forests store as biomass, and the net impact of deforestation and subsequent regrowth on atmospheric carbon dioxide that results from human-influenced activities and climate variations. GEDI is the first mission optimized for vegetation measurements from space and provides the first, global, and transparently available data set that can be used by various U.S. agencies at relevant scales for both policy and land management. Launched in December 2018, GEDI is currently in prime operations phase.

Recent Achievements

GEDI has completed over 18 months on orbit, collecting over seven billion observations of the Earth's forests and topography. The first year of GEDI observations is now publicly available at the Land Processes Distributed Active Archive Center (DAAC), and this data comprises the most complete maps yet, available for forest height, canopy cover, and bare earth topography. The GEDI instrument is currently targeting the fires in the Western U.S to provide up-to-date information on carbon emissions from these fires, and to provide critical information on how the fires may spread. The project collaborated with the German Aerospace Center (DLR) to fuse GEDI observations with the commercial archive of the DLR TanDEM-X radar satellites to produce more accurate estimates of height and biomass, resulting in detailed maps over Gabon. The GEDI data, combined with observations from Landsat, produced the first 30-meter canopy height of the globe.

Planned Future Achievements

In 2021, the GEDI project will produce maps of global biomass and release two years of data, including all data products on canopy structure, topography, and biomass. The GEDI project will continue its collaboration with DLR and provide high-resolution maps for other pan-tropical countries. NASA will

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use the GEDI data to drive a carbon model that predicts how changes in land use (such as deforestation) may contribute to carbon dioxide emissions to the atmosphere.

EARTH VENTURE MANAGEMENT

Earth Venture Management provides the development of AO solicitations and the Technical, Management, and Cost evaluations of proposals received in response to the AO solicitations. Additionally, it supports the airborne assets that the EVS investigations rely on for their airborne campaigns.

MULTI-ANGLE IMAGER FOR AEROSOLS (MAIA) (EVI-3, SELECTED IN 2016)

MAIA will use a multi-angle imager to assess linkages between different airborne particulate matter types and human health (including adverse birth outcomes, cardiovascular and respiratory disease, and premature death). This project will retrieve concentrations of fine and coarse particles, sulfate, nitrate, organic and black carbon, and mineral dust particles in major urban areas around the globe on a one-kilometer grid. The MAIA science team will correlate the data with birth, death, and hospital records and will use established epidemiological methodologies to correlate the exposure to particulate matter with adverse health outcomes. General Atomics will provide services required to host the MAIA instrument on a commercial satellite in low-Earth orbit. NASA plans to launch MAIA in FY 2023.

Recent Achievements

The MAIA project completed assembly and test of the instrument camera in FY 2020 and is preparing for calibration prior to integration to the MAIA Instrument. The project assembles the primary structure and integrates the instrument electronics in preparation for testing. The project procures hardware for measuring ground-level speciated particle pollution concentrations. Additionally, the MAIA project establishes partnerships with the Department of State and U.S. Agency for International Development to facilitate deployment, operation, and analysis of the data from these ground-based monitors. The MAIA Science Data System delivers software executables for generation of map-projected, calibrated radiometric and polarimetric data products to the operational processing environment at the NASA Atmospheric Science Data Center. Despite these achievements, the project encountered significant delays when COVID-19 closed facilities at the Jet Propulsion Laboratory (JPL), stopping all hands-on lab work until June 2020. The subsequent limited restart of on-site work has allowed progress to resume, but at a less efficient pace resulting in an increase in the Agency cost of $10.2 million and delaying the instrument delivery 11 months.

Planned Future Achievements

In light of the COVID-19 impacts, MAIA will complete its instrument integration and most of the testing to deliver the instrument directly to General Atomics in early FY 2022 and begin integration to the Host Spacecraft. Launch of the General Atomics Orbital Test Bed–2 (OTB-2) Host Spacecraft is slated for no later than November 2022.

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TIME-RESOLVED OBSERVATIONS OF PRECIPITATION STRUCTURE AND STORM INTENSITY WITH A CONSTELLATION OF SMALLSATS (TROPICS) (EVI-3, SELECTED IN 2016)

TROPICS will make measurements over the tropical latitudes to observe the thermodynamics and precipitation structures of Tropical Cyclones (TCs) over much of the storm systems' lifecycles. TROPICS will take measurements of the temperature within the atmosphere, spatially and vertically resolved, as well as humidity, cloud ice, precipitation horizontal structure, and instantaneous surface rain rates. These measurements and the increased temporal resolution provided by the CubeSat constellation will enable better understanding of the TC lifecycles and the environmental factors that affect the intensification of TCs.

The TROPICS mission consists of six CubeSats, which will each have a cross-track scanning multiband passive microwave radiometer in a 1U payload (1U, a CubeSat unit, is equivalent to a 4-inch cubic box).

Recent Achievements

In FY 2020, TROPICS successfully completed the System Acceptance Review / Pre-Storage Review and delivered the six CubeSat Space Vehicles to storage. NASA awarded a contract to launch the TROPICS Pathfinder (Qualification Unit) as a risk-reduction mission, permitting the checkout and optimization of all mission elements, in advance of the launch of TROPICS six CubeSats.

Planned Future Achievements

NASA will award a contract in FY 2021 for the multiple launches of the six TROPICS CubeSats within a 120-day period. NASA will target no earlier than mid-year FY 2022 for the first of these launches.

GEOSTATIONARY CARBON CYCLE OBSERVATORY (GEOCARB) (EVM-2, SELECTED IN 2016)

GeoCarb will advance our understanding of Earth's natural exchanges of carbon between the land, atmosphere, and ocean. The primary goals of the mission are to monitor plant health, vegetation stress throughout the Americas, and to probe, in unprecedented detail, the natural sources, sinks, and exchange processes that control carbon dioxide, carbon monoxide, and methane in the atmosphere.

The hosting and launch options for GeoCarb are under study. The mission will make observations over the Americas from an orbit of approximately 22,000 miles (35,400 kilometers) above the equator. GeoCarb will measure daily the total concentration of carbon dioxide, methane, and carbon monoxide in the atmosphere with a horizontal ground resolution of three to six miles (5 to 10 kilometers). GeoCarb also will measure solar-induced fluorescence, a signal related directly to changes in vegetation photosynthesis and plant stress.

Recent Achievements

In FY 2020, NASA transferred GeoCarb project management from the University of Oklahoma to GSFC, following a continuation review to convert GeoCarb from a Principal Investigator-led to a directed mission. Since then, the project completed its Critical Design Review. The GeoCarb project also completed most of the payload design and drawings for flight procurements. The project conducted a successful Integrated Baseline Review (IBR) with the prime contractor Lockheed Martin Corporation; released the RFI for host options; and started integration and testing preparation after the delivery of

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spectrograph. Additionally, the project supported the NASA Space Apps Challenge event by submitting the "Carbon Footprint" challenge, which had 700 participants from around the world.

Planned Future Achievements

As stated above, this budget includes an additional $117 million in lifecycle cost for the GeoCarb mission to mitigate COVID impacts and to accommodate changes to hosting/launch plans. Due to COVID-19, the California wildfires, hosting, and instrument technical challenges, all onsite work was stood down starting mid-March 2020. With continued safe-at-work protocols in place, the project is experiencing additional inefficiencies, which will cause a slip of instrument delivery by a total of 14 months, from January 2022 to March 2023, and incur a corresponding cost increase. NASA is assessing the impacts for the Agency cost estimate and baseline launch readiness date and expects to finalize revised estimates no later than FY 2021 Q3. The GeoCarb project will select vendors for the telescope structure and the main bench in FY 2021. In FY 2022, the project will complete the instrument hardware integration, testing, and prepare for the pre-environment review and pre-ship review.

EARTH VENTURE SUBORBITAL-3 (EVS-3; SELECTED IN 2018)

Five investigations started in 2020 to investigate a range of pressing research areas such as intense East Coast snowfall events and the impact of small-scale ocean currents on global climate. These investigations are:

- Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) studies the formation of snow bands in East Coast winter storms. Better understanding of the mechanisms of snow band formation and the factors that influence the location of the most intense snowfall will help improve forecasts of these extreme weather events.
- Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment (ACTIVATE) identifies how aerosol particles change cloud properties in ways that affect Earth's climate system. The investigation will focus on marine boundary layer clouds over the western North Atlantic Ocean that have a critical role in our planet's energy balance.
- Delta-X investigates the natural processes that maintain and build land in major river deltas threatened by rising seas. The project will improve models that predict loss of coastal land from sea level rise by improving estimates of how deltas add land—a process that involves trapping sediments and creating organic soils as plants grow.
- Dynamics and Chemistry of the Summer Stratosphere (DCOTSS) explores how strong summertime convective storms over North America can change the chemistry of the stratosphere. These storms regularly penetrate deep into the lower stratosphere, carrying pollutants that can change the chemical composition of this atmospheric layer, including ozone levels.
- Sub-Mesoscale Ocean Dynamics and Vertical Transport (S-MODE) examines the potentially large influence that small-scale ocean eddies have on the exchange of heat between the ocean and the atmosphere. The project will collect a benchmark data set of climate and biological variables in the upper ocean that influence this exchange.

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Recent Achievements

During FY 2020, NASA held confirmation assessment meetings for two investigations (S-MODE and DELTA-X). The same investigations held successful investigation confirmation reviews and moved into their implementation/deployment phase.

IMPACTS, a NASA field campaign that studies snowstorms along the eastern seaboard of the United States, conducted its first deployment in FY 2020, on a P-3 out of NASA WFF and an ER-2 out of Hunter Army Airfield in Savannah, GA, and held its first virtual science team meeting.

ACTIVATE investigation conducted its first deployment in FY 2020, out of NASA Langley Research Center (LaRC). The deployment successfully collected the required science data. However, due to the COVID-19 pandemic, the ACTIVATE team shortened the deployment. During the shutdown, ACTIVATE worked on a plan to safely return to flight status and successfully completed their second deployment from August to September 2020.

Due to the COVID-19 pandemic, the remaining three EVS-3 investigations (DCOTSS, DELTA-X, and S-MODE) delayed their first field deployments from 2020 to 2021.

Planned Future Achievements

ACTIVATE will conduct deployments in January-February 2021 and May-June 2021, both at NASA LaRC and using the LaRC Falcon and UC12 aircraft. IMPACTS will undertake its third deployment in January/February 2021 using the WFF P3B based at Wallops Island Flight Facility and the AFRC ER-2 based at Dobbins Air Reserve Base in Marietta, Georgia. DELTA-X, DCOTSS and S-MODE will begin their first deployments during 2021. DCOTSS and DELTA-X will hold their second science team meetings while ACTIVATE has delayed its second science team meeting to the end of CY 2021, to allow more time for data processing and analysis.

EARTH SURFACE MINERAL DUST SOURCE INVESTIGATION (EMIT) (EVI-4; SELECTED IN 2018)

EMIT will use a sensor mounted to the exterior of the ISS to determine the mineral composition of natural sources that produce dust aerosols around the world. Scientist do not currently have a global inventory of the natural mineral sources of dust, and as a result, the global impacts of dust on weather, atmospheric circulation, and other aspects of Earth's environment are not well established.

EMIT's hyperspectral instrument will measure the different wavelengths of light emitted by minerals on the surface of deserts and other dust sources in order to determine their composition. By measuring in detail which minerals make up the dust, EMIT will help answer the critical question of whether mineral-based dust has a cooling or warming effect on the atmosphere. EMIT's modeling component will use the data collected to advance the understanding of the role of atmospheric dust in Earth's climate and better predict how it can be expected to change in the future.

Recent Achievements

EMIT successfully completed the PDR, followed by KDP-C, as well as the Critical Design Review in FY 2020. Despite completing these milestones, the project encountered significant challenges just as they entered Phase C, due to the California wildfires and when COVID-19 closed facilities at the Jet Propulsion Laboratory (JPL), stopping all hands-on hardware work until June 2020. The subsequent limited restart of on-site work has allowed progress to resume, but at a less efficient pace.

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Planned Future Achievements

EMIT will continue instrument development, integration, and testing activities in FY 2021 within the limited-access and social-distancing constraints at JPL. The EMIT project will target instrument delivery and launch readiness for FY 2022.

POLAR RADIANT ENERGY IN THE FAR INFRARED EXPERIMENT (PREFIRE) (EVI-4; SELECTED IN 2018)

PREFIRE will fly miniaturized thermal spectrometers on a pair of small CubeSat satellites to measure far-infrared emissions and how they change throughout the day and over seasons. These CubeSats will orbit Earth's poles to probe a little-studied portion of the radiant energy emitted by Earth for clues about Arctic warming, sea-ice loss, and ice-sheet melting. These observations will allow scientists to assess how changes in thermal infrared emissions at the top of Earth's atmosphere are related to changes in cloud cover and surface conditions below, such as the amount of sea ice and meltwater on the surface of ice. NASA plans to launch PREFIRE in FY 2023.

Recent Achievements

NASA awarded a contract to develop the CubeSat buses for the PREFIRE project, which features a groundbreaking technology that allows the spacecraft to perform autonomous navigation onboard without additional hardware. The project conducted a successful SRR and CDR for both the CubeSat bus and operations. The PREFIRE project completed its preliminary design review, leading to a successful KDP-C in September 2020.

Planned Future Achievements

The PREFIRE project will hold its CDR, Systems Integration Review, and pre-ship review in FY 2021. The project will deliver the integrated CubeSats in FY 2022.

GEOSYNCHRONOUS LITTORAL IMAGING AND MONITORING RADIOMETER (GLIMR) (EVI-5; SELECTED IN 2019)

GLIMR will provide unique observations of ocean biology, chemistry, and ecology in the Gulf of Mexico, portions of the southeastern United States coastline, and the Amazon River plume – where the waters of the Amazon River enter the Atlantic Ocean. It will closely monitor the health of our oceans and assess risks for coastal communities to protect our environment.

NASA will integrate GLIMR on a NASA-selected platform and launch in the 2026-2027 timeframe into a geosynchronous orbit where it will monitor a wide area, centered on the Gulf of Mexico, for up to 15 hours a day. From this vantage point, the hyperspectral ocean color radiometer will measure the reflectance of sunlight from optically complex coastal waters in narrow wavebands. GLIMR will gather observations of a given area each day in a way that would not be possible from a satellite in a low-Earth orbit. These observations are a critical capability in studying phenomena, such as the lifecycle of coastal phytoplankton blooms and oil spills.

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Recent Achievements

NASA LaRC made progress in establishing the contractual vehicle with the PI institution, University of New Hampshire (UNH), so that formulation work can be started in FY 2021.

Planned Future Achievements

NASA expects to award the GLIMR contract in FY 2021. The project will begin formulation activities and complete the SRR/mission definition review in early FY 2022.

LIBERA (EVC-1; SELECTED IN 2020)

Libera is NASA’s first mission selected under the EVC element. The project, named for the daughter of Ceres in ancient Roman mythology, provides continuity of the Clouds and the Earth’s Radiant Energy System (CERES) Earth Radiation Budget (ERB) observations. Its primary goal is to extend seamlessly the ERB record, essential for recognizing changes to Earth’s climate system and for constraining future predictions. NASA plans to launch Libera in 2028, and NOAA's JPSS-3 satellite will host the Libera instrument.

Recent Achievements

NASA selected Libera under NASA's first Earth Venture Continuity (EVC-1) Announcement of Opportunity in February 2020. The Libera Principal Investigator is at the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado.

Planned Future Achievements

Libera is in formulation and is planning a SRR/mission definition review in FY 2021 followed by a Key Decision Point Review B (KDP-B) that allows the project to enter the preliminary design and technology completion phase. Libera will conduct a preliminary design review in FY 2022 followed by a KDP-C confirmation review.

Program Schedule

Date	Significant Event
FY 2021	EVM-3 (mission) solicitation released
FY 2021	EVI-6 (instrument) solicitation released
FY 2021	Libera SRR/MDR
FY 2021	TEMPO Confirmation Review
FY 2022	EVS-4 (suborbital) solicitation released
FY 2022	MAIA Instrument Delivery host spacecraft
FY 2022	EMIT instrument delivery
FY 2022	Libera PDR
FY 2022	Libera Confirmation Review

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Date	Significant Event
FY 2022	TROPICS launch readiness
FY 2023	EMIT launch readiness
FY 2023	EVC-2 (Continuity Measurement) solicitation released
FY 2023	TEMPO launch readiness
FY 2023	PREFIRE CubeSat delivery
FY 2023	PREFIRE launch readiness
FY 2024	EVI-7 (instrument) solicitation released
FY 2024	MAIA launch readiness
FY 2025	EVM-4 (mission) solicitation released
FY 2025	EVC-3 (Continuity Measurement) solicitation released
FY 2026	EVS-5 (suborbital) solicitation released
FY TBD	GeoCarb launch readiness

Program Management & Commitments

The Earth System Science Pathfinder (ESSP) program at (LaRC) manages the Venture Class projects. The “Provider” in the following table lists the PI institution for each project.

Program Element	Provider
EVS-3: IMPACTS	Provider: University of Washington Lead Center: LaRC Performing Center(s): ARC, AFRC, GSFC Cost Share Partner(s): N/A
EVS-3: ACTIVATE	Provider: University of Arizona Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A
EVS-3: DCOTSS	Provider: Texas A&M University Lead Center: LaRC Performing Center(s): AFRC, ARC, GSFC Cost Share Partner(s): N/A

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Program Element	Provider
EVS-3: S-MODE	Provider: Woods Hole Oceanographic Institute Lead Center: LaRC Performing Center(s): JPL, JSC Cost Share Partner(s): N/A
EVS-3: Delta-X	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
EVM-1: CYGNSS	Provider: University of Michigan Lead Center: LaRC Performing Center(s): N/A Cost Share Partner(s): N/A
EVM-2: GeoCarb	Provider: University of Oklahoma Lead Center: LaRC Performing Center(s): ARC, GSFC, JPL Cost Share Partner(s): N/A
EVI-1: TEMPO	Provider: Smithsonian Astrophysical Observatory Lead Center: LaRC Performing Center(s): LaRC, GSFC Cost Share Partner(s): N/A
EVI-2: ECOSTRESS	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): USDA
EVI-2: GEDI	Provider: University of Maryland Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
EVI-3: TROPICS	Provider: MIT Lincoln Laboratory Lead Center: LaRC Performing Center(s): GSFC Cost Share Partner(s): N/A
EVI-3: MAIA	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A

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Program Element	Provider
EVI-4: EMIT	Provider: JPL Lead Center: JPL Performing Center(s): GSFC, JPL Cost Share Partner(s): N/A
EVI-4: PREFIRE	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
EVI-5: GLIMR	Provider: University of New Hampshire Lead Center: LaRC Performing Center(s): LaRC, GSFC Cost Share Partner(s): N/A
EVC-1 LIBERA	Provider: University of Colorado Laboratory for Atmospheric and Space Physics Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A

Acquisition Strategy

NASA will issue Venture Class solicitations at intervals of every four years for EVS and EVM, and every three years for EVI and EVC, alternating every 18 months. NASA will select all Venture Class missions through full and open competition.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
CYGNSS	PI Institution: University of Michigan Instrument Provider: Southwest Research Institute Launch Vehicle Provider: NASA	PI: Ann Arbor, MI Instrument: San Antonio, TX Launch Vehicle: Cape Canaveral, FL
TEMPO	PI Institution: Smithsonian Astrophysical Observatory Instrument Provider: Ball Aerospace & Technologies Corp. Host Services Provider: Maxar Technologies	PI: Cambridge, MA Instrument: Boulder, CO Host Services: Westminster, CO
GeoCarb	PI Institution: University of Oklahoma Instrument Provider: Lockheed Martin Launch Vehicle Provider: TBD	PI Institution: Norman, OK Instrument: Palo Alto, CA Launch Vehicle Provider: TBD

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Element	Vendor	Location (of work performance)
GLIMR	PI Institution: University of New Hampshire Instrument provider: Raytheon Host Services Provider: TBD	PI: Durham, New Hampshire Instrument: El Segundo, CA Host Services: TBD
Libera	PI Institution: University of Colorado Laboratory for Atmospheric and Space Physics Instrument provider: LASP Host Services Provider: NOAA (JPSS-3)	PI: Boulder, CO Instrument: Boulder, CO Host Services: TBD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Q1 FY 2020	EMIT PDR	Successful	Q4 FY 2020
Performance	SRB	Q2 FY 2020	GeoCarb CDR	Successful	Q2 FY 2024
Performance	SRB	Q4 FY 2020	EMIT CDR	Successful	Q1 FY 2022
Performance	SRB	Q3 FY 2021	PREFIRE CDR	TBD	Q1 FY 2022
Performance	SRB	Q1 FY 2022	Libera PDR	TBD	Q2 FY 2022
Performance	SRB	Q1 FY 2022	PREFIRE ORR	TBD	N/A
Performance	SRB	Q1 FY 2023	TEMPO ORR	TBD	N/A
Performance	SRB	Q2 FY 2024	GeoCarb ORR	TBD	N/A

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FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
ESSP Missions Research	16.5	18.0	**17.8**	25.8	29.3	29.3	29.8
Orbiting Carbon Observatory-3	7.5	7.0	**6.5**	2.8	0.0	0.0	0.0
OCO-2	11.0	9.9	**10.1**	10.4	10.7	10.7	10.7
GRACE	0.6	1.0	**0.0**	0.0	0.0	0.0	0.0
CloudSat	8.9	10.3	**8.9**	4.9	0.0	0.0	0.0
Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)	6.6	6.2	**5.1**	4.5	0.0	0.0	0.0
Total Budget	**51.1**	**52.5**	**48.4**	**48.4**	**39.9**	**39.9**	**40.5**
Change from FY 2021			**-4.1**				
Percentage change from FY 2021			**-7.8%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Earth System Science Pathfinder (ESSP) Other Missions and Data Analysis projects include operating missions and mission-specific research. These innovative missions will enhance understanding of the current state of the Earth system and enable continual improvement in the prediction of future changes.

Mission Planning and Other Projects

ESSP MISSIONS RESEARCH

ESSP Missions Research provides funds for the science teams supporting ESSP operating missions. The science teams are comprised of competitively selected individual investigators who analyze data from the missions to address relevant science questions.

Recent Achievements

A solicitation for a new science team for Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) was first competed in ROSES 2019 and a Global Ecosystem Dynamics Investigation (GEDI) science team was first competed in ROSES 2020. NASA initiated awards for these science teams in FY 2020. In addition, NASA will initiate a science team for the Time-Resolved

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Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission in FY 2022.

The Orbiting Carbon Observatory 2 (OCO-2) is NASA's first satellite dedicated to monitoring CO2 from space and provides novel insight into CO2 fluxes across the globe. The OCO-2 retrievals have undergone multiple updates since the satellite's launch, and the retrieval algorithm is now on its ninth version.

During a particularly intense period in the Australian 2019/2020 fire season, a series of powerful thunderstorms fueled by strong bushfires in southeast Australia emitted unprecedented amounts of water vapor, smoke, and other pollutants to heights 16 km above the surface. Researcher's observations from NASA's Microwave Limb Sounder (MLS), NASA's Cloud-Aerosol LIdar with Orthogonal Polarization (CALIOP), and the National Oceanic and Atmospheric Administration (NOAA) Ozone Mapping and Profiler Suite (OMPS) show that the plume subsequently rose from the lowermost stratosphere (15–16 km) to altitudes above 31 km in less than two months. Model calculations show that solar heating of the very-dark plume drove this rapid ascent, creating a temperature anomaly, with colder air above the plume and warmer air below, along with an anticyclonic circulation that helped maintain the coherence of the plume over this period.

New LiDAR remote-sensing missions, such as the Global Ecosystem Dynamics Investigation (GEDI) and Ice, Cloud and land Elevation Satellite 2 (ICESat-2) are providing robust measurements of forest structure at global scales. Simulation studies demonstrate that scientists are using GEDI data to characterize multiple components of forest structure by including canopy cover and biomass at global scales. Leveraging these GEDI-based structure measurements could gain a better understanding of biodiversity within forested ecosystems.

Combining data from multiple sensors often provides additive and complimentary information that helps the community better understand and monitor volcanic activity. An article published in Remote Sensing of Environment in 2020 provided a new combination of using multi-sensor data for volcano monitoring. Incorporating thermal-infrared data from the Moderate Resolution Imaging SpectroRadiometer to identify thermal anomalies, ultraviolet data from the Ozone Monitoring Instrument and OMPS to track SO2 plumes, LiDAR data from CALIOP and multi-angle visible and near-infrared data from the Multi-angle Imaging SpetroRadiometer (MISR), enables the observation of volcanic ash and aerosol properties occurring from 2000 to 2018 on the Kamchatka Peninsula. In addition, MISR data were able to capture downwind plume-particle evolution of ash, providing a new means to remotely quantify and monitor the vertical extent and particle characteristics of ash plumes.

California's Central Valley is one of the major food production regions in the world where municipality and agricultural needs rely heavily on groundwater resources. A study in Geosciences observes a strong correlation between the Gravity Recovery and Climate Experiment (GRACE) mission satellite groundwater anomaly variation data and subsidence measures using ESA Sentinel-1 data in the Central Valley. The long-term subsidence record shows clear slowdown/cessation in the winter of 2016–2017, the second wettest-rainy season on record, which likely reflects the basin-wide response of a compacting aquifer system to the increase in water recharge and decrease in groundwater pumping. The research indicates that subsidence measurement from satellite data is a very useful indicator for tracking groundwater storage change. Research results also suggest that the GRACE data combined with subsidence measurements from satellite data could provide for improved groundwater storage estimates at fine resolution.

Scientists have used Cyclone Global Navigation Satellite System (CYGNSS) measurements over ocean and land to characterize components of the Earth system, to understand its controlling processes, and to

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improve our ability to predict its development, as described in several publications. Over ocean, CYGNSS measurements of hurricane winds produce improved storm center location fixes. Scientists use its tropical wind speed and surface flux products to examine important surface flux feedbacks that can destabilize the Madden-Julian Oscillation. Over land, CYGNSS can map changes in volumetric-soil moisture content and produce flood-inundation maps. Imaging of inland water extent is used to measure river flowrate via changes in river width and produce high-resolution watermasks and flood maps for long-term hydrologic studies (yearly maps), seasonal hydrological studies, and near-real time identification of flooded areas.

Operating Missions

OCO-3

Orbiting Carbon Observatory-3 (OCO-3), which launched in May 2019, is a complete stand-alone payload built using the spare OCO-2 flight instrument, with additional elements added to accommodate installation and operation on the ISS. The OCO-3 instrument consists of three high-resolution grating spectrometers that collect space-based measurements of atmospheric carbon dioxide with the precision, resolution, and coverage needed to assess the spatial and temporal variability of carbon dioxide over an annual cycle.

Recent Achievements

The OCO-3 mission began delivering its primary science data products to the general public in January 2020. These data products consist of atmospheric carbon dioxide measurements that are complementary to the Orbiting Carbon Observatory-2, spanning latitudes from 52 N to 52 S, with unique dense data collections over 50-mile by 50-mile regions. The mission also provides a solar-induced chlorophyll fluorescence (SIF) data product. SIF is a measurement of photosynthesis activity, and therefore, an indicator of plant health. These data products are now serving the needs of scientists/researchers as well as those in the science applications community.

OCO-2

Orbiting Carbon Observatory-2 (OCO-2), which launched in July 2014, collects precise carbon dioxide measurements across the globe each day from its vantage point in low-Earth orbit. With this data scientists are gaining greater insight into how much carbon dioxide the Earth emits by natural sources and human activities, and the natural process for removing carbon dioxide from the atmosphere. This information may help decision-makers manage carbon dioxide emissions and reduce the human impact on the environment.

The OCO-2 instrument has collected almost one million soundings globally each day since September 2014. OCO-2 is currently in extended mission operations.

Recent Achievements

NASA accepted the 2020 Earth Science Senior Review endorsement of the OCO-2 mission to continue extended operations through 2026.

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OCO-2 has operated successfully for more than six years, creating a high-quality record of the changes in the global distribution of carbon dioxide through all seasons and through major changes during El Niño and La Niña climate cycles. The project released an improved dataset covering the entire six years for public distribution and the science community. Recent studies show the value of the simultaneous OCO-2 observations of carbon dioxide and plant productivity (growth) distinguish the release of carbon dioxide due to human activity in urban areas from the smaller, but important, role played by plants or crops. The recently released OCO-3 data, combined with the OCO-2 dataset, provide scientists with a new and more comprehensive view of the carbon cycle at urban to regional scales. Studies also used OCO-2 data to show the impact of the COVID-19 pandemic on atmospheric carbon dioxide as countries implemented restrictions on travel; this contributed to the international dashboard at: https://www.eodashboard.org/

CLOUDSAT

CloudSat, which launched in April 2006, measures cloud characteristics to increase understanding of the role of clouds in Earth's radiation budget. This mission provides estimates of the percentage of Earth's clouds that produce rain, provides vertically-resolved estimates of how much water and ice are in Earth's clouds, and estimates how efficiently the atmosphere produces rain from clouds. CloudSat collects information about the vertical structure of clouds and aerosols that other Earth-observing satellites do not collect. This data improves models and provides a better understanding of the human impact on the atmosphere.

CloudSat is currently in extended operations.

Recent Achievements

NASA accepted the 2020 Earth Science Senior Review endorsement of the CloudSat mission to continue extended operations through 2021.

In the past year, CloudSat has improved the operational cloud layer height algorithms used by weather forecasters and derived from the Advanced Baseline Imager on the Geostationary Operational Environmental Satellites. The global coverage, offered by CloudSat, provides a verification dataset for continued evaluation and improvement of these important operational data. CloudSat continues to provide critical verification data for global snowfall products produced by NASA's Global Precipitation Measurement (GPM) mission. Updates to GPM-CloudSat dataset observations refined the GPM snowfall data products. Furthermore, the project continues to exploit synergies with other NASA missions. For example, CloudSat released and continued refinement of a new-synergy cloud product that combines information from CALIPSO and the OCO-2 satellite with CloudSat, resulting in the first-ever direct measurements of cloud thickness of low-altitude clouds and fog. The utility of CloudSat to the science community is evident in the more than 3,000 peer-reviewed publications that cites the data.

OTHER MISSIONS AND DATA ANALYSIS

CLOUD-AEROSOL LIDAR AND INFRARED PATHFINDER SATELLITE OBSERVATION (CALIPSO)

The CALIPSO mission, which launched in April 2006, provides the first comprehensive three-dimensional measurement record of aerosols, helping to better understand how aerosols form, evolve, and are transported over the globe. The mission provides data on the vertical structure of clouds, the geographic and vertical distribution of aerosols, and detects sub-visible clouds in the upper troposphere. CALIPSO also indirectly estimates the contribution of clouds and aerosols to atmospheric temperature.

CALIPSO is currently in extended operations.

Recent Achievements

NASA accepted the 2020 Earth Science Senior Review endorsement of the CALIPSO mission to continue extended operations through 2021.

CALIPSO continues to provide unique vertical profile observations of clouds and atmospheric particle (aerosol) layers over the globe. Last year, the CALIPSO mission released a new data product, which summarizes three-dimensional cloud observations in support of an international effort to evaluate the reliability of cloud-data products from weather and research satellites. The mission also released a major update to the imaging infrared radiometer cloud data products to enhance understanding of the formation of cirrus clouds and their impact on Earth's energy balance. The team successfully implemented several improvements to the CALIPSO data algorithms to address specific needs by the scientific community. Two data releases will feature these algorithms in 2021. In addition, the team facilitated the use of CALIPSO observations by air quality forecasting agencies during the 2020 California wildfire season and in the wake of the January 2020 Australian bushfires event through the NASA Applied Sciences program.

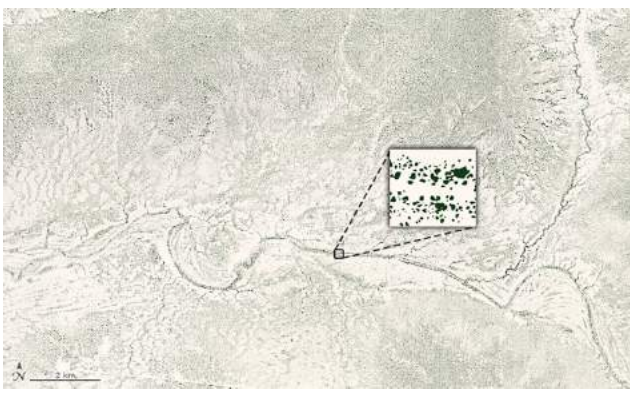
EARTH SCIENCE DATA SYSTEMS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**243.5**	**278.6**	**330.7**	**338.0**	**368.4**	**377.5**	**392.8**
Change from FY 2021			**52.1**				
Percentage change from FY 2021			**18.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Counting Trees in Africa's Drylands: An international team of scientists has used artificial intelligence and data from NASA's Commercial SmallSat Data Acquisition program to identify an unexpectedly large number of trees spread across areas of western Africa. Each pixel on the graphic above represents about 20in (0.5m) and allows scientists to count individual treetops from space.

The Earth Science Data Systems (ESDS) program oversees the life cycle of Earth science data with the principal goal of maximizing the scientific return from NASA's missions and experiments for research and applied scientists, decision makers, and the United States.

The ESDS program acquires, processes, preserves, and distributes observational Earth science data from spacecraft, aircraft, and in-situ sensors to support Earth Science research focus areas. The ESDS program primarily accomplishes this via the Earth Observing System Data and Information System (EOSDIS), which has been in operation since 1994.

EOSDIS has continuously evolved to take advantage of improved technology to meet the increasing demands of data providers and users. By 2022, the ingest rate of data into the EOSDIS archive is projected to grow from the current 3.9 petabytes per year to as much as 47.7 petabytes per year. As this ingest rate increases, the total volume of data stored in the EOSDIS archive is also expected to grow from its current size of 27 petabytes to a projected 250 petabytes by 2025.

This anticipated growth in both the data ingest rate and the overall archive volume poses challenges for archiving, distributing, and analyzing the data. To address these challenges, the ESDS program adopted a strategic vision to develop and operate multiple components of EOSDIS in a commercial cloud environment to meet the needs of future missions with high data volumes (e.g., Surface Water Ocean Topography [SWOT] and NASA-ISRO Synthetic Aperture Radar [NISAR]) as well as providing improved data management and user access for many ongoing Earth science missions.

EARTH SCIENCE DATA SYSTEMS

The program continuously evolves its capabilities by communicating with users, adopting new technologies, and supporting vibrant competitive research elements within the Data System Evolution (DSE) project. These activities help prioritize data system investments to more efficiently manage user needs and identify technologies to improve the processing, preservation, and access to the diverse data NASA collects.

For more information, go to: https://earthdata.nasa.gov

EXPLANATION OF MAJOR CHANGES IN FY 2022

The ESDS budget now includes the Commercial SmallSat Data Acquisition (CSDA) project, which has been transferred from the Earth System Science Pathfinder Program. In FY 2022, the budget for CSDA will increase to support the purchase and evaluation of data from new vendors and data license modifications for existing vendors. Data license modification will allow data purchased by NASA to be used by other government agencies, contractors, and grantees.

The budget provides additional support for the recently approved Open Sourced Science (OSS) activity, with the goal to create an open science ecosystem to dramatically increase the speed of scientific discovery. This project will develop Science Mission Directorate (SMD) wide capabilities for search and discovery of data, software, and publications, support open source scientific software, evaluate advanced data and computing technologies, and initiate a student-focused data science program.

ACHIEVEMENTS IN FY 2020

The EOSDIS archives grew to over 43.3 petabytes in FY 2020. ESDS distributed nearly 1.9 billion data products to more than 4 million users around the world. ESDS provided data stewardship to over 11,800 unique data products from more than 100 instruments.

The program released 524 new datasets from new and continuing missions for public access. The program provided the ability to search over 34,000 data collections in the Common Metadata Repository, with 98 percent of queries completing in less than 1 second. The Common Metadata Repository itself has grown to manage over 710 million files of sensor data from Earth science missions.

ESDS continued the development of a commercial cloud environment (Earthdata Cloud) in order to meet the needs of future high data volume missions such as SWOT and NISAR, as well as to provide data management and user access for many ongoing Earth science missions.

In FY 2020, the Global Hydrology Resource Center Distributed Active Archive Center (DAAC) began to operate completely in the Earthdata Cloud and transitioned the first set of high priority data sets from three other DAACs. High priority datasets will maximize the use of commercial cloud technology.

The NASA Sentinel Gateway continued to serve data from our partnership with the European Space Agency (ESA), delivering 55 terabytes of data per week from ESA to the DAACs. The total archive of Sentinel data is now 11 petabytes. During FY 2020, over 25 million files of data (more than 15 petabytes) were distributed by NASA from ESA's Sentinel 1-A/B, 3A/B, 5-P missions in support of NASA science activities.

ESDS supported over 280 unique near-real-time datasets in the Land, Atmosphere Near real-time Capability for EOS (LANCE) system. LANCE produces over 16 terabytes of data per week within 3

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hours of satellite acquisition. Advanced Microwave Scanning Radiometer 2 (AMSR2) and Visible Infrared and Imaging Radiometer Suite (VIIRS) - Land and Atmosphere added new Earth Science data products.

The DSE project's Interagency Implementation and Advance Concepts Team (IMPACT) team developed the NASA COVID-19 dashboard to view the impacts of pandemic as seen from space. Multiple science and technical teams developed the dashboard collaboratively. The dashboard presents various indicators - air quality, economic, water quality, and agriculture - to demonstrate the effects of COVID-19.

The DSE project's NASA Advancing Collaborative Connections for Earth System Science (ACCESS 2019) solicitation closed in January 2020. The announcement specifically sought technology developments focusing on Machine Learning and Enabling Science in the Cloud. NASA selected 11 projects.

NASA released the NASA Citizen Science for Earth Science Program (CSESP 2020) solicitation in FY 2020. In addition, the NASA Earth Science Data Analytics (ESDA) Citizen Science Data Working group released a whitepaper on best practices for the management of citizen science data, which is composed primarily of currently funded investigators in the program.

The Commercial SmallSat Data Acquisition (CSDA) project successfully conducted its first evaluation of commercial data products. The pilot activity ended in early 2020 with favorable results for the three vendors evaluated. The project published results of the evaluation.

For more information, go to: https://earthdata.nasa.gov/esds/csdap/csdap-pilot-evaluation

The CSDA project entered into longer-term agreements for the data evaluated during the pilot for broader use by the NASA scientific community.

WORK IN PROGRESS IN FY 2021

ESDS is focusing on open source cloud-native software to provide user services on data including the ability to subset and subsample. The program will focus on developing and enabling cloud-optimized formats and standardized tools that will work across data stored in the Earthdata Cloud. Additionally, high value data sets will be migrated into the Earthdata Cloud.

ESDS is continuing to work with several flight projects, instrument teams, and science teams to prepare for upcoming missions. Specific attention continues at the DAACs to add legacy airborne datasets to the more conventional collections.

The DSE IMPACT team will support the Satellite Needs Working Group (SNWG) and NASA in the assessment of the 2020 SNWG agency survey. The team is producing an initial automated evaluation of each agency's Earth observation needs.

In FY 2021, the CSDA project will begin evaluation vendors from the second onramp and release the third onramp Request for Information (RFI). For these acquisitions, NASA will be seeking end-user license agreements (EULAs) to enable broad levels of dissemination of the commercial data with the U.S. government agencies and partners. CSDA is coordinating with other U.S. government agencies to define government wide standard EULAs and coordinating on procurement and evaluation activities.

OSS began in FY 2021 and has already initiated activities to establish an open science ecosystem. Initial requirements for an SMD-wide information catalog are progressing, which will inform the development of a pilot catalog in early FY 2022. Two Research Opportunities in Space and Earth Science (ROSES)

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announcements were released to support widely used open source scientific software and a machine learning working group was formed.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The program will expand its capabilities to support data from new missions, including data from Earth Venture investigations, NISAR, and SWOT. The Earthdata Cloud will add high priority data from the current data collection. A fully tested, on-premise backup system will be in place for cloud datasets. Services that enable users to work on datasets in the Earthdata Cloud will be available.

The DSE IMPACT team will support the 2022 SNWG survey development and manage the formulation and development of new data products identified in the 2020 SNWG survey assessment. The IMPACT team will transition the COVID-19 dashboard framework into an interactive storytelling platform for Earth science data.

The CSDA project will work to greatly expand the Agency's investment and provide data access, including commercial climate data, using standard EULAs.

OSS will deploy a pilot version of the SMD information catalog and will initiate a data science internship program to support students in SMD-related science fields, with particular focus on underrepresented populations.

Program Elements

EARTH SCIENCE DATA AND INFORMATION SYSTEM (ESDIS)

The ESDIS project manages the geographically distributed science systems of EOSDIS including the Distributed Active Archive Centers (DAAC), Science Investigator-led Processing Systems (SIPS), the Land, Atmosphere Near real-time Capability for the Earth Observing System (LANCE), and core systems. Together these systems support processing of satellite data and seamless interdisciplinary access to EOSDIS data, including data products, data services, and data handling tools for a broad range of user communities including scientists, U.S. Government agencies, commercial users, and the general public.

- SIPS generate high-quality science products from Terra, Aqua, Aura, S-NPP, and JPSS missions at facilities under the direct control of the instrument principal investigators / team leaders. Products produced at SIPS undergo extensive quality assurance before the Program transfers them to DAACs for archiving and distribution to users.
- DAACs archive, document, and distribute data and provide user support for NASA's past and current Earth-observing satellites, Sentinel 1, 3, and 5P satellites, airborne investigations, and field measurement programs. Acting in concert, the DAACs provide reliable, robust services to users whose needs may cross the traditional boundaries of a science discipline, while continuing to support the unique needs of users within specific science discipline communities. The DAAC facilities, hosted at NASA or other institutions, each specialize in a science discipline such as atmosphere, calibrated radiance, solar radiance, cryosphere, human dimensions, land, or ocean science.

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- LANCE generates and provides access to near real-time products from the Atmospheric Infrared Sounder, Advanced Microwave Scanning Radiometer 2, Microwave Limb Sounder, Moderate Resolution Imaging Spectroradiometer, Measurement of Pollution in the Troposphere, Ozone Monitoring Instrument, Ozone Mapping Profiler Suite, and Visible Infrared Imaging Radiometer Suite (VIIRS) (VIIRS-Land and VIIRS Atmosphere) instruments in less than three hours from the time of observation. The data support NASA applications users who are interested in monitoring and analyzing a wide variety of natural and man-made phenomena.

The EOSDIS system supports several core systems to provide a common entry point to discover access and visualize data from the distributed DAACs and SIPS. The program developed core systems to reduce duplication and improve user access to EOSDIS data, including:

- Common Metadata Repository (CMR) is a high-performance, high-quality, continuously evolving metadata system that catalogs all data and service metadata records for EOSDIS;
- Global Imagery Browse Services (GIBS) provides visual representations of NASA Earth science data at full resolution in a free, open, and interoperable manner;
- NASA-compliant General Application Platform is a cloud-based platform that provides a scalable and flexible application platform solution;
- Cumulus is a cloud optimized software package for performing Earth science data ingest, archive, and distribution capabilities to support all EOSDIS missions;
- Earth Observing System Networks provide end-to-end network connectivity between users and geographically distributed DAACs via a variety of physical networks including wide area and local area networks;
- The NASA Earthdata website (see: https://earthdata.nasa.gov) integrates information from across EOSDIS. Earthdata is the entry point for EOSDIS data, articles, documentation, and collaboration; and
- The NASA Sentinel Gateway transfers data from the European Commission's Copernicus Programme Sentinel 1-A/B, 3-A/B, and 5P satellites to DAACs for archival and distribution to users.

DATA SYSTEM EVOLUTION (DSE)

The Data System Evolution project funds various research opportunities, as well as interagency initiatives and promotion of data and service interoperability through development and implementation of standards. DSE is composed of two competitive components: Advancing Collaborative Connections for Earth System Science (ACCESS), and Citizen Science for Earth Systems Program (CSESP). DSE also supports the Interagency Implementation and Advance Concepts Team (IMPACT) activity and the development of long-term data records needed by NASA scientists.

- The IMPACT team works with other Government agencies to increase the use of NASA Earth observation data. The team also assesses, independently evaluates, and makes recommendations to improve EOSDIS services and processes, leads stewardship of airborne science observations, and develops proof of concept data system capabilities. IMPACT works closely with the Satellite Needs Assessment Working Group (SNWG) and collaborates with other agencies to design and implement

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systematic plans to assist other agencies in incorporating NASA Earth observation data into their workflows.

- ACCESS supports the evolution of ESDIS by investing in technology to enhance the analysis, delivery, and preservation of Earth science data. NASA solicits proposals in this competitive program element every two years. The intent is to identify and develop promising technology prototypes into operational tools to infuse into the EOSDIS.
- CSESP consists of two elements: (1) the collection and analysis of data by citizen scientists across all Earth Science focus areas and (2) technological development and production of low-cost sensors for measurement and monitoring. NASA solicits proposals in this competitive program element every three years.

DSE activities also support the widespread use of NASA Earth science observations through the development and implementation of standards, through collaborations with other space agencies, and by leading activities to improve discoverability of NASA data within Geoplatform.gov.

For more information, go to: https://www.geoplatform.gov/

OPEN SOURCED SCIENCE

Open Sourced Science is a new element focused on implementing objectives outlined in “Strategy for Data Management and Computing for Groundbreaking Science 2019-2024." ESDS is leading several foundational activities and collaborating with other SMD divisions for this effort. The primary goal is to create an open science ecosystem that takes concepts used in the development of open source software and applies them to the scientific process. Opening the scientific process will lead to increased transparency, inclusion, accessibility, and reproducibility of scientific results.

During the initial years of this project, NASA will establish the foundation of an open sourced science ecosystem including the development of an information catalog to improve access and discoverability of data, software, and research results across SMD. NASA will also make investments to support open source software projects and incentivize further openness in the scientific process, including open access to and advancement of mission, analysis, modeling, and simulation software. NASA will conduct an evaluation of advanced technologies to accelerate research, including cloud, high end computing and open Artificial Intelligence and Machine Learning. Finally, NASA will develop a student-focused data science program to build a diverse and equitable open science community through training, workshops, competitions, and incentives.

COMMERCIAL SMALLSAT DATA ACQUISITION

The Commercial SmallSat Data Acquisition (CSDA) project (previously known as the Small Satellite Constellation Initiative) identifies, evaluates, and acquires data from commercial sources to support NASA's Earth science research and applications activities. This will provide a cost-effective means to augment and/or complement the suite of Earth observations acquired by NASA and other U.S. Government agencies, as well as those acquired by international partners. NASA will emphasize data acquired by small-satellite constellations, affording the means of complementing NASA acquired data with higher resolutions, increased temporal frequency, or other novel capabilities in support of existing Earth science and application activities.

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NASA-funded researchers examine and analyze the data set(s) to determine the utility of the commercial data products. CSDA provides an opportunity for vendors with new or significantly enhanced capabilities to have their data evaluated by NASA for longer-term procurement.

MAKING EARTH SYSTEM DATA RECORDS FOR USE IN RESEARCH ENVIRONMENTS (MEASUREs)

The overall objective of MEaSUREs is to provide Earth science higher-level data products and services driven by NASA's Earth science goals. These data products, called Earth Science Data Records, are critical for understanding Earth System processes; assessing variability, long-term trends, and changes in the Earth System; and providing input and validation means to modeling efforts. MEaSUREs is a competitive program element solicited every five years.

MEaSUREs emphasizes linking together multiple satellites into a constellation, developing the means of utilizing a multitude of data sources to form a coherent time series, and facilitating the use of NASA's extensive data in the development of comprehensive Earth system models. In addition, MEaSUREs activities include infusion or deployment of applicable science tools that contribute to data product quality improvement, consistency, merging or fusion, or understanding.

PROGRAM SCHEDULE

The ESDS program solicits research opportunities approximately every two years for ACCESS, every three years for Citizen Science for Earth System Science, and every five years for MEaSUREs. The CSDA project provides on-ramp opportunities for new vendors every 18-24 months. The ESDIS project continuously delivers software to improve functionality and improve efficiency.

Date	Significant Event
Q2 FY 2021	ROSES CSESP Solicitation Released
Q4 FY 2021	Cumulus Operational for SWOT
Q1 FY 2022	CSDA Program RFI Released
Q2 FY 2022	ROSES MEaSUREs Solicitation Released CSDA On-Ramp Released 4
Q1 FY 2023	ROSES ACCESS Solicitation Released
Q1 FY 2023	CSDA Program RFI Released
Q1 FY 2024	CSDA Program RFI Released
Q2 FY 2024	ROSES CSESP Solicitation Released CSDA On-Ramp Released 5
Q1 FY 2025	ROSES ACCESS Solicitation Released
Q1 FY 2025	CSDA Program RFI Released
Q1 FY 2026	ROSES CSESP Solicitation Released

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Date	Significant Event
Q1 FY 2026	CSDA Program RFI Released

Program Management & Commitments

The Earth Systematic Missions program at GSFC provides program management for the ESDIS project. NASA Headquarters manages the Commercial SmallSat, DSE, and MEaSUREs projects.

Program Element	Provider
EOSDIS core system	Provider: Various Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Alaska Synthetic Aperture Radar Facility (Fairbanks, AK)	Provider: University of Alaska Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Atmospheric Science Data Center (Hampton, VA)	Provider: LaRC Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A
Goddard Earth Science Data and Information System Center (Greenbelt, MD)	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Land Processes Data Center (Sioux Falls, SD)	Provider: USGS Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
National Snow and Ice Data Center (NSIDS; Boulder, CO)	Provider: University of Colorado Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Oak Ridge National Laboratory DAAC (Oak Ridge, TN)	Provider: Oak Ridge National Laboratory Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A

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Program Element	Provider
Physical Oceanography DAAC (Pasadena, CA)	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
Socio-economic Data and Applications Center (SEDAC; Palisades, NY)	Provider: Columbia University Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Crustal Dynamics Data Information System (Greenbelt, MD)	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Global Hydrology Research Center (Huntsville, AL)	Provider: University of Alabama Lead Center: MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A

Acquisition Strategy

Research opportunities within DSE are available through NASA's ROSES announcements. NASA competitively selects ESDIS support contracts through full and open competition.

Commercial SmallSat data acquisitions are initiated via FedBizOpps and, following a favorable evaluation if deemed of sufficient value, will be purchased by NASA for broader sustained use. Contract types will be selected on a vendor-by-vendor basis that are best suited to provide long-term access to data.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
EOSDIS Evolution & Development	Raytheon	Riverdale, MD
National Snow and Ice Data Center	University of Colorado	Boulder, CO
Alaska SAR Facility	University of Alaska	Fairbanks, AK
SEDAC	Columbia University	Palisades, NY
Commercial SmallSat Data	Spire Global, Inc.	San Francisco, CA
Commercial SmallSat Data	Planet Labs, Inc.	San Francisco, CA

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INDEPENDENT REVIEWS

The American Customer Satisfaction Index measures customer satisfaction with the NASA Earth Observing System Data and Information System (EOSDIS) at a national level for each Distributed Active Archive Center (DAAC) on an annual basis. The average aggregate Customer Satisfaction Index score for NASA EOSDIS over the last 11 years is 77. It also identifies the key areas that NASA can leverage across the DAACs to continuously improve its service to its customers.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	American Customer Satisfaction Index	2020	Survey current EOSDIS users to assess satisfaction with current services	Customer Satisfaction Index: 77	2021

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FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**69.6**	**82.2**	**91.1**	**93.3**	**95.9**	**108.1**	**110.2**
Change from FY 2021			**8.9**				
Percentage change from FY 2021			**10.8%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The Hyper-Angular Rainbow Polarimeter (HARP) CubeSat (illustrated above), is demonstrating a new hyper-angular polarimeter that can characterize aerosol and cloud properties. HARP sent back its first images in April 2020. The flight validation is proving that CubeSat-size technology can provide science-quality multi-angle imaging data. In August 2020, HARP was named "SmallSat Mission of the Year" by the American Institute of Aeronautics and Astronautics.

Advanced technology plays a major role in enabling Earth science research and applications. The Earth Science Technology Program (ESTP) enables previously infeasible science investigations, improves existing measurement capabilities, and reduces the cost, risk, and/or development times for Earth science instruments and information systems.

EXPLANATION OF MAJOR CHANGES IN FY 2022

Increased funding in FY 2022 will support activities to accelerate technology developments and demonstrations supporting climate variability and climate change science.

ACHIEVEMENTS IN FY 2020

The ESTP worked on 140 active projects in FY 2020. For eligible projects, 55 percent advanced at least one Technology Readiness Level (TRL) during FY 2020 and at least 12 projects advanced more than one TRL. Historically, student participation in Earth Science Technology Office projects has been substantial, with more than 960 students from 154 institutions participating in the ESTP. In FY 2020, more than 125 students from 44 institutions were involved in ESTP-funded work.

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ESTP projects are also contributing to scientific and technical literature: 140 active projects published over 70 peer-reviewed journal articles and gave more than 380 conference presentations over the total period of funding.

The program infused several projects into science measurements, airborne campaigns, data systems, or other follow-on activities during the year. For example, NASA deployed the in-situ SoilSCAPE (Soil Moisture Sensing Controller And oPtimal Estimator) network in Colorado's San Luis Valley in late 2019 to provide calibration/validation soil moisture data for the CYGNSS (Cyclone Global Navigation Satellite System) mission.

The Aerosol Cloud meTeorology Interactions oVer the western ATlantic Experiment (ACTIVATE) project selected the High Spectral Resolution Lidar-2 instrument, funded within the Earth Science Technology program, to provide globally-relevant data about changes in marine boundary layer cloud systems, atmospheric aerosols, and multiple feedbacks that warm or cool the climate.

WORK IN PROGRESS IN FY 2021

With emphasis on the measurements identified by the 2017 Earth Science Decadal Survey, ESTP plans to award funding for new projects through the Advanced Component Technology (ACT) program element, resulting from a competitive solicitation released in FY 2020. ESTP also plans to issue new solicitations in FY 2021 for the In-Space Validation of Earth Science Technologies (InVEST), Instrument Incubator Program (IIP), Advanced Information Systems Technology (AIST), and Decadal Survey Incubation (DSI) program elements. The DSI solicitation will be the first for this program element, and ESTP anticipates competitively selected projects that address technology needs for the Planetary Boundary Layer and Surface Topography and Vegetation targeted observable areas.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

In FY 2022, the program plans to select awards under the InVEST, IIP, AIST, and DSI program elements. The ESTP plans to release competitive solicitations under the ACT and Sustainable Land Imaging-Technology program elements. The program also plans several technology demonstrations / launches (up to four CubeSats) for FY 2022.

The program has several activities planned for accelerating technology developments and demonstrations supporting climate variability and climate change science. NASA expects two CubeSat developments to advance and another to launch in FY 2022. Arcstone, a compact spectrometer in a 6U CubeSat designed under the IIP to establish climate level absolute spectral calibrations using the Moon, will advance to launch readiness. The Stratospheric Aerosol and Gas Experiment, SAGE IV is a compact occultation imager in a CubeSat form that will undergo preformulation study activities to advance readiness for an Earth Venture proposal for affordable sustainable continuity measurements of ozone and aerosols. The NanoSat Atmospheric Chemistry Hyperspectral Observation System (NACHOS) hyperspectral imager flight-like engineering unit, developed under the InVEST program, will integrate and launch along with the flight model to enable a mini-pathfinder constellation for tracking greenhouse gas emissions. The program also plans to jumpstart a digital twin Earth prototype framework leveraging several AIST projects. The digital twin Earth prototype will mirror a localized Earth science system of an urban area and utilize the combination of data analytics, machine learning, and state-of-the-art models to conduct

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"what if" investigations that can result in actionable predictions and relate natural and physical events to urban development and human activities.

Program Elements

ADVANCED TECHNOLOGY INITIATIVES (ATI)

This project enables development of critical component and subsystem technologies for instruments and platforms, mostly in support of the Earth Science Decadal Survey. Current awards focus on areas such as space-qualified laser transmitters, passive optical technologies, and microwave and calibration technologies. Other awards support measurements of solar radiance, ozone, aerosols, and atmospheric gas columns for air quality and ocean color, and for coastal ecosystem health and climate emissions.

The InVEST program element selects new technologies to validate in space prior to use in a science mission. This is necessary because the space environment imposes stringent conditions on components and systems, some of which cannot be tested on the ground or in airborne systems. Validation of Earth science technologies in space will further reduce the risk of new technologies in future Earth Science missions.

INSTRUMENT INCUBATOR

This project develops instruments, instrument concepts, and measurement techniques at the system level, including laboratory breadboards and operational prototypes that often lead to ground or airborne demonstrations. NASA currently funds 30 Instrument Incubator efforts. These instrument prototypes support multiple measurements including carbon dioxide, carbon monoxide, ocean color, and solar spectrum (from ultraviolet to infrared) for Earth science. Instrument Incubator supports the development of instrument design and prototyping through laboratory and/or airborne demonstrations for innovative measurement techniques that have the highest potential to meet the measurement capability requirements of the NASA Earth science community in both the optical and the microwave spectrum.

DECADAL INCUBATION

NASA created this project in response to the recommendation of the 2017 Earth Science Decadal Survey. It focuses on maturing observing systems, instruments, technologies, and measurement concepts to address high priority science for the next decade (2027 – 2037) in two targeted observable areas. These observable areas are the Planetary Boundary Layer and Surface Topography and Vegetation. Anticipated developments in this project include various observation and information system technologies, modeling/system design, analysis activities, and small-scale pilot demonstrations in support of the two observable areas.

EARTH SCIENCE TECHNOLOGY

ADVANCED INFORMATION SYSTEMS TECHNOLOGY (AIST)

This project develops end-to-end information technologies that enable new Earth observation measurements and information products. The technologies help process, archive, access, visualize, communicate, and understand Earth science data. Currently, AIST activities focus on two primary areas of need to support future Earth system science measurements:

- Analytic Center Framework (ACF): ACF technology projects aim to harmonize tools, data, and computing environments to meet the needs of Earth science investigations of physical processes and natural phenomena. These investigations integrate new or previously unlinked datasets, tools, models, and a variety of computing resources together into a common platform to address previously intractable scientific questions. Additionally, these projects seek to generalize custom or unique tools used by a limited community in order to make them accessible and useful to a broader community.
- New Observing Strategies (NOS): NOS technologies support planning, evaluating, implementing, and operating a dynamic set of observing assets consisting of various instruments located at different vantage points (e.g., in-situ, airborne, and on-orbit) to create a more complete picture of a natural phenomenon or physical process. The emergence of new sources of observational data (including high-quality instruments on SmallSats, CubeSats, and commercial space platforms) allows measurement of phenomena that could not be studied using previously available observational techniques.

Program Schedule

Date	Significant Event
Q2 FY 2021	ROSES-2021 solicitation
Q1 FY 2022	ROSES-2021 selection no earlier than six months of receipt of proposals
Q2 FY 2022	ROSES-2022 solicitation
Q1 FY 2023	ROSES-2022 selection no earlier than six months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation
Q1 FY 2024	ROSES-2023 selection no earlier than six months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation
Q1 FY 2025	ROSES-2024 selection no earlier than six months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation
Q1 FY 2026	ROSES-2025 selection no earlier than six months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation

EARTH SCIENCE TECHNOLOGY

Program Management & Commitments

Program Element	Provider
Instrument Incubator	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, MSFC, AFRC Cost Share Partner(s): N/A
Advanced Information Systems	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, MSFC, ARC, JSC Cost Share Partner(s): N/A
Advanced Technology Initiatives	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC Cost Share Partner(s): N/A
Decadal Incubation	Provider: Various Lead Center: HQ Performing Center(s): GSFC, LaRC, JPL Cost Share Partner(s): N/A

Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as through the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA centers, industry, and academia as well as other Government agencies, Federally Funded Research and Development Centers, and nonprofit organizations.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	National Academies of Science, Committee on Earth Science, and Applications from Space (CESAS)	Mar 2020	Provide results of the ESTP and outline program's ongoing response to 2017 Decadal Survey	CESAS was pleased with the current status of the program	2021

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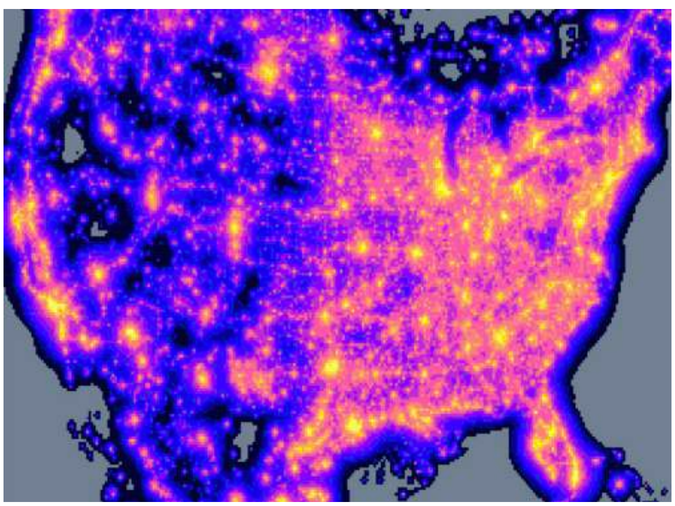
FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**53.3**	**62.9**	**72.7**	**74.2**	**77.3**	**100.8**	**103.7**
Change from FY 2021			**9.8**				
Percentage change from FY 2021			**15.6%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



An Ecological Forecasting project used NASA satellite data to understand the impacts of light and noise pollution on bird phenology and fitness. This map, constructed with VIIRS data, shows areas with increased light pollution (yellow and pink) compared to the night sky (darker blues).

The Applied Sciences program leverages NASA Earth Science satellite measurements and new scientific knowledge to enable innovative and practical uses by public and private sector organizations. It supports near-term uses of Earth science knowledge, discovers, and demonstrates new applications, facilitates adoption of applications, and builds capabilities.

Applied Sciences projects improve decision-making activities to help the United States better manage its resources, improve quality of life, and strengthen the economy. NASA develops Earth science applications in collaboration with end-users in public, academic, and private organizations.

The program supports activities in thematic Earth science applications areas, in capacity building with uses of Earth observations, and in planning for future NASA missions.

Examples of these applications include:

- The U.S. Department of Agriculture uses NASA soil moisture data to support its monthly global crop production estimates;
- The U.S. Forest Service uses wildfire detection data and progression predictions to improve determination of fire boundaries and to expedite restoration of key ecosystems;

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- The Centers for Disease Control and Prevention's Environmental Public Health Tracking Network includes data for county-level ultraviolet (UV) exposure information;
- State and local government use satellite-based water quality data to assess algal bloom magnitude, frequency, duration, and extent to map indicators and threats to human health from harmful algal blooms;
- Disaster-response organizations use data from multiple Earth observing satellites to identify damaged areas following hazards such as hurricanes, floods, and wildfires;
- Tourism industries, coastal resource managers, and others use satellite data to identify the amount and location of Sargassum seaweed in the Atlantic and the Gulf of Mexico to mitigate Sargassum beaching events that cause serious problems for the environment, human health, and economy;
- Local governments use satellite-based land-surface temperature data, emissivity data, and imagery to identify populations most vulnerable to extreme heat and guide service efforts; and
- The Volcanic Ash Advisory Centers use satellite observations of volcanic ash to inform air traffic controllers and the aviation industry of hazards along major airplane routes.

The program supports the sustained use of these products in the decision-making process of user organizations. The program also encourages potential users to envision and anticipate possible applications from upcoming satellite missions and to provide input to mission development teams to increase the societal benefits of NASA missions.

For more information, go to: https://appliedsciences.nasa.gov/

EXPLANATION OF MAJOR CHANGES IN FY 2022

Additional funding has been provided to initiate an Applications and Research Team focused on science-informed solutions and addressing climate impacts together with underserved communities. Applied Sciences will initiate efforts to build resilience to environmental disruptions and climate risks, including activities focused on infrastructure and supply chains. Applied Sciences will target specific activities on wildfires and make further improvements to the Prediction of Worldwide Energy Resources (POWER) tool, which provides solar and meteorological data sets from NASA research for the support of renewable energy, building energy efficiency, and agricultural needs.

ACHIEVEMENTS IN FY 2020

An air quality warning system in Puerto Rico, that provides an additional three days of notice for poor air quality, went into effect just in time for a massive August dust storm. The system used on-the-ground sensors in combination with data from the Moderate Resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) sensors on the Terra and Aqua satellites and NOAA's GOES-16 satellite.

NASA made progress in developing a transformative tool in water management in the Western U.S. called OpenET. It will put NASA data into the hands of farmers, water managers, and conservation groups, combining Landsat with data from several other satellites including GOES, Sentinel-2, Suomi NPP, Terra, and Aqua.

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An activity in partnership with the U.S. Veterans' Administration developed a tool that uses the Multi-angle Imaging Spectroradiometer (MISR) and the Modern-era Retrospective Analysis for Research Applications, version 2, to monitor environmental exposure risks during military deployments.

In August 2020, a severe derecho hit parts of Iowa, Illinois, and Indiana. It caused widespread damage across Iowa's key agricultural regions, bending and flattened crops over roughly one-third of the state. NASA Harvest, the Agency's food security and agriculture program, produced damage extent and severity estimates by crop type across the state, using Synthetic Aperture Radar data to quickly provide critical information of the storm impacts on crops in the area.

NASA Harvest developed a new, online dashboard to analyze COVID-19 impacts on agriculture and food security. This NASA Harvest COVID-19 Dashboard provided easily accessible tools to help stakeholders quantify the pandemic's impact on agricultural production and food security worldwide.

The California Department of Water Resources now integrates remotely sensed Snow Water Equivalent (SWE) data into the streamflow volume forecasts it issues through an activity funded by the Water Resources program area. The streamflow volume forecasts inform critical water-allocation decisions for agriculture operations and other uses. The forecasts rely on a dataset called MODIS Snow Covered Area and Grain-Size, which uses data from the Terra satellite to determine snow properties. The SWE data was especially important for the April-July forecast this year since COVID-19 social- distancing laws prevented ground measurements at 50 percent of the remote snow survey sites across the Sierra Nevada.

The DEVELOP program, a workforce development effort that partners early career professionals with user organizations to apply Earth science data, engaged 239 people through 49 feasibility activities. Due to COVID-19, the program conducted its first fully virtual term in the summer of 2020 with participants working from 23 U.S. states. Through a partnership with the U.S. Department of State, two DEVELOP activities focused on community concerns relating to water and ecological forecasting in Bhutan. Nine Bhutanese scholars engaged in the summer term.

The Applied Remote Sensing Training Program (ARSET) conducted 13 virtual and in-person trainings, with a record reach of 20,665 contacts, including participation from all 50 U.S. states again this year. A training on Remote Sensing of Coastal Ecosystems broke the program's single-session attendance record and had more than 2,900 people from nearly 1,900 unique organizations in 114 countries. As part of COVID-19 response, the ARSET Training program created a new webinar series about what pollutants can be measured from space, how satellites make these measurements, how to interpret satellite data, and how to download and create visualizations.

The Applied Sciences project supported multiple partners in their response and recovery for many disasters, including wildfires in the western U.S., multiple hurricanes, and tornadoes in the southern and central United States. They supported the Federal Bureau of Investigation in investigating a massive explosion in the port of Lebanon, Beirut by providing 10-meter resolution damage proxy maps generated by the advanced rapid imaging and analysis team. The maps allowed agents to sketch areas of focus for ground surveying, resulting in discovering significant areas of damage not previously located.

The Navajo Nation spans more than 70,000 square kilometers that is prone to frequent and pervasive droughts and suffers from poor water-supply reliability. A team working with the Western Water Applications Office developed the Drought Severity Evaluation Tool, a user-friendly web application that combines many datasets such as precipitation and temperature from NASA satellites with drought metrics from models and ground-based rain measurements. This tool can help emergency managers and can be used to allocate drought-relief funding throughout the community. In the past year, the team conducted two trainings with staff from the Navajo Nation's Department of Water Resources.

An ecological forecasting activity from the University of Southern Florida now delivers monthly bulletins that allow tourism industries and coastal resource managers to use satellite data about the location of Sargassum seaweed to mitigate impacts from beaching events on utilities, recreation, and water intakes. These bulletins use MODIS and VIIRS data to provide a forecast of the amount and location of Sargassum seaweed in the Atlantic and the Gulf of Mexico.

On August 19, 2020, a SERVIR team of researchers from NASA and the University of California Irvine released a new web tool for tracking forest fires in Amazonia. The tool analyzes satellite imagery, including fire detection data from the VIIRS sensors on Suomi-NPP and NOAA-20 and land cover data from Landsat and MODIS, to identify types of fires, including deforestation fires. The tool brought new clarity into the 2020 fire season and will continue to provide helpful information into future seasons.

WORK IN PROGRESS IN FY 2021

The Applied Sciences program will expand activities for strengthening ties with the private sector on uses of Earth observations. The program will develop a private sector strategy that includes improved engagement with private sector, increased private sector uses of Earth observations, greater feedback from the private sector on information products and research questions, increased involvement in satellite missions' lifecycles, and greater opportunities to scale successful applications.

The Ecological Forecasting program area is examining how to scale conservation efforts in the Western United States as a model for conservation globally and is working with the Metropolitan Group to conduct an assessment of current and planned conservation collaborations and consortia. Additionally, the Ecological Forecasting area will have 11 application activities conclude this year and will be conducting a competitive solicitation this year.

The Water Resources program area has supported the development of OpenET, a web-based platform that puts NASA Earth science data on water use into the hands of farmers, water managers, and conservation groups. OpenET becomes available to the general public in FY 2021, supplying evapotranspiration data across 17 western U.S. states. OpenET represents an on-going system for measuring and distributing data daily on the scale of individual fields about "evapotranspiration," which is a crucial measurement for farmers and other water managers.

Seven of the remaining 11 applications activities within the Health and Air Quality program area will continue this year, with the remaining four activities concluding this year. The application activities that will continue include working with health managers and stakeholders on the uses of Earth observations for regional haze planning, background ozone for state implementation plans, air pollution, and climate indicators, and health burden of wildfires. Applied Sciences will select members for a new Health and Air Quality Applied Science Team this year.

Thirty activities that support numerous elements in the Group on Earth Observations (GEO) Work Programme will conclude. These projects worked to enhance global water sustainability, provide more comprehensive views of wildfires, and developed integrated information systems to reduce environment-related health risks.

Ten application projects within the Disasters program area will continue. These activities emphasize a multi-hazard risk assessment approach to help communities worldwide manage, mitigate, and plan

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responses to a wide array of disasters. The projects focus on a range of topics including floods, wildfires, landslides, oil spills, volcanic ash, hailstorms, and rapid damage mapping.

Twelve application activities within the Water Resources program area will continue. These activities span the topics of improving soil moisture monitoring for water resource management, examining the factors that impact groundwater availability, and augmenting hydrological prediction capabilities at the state level. Nine application activities will conclude this year. The Water Resources program area will conduct a competitive solicitation for new projects this year.

ARSET will conduct approximately 15 trainings. All learning materials will be available in English and Spanish, with some trainings delivered in both languages. During its three terms, DEVELOP will conduct 50-55 projects with between 200 and 220 participants across their 11-12 nodes.

With leadership from Applied Sciences, the Group on Earth Observations (GEO) and the United Nations Habitat Programme developed an Earth Observation Toolkit for Sustainable Cities and Communities Programme to help achieve the United Nations Sustainable Development Goal (SDG) 11 to "make cities and human settlements inclusive, safe, resilient, and sustainable." A regionally representative group of countries and cities will act as case studies and demonstration pilots highlighting how applying Earth observations support their monitoring, reporting, and planning activities in relation to SDG 11 and urban-related priorities. A beta version of the toolkit was released in February 2021.

Applied Sciences plans to begin implementation of the NASA POWER tool, which supports use of NASA Earth observations by the renewable energy and building design industries (see: https://power.larc.nasa.gov/).

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The Applied Sciences Program plans to initiate activities selected via its FY 2021 solicitations for the Ecological Forecasting and Water Resources application areas and for new Health and Air Quality Applied Science Team members.

Applied Sciences will initiate an Applications and Research Team focused on science-informed solutions and addressing climate impacts together with underserved communities, consistent with the Administration's environmental justice and equity goals. Applied Sciences will initiate efforts to build resilience to environmental disruptions and climate risks, including activities focused on infrastructure and supply chains. Applied Sciences will target specific activities on wildfires and make further improvements to the POWER tool.

Twenty activities by the third SERVIR Applied Science Team will conclude their work done in partnership with SERVIR regional hubs in Eastern and Southern Africa, West Africa, Lower Mekong, Hindu Kush Himalaya, and Amazonia. The activities address challenges in food security, weather and climate, land cover, disasters, water resources, and uses of Earth observations for international development. SERVIR will select its fourth Applied Sciences Team to begin work the following year.

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Program Elements

CAPACITY BUILDING

The Capacity Building project enhances U.S. and developing countries' capacity (e.g., human, scientific, technological, institutional, and resource capabilities) to make decisions informed by Earth science data and models. Capacity Building develops skills in current and future workforce and creates opportunities in under-served areas to broaden the benefits of Earth observations. This project supports training, information product development, internships, data access tools, short-term application test activities, user engagement, and partnership development. This project has three primary elements:

- SERVIR: A joint venture with the U.S. Agency for International Development (USAID) that supports developing countries to improve their environmental management and resilience to climate change through uses of Earth observations in development decision making
- ARSET: A professional-level training program for accessing and using Earth observations data through computer-based webinars and hands-on courses for all types of organizations
- DEVELOP: A national training and development program for individuals to gain experience applying Earth observations through 10-week interdisciplinary activities to address community needs

MISSION AND APPLIED RESEARCH

The Mission and Applied Research project enables involvement by applications-oriented users in the planning and development of Earth Science satellite missions. It enables end-user engagement to identify applications early in and throughout the mission life cycle, and integrates end-user needs in design and development, enabling user feedback and broadening advocacy. Mission and Applied Research organizes community workshops to identify priority needs as well as studies to inform design trade-offs and identify ways to increase the applications value of missions. This project advises flight projects on activities to develop the applications dimension of a mission in development to help broaden benefits and maximize the return from the investment in the mission.

DISASTER SUPPORT

The Disaster Support project enables development of innovative applications using NASA satellite mission data as well as other activities to ensure timely, valuable support to responders when disasters occur. The Disaster Support project sponsors the use and integration of Earth observations in the decisions and actions of disaster-related organizations, including use of feasibility studies, in-depth activities, workshops, and needs assessments. The project also sponsors activities to improve a preparatory-based approach to enhance value and usability of NASA Earth Science products in support of disaster response and recovery across a wide range of disaster types including floods, earthquakes, volcanoes, and landslides. This project pursues partnerships with disaster groups that can carry forward NASA-developed information and tools to support the responders they serve. The project will begin to focus greater attention on supporting disaster risk assessment and disaster resilience.

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APPLICATIONS

The Applications project sponsors the integration of Earth observations in the decisions and actions of community organizations. There are formal applications areas in Ecological Forecasting, Food Security and Agriculture, Health and Air Quality, and Water Resources. The applications areas support feasibility studies, in-depth activities, applied science teams, consortia, workshops, and needs assessments. Each applications area participates in major conferences and events that their partners attend in order to meet and engage managers and users.

- Ecological Forecasting: The ecological forecasting applications area promotes the use of Earth observations and models to analyze and forecast changes that affect ecosystems and to develop effective resource management strategies. Primary user communities are natural resource managers (both land and marine) and those involved in conservation and sustainable ecosystem management.
- Food Security and Agriculture: The food security and agriculture applications area promotes the use of Earth observations along the value chain for the functioning and resilience of food systems. The area supports a multi-organizational consortium to enhance domestic and international food security and improved agricultural practices, especially for economic progress and humanitarian pursuits.
- Health and Air Quality: The health and air quality application area promotes the use of Earth observations data and models in the implementation of air quality standards, policy, and regulations for economic and human welfare (particularly involving environmental health and infectious diseases). This area addresses issues of toxic and pathogenic exposure and health-related hazards and their effects for risk characterization and mitigation.
- Water Resources: The water resources applications area supports the use of Earth observations in water resources management related to water demand, supply, and quality. The area includes five functional themes: drought, streamflow and flood forecasting, evapotranspiration and irrigation, water quality, and climate effects on water resources.

In addition to these activities, the Applications project supports the following initiatives:

- NASA Harvest Consortium: The program sponsors a multi-organizational consortium to advance the use of Earth observations for enhanced food security and improved agricultural practices, especially benefitting private sector stakeholders domestically and humanitarian efforts internationally.
- Group on Earth Observations (GEO) Work Programme: Applied Sciences supports specific elements in the GEO Work Programme to further U.S. and NASA interests internationally, leveraging resources of other countries and organizations. This initiative specifically fosters a broader involvement of domestic organizations in a U.S. national approach to GEO and the Work Programme, increasing opportunities for these organizations.
- VALUABLES Consortium: The Valuation of Applications Benefits Linked to Earth Science. The program supports a multi-organizational consortium to support the development of analytic techniques to quantify the benefits, in social and economic terms, from uses of Earth observations to improve decisions. VALUABLES also helps build familiarity in the Earth science community with concepts and methods and helps communicate the benefits of Earth observations.
- Western Water Applications Office: The Western Water Applications Office (WWAO) is a targeted initiative to contribute Earth observations to help solve important and pressing water-resource problems faced by the western United States. WWAO involves several NASA centers to engage

public and private sector stakeholders in the western water management community for innovative ways to apply Earth observations in managing water supply and accommodating a growing demand.

Program Schedule

Date	Significant Event
Q1 FY 2021	ROSES-2020 selection within six to nine months of receipt of proposals
Q2 FY 2021	ROSES-2021 solicitation release
Q1 FY 2022	ROSES-2021 selection within six to nine months of receipt of proposals
Q2 FY 2022	ROSES-2022 solicitation release
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation release
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation release
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation release
Q1 FY 2026	ROSES-2025 selection within six to nine months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation release

Program Management and Commitments

Program Element	Provider
Applications	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): U.S. Forest Service, National Park Service (NPS), U.S. Department of Agriculture, NOAA, USGS, U.S. Fish and Wildlife Service, Environmental Protection Agency (EPA), Bureau of Land Management, Centers for Disease Control and Prevention

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Program Element	Provider
Capacity Building	Provider: Various Lead Center: LaRC, MSFC, GSFC Performing Center(s): ARC, GSFC, JPL, MSFC, LaRC Cost Share Partner(s): USGS, Groundwork USA, U.S. Department of Agriculture, University of Georgia, NOAA, Arizona State University, Boston University, USAID, EPS, NOAA, NWS
Disaster Support	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): Department of Homeland Security (DHS), NOAA, USDA, USGS, USAID, USACE, National Guard
Mission and Applied Research	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): USDA, CNES, ISRO, Joint Research Centre (JRC), European Space Agency

Acquisition Strategy

NASA bases the Earth Science Applied Science acquisitions on full and open competition. Grants are peer reviewed and selected based on NASA research announcements and other related announcements.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Applied Sciences Advisory Committee	Jul 2020	Review strategy and implementation	Provided recommendations on private sector engagement and suggested several modes of engagement such as incubators and accelerators. Endorsed the technical content strategy and recommended full implementation to advance communications.	Jul 2021
Relevance	Applied Sciences Advisory Committee	Jul 2021	Review strategy and implementation	TBD	Jan 2022

PLANETARY SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Planetary Science Research	286.0	304.1	**306.9**	290.1	300.1	301.9	301.2
Planetary Defense	150.0	151.0	**197.2**	220.7	226.5	224.2	170.6
Lunar Discovery and Exploration	300.0	443.5	**497.3**	501.3	458.3	458.3	458.3
Discovery	508.7	451.3	**364.8**	227.6	303.8	529.4	750.5
New Frontiers	136.8	160.0	**271.7**	446.8	500.4	494.9	372.3
Mars Exploration	565.7	334.8	**267.8**	251.9	249.1	228.1	229.8
Mars Sample Return	0.0	246.3	**653.2**	772.3	800.0	700.0	600.0
Outer Planets and Ocean Worlds	632.0	462.5	**494.8**	331.2	265.5	135.7	115.7
Radioisotope Power	133.5	146.3	**146.4**	154.6	162.8	154.4	170.4
Total Budget	**2,712.6**	**2,699.8**	**3,200.0**	**3,196.3**	**3,266.5**	**3,226.9**	**3,168.7**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Planetary Science

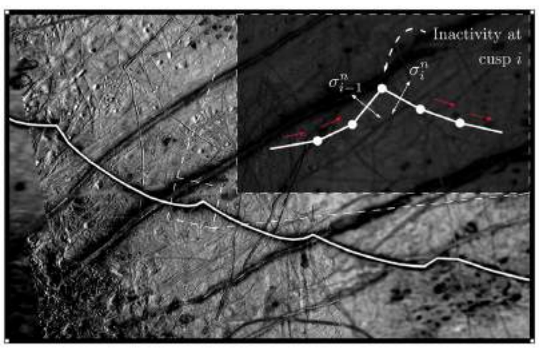
PLANETARY SCIENCE RESEARCH

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Planetary Science Research and Analysis	209.8	223.2	**221.9**	203.6	206.3	203.6	203.6
Other Missions and Data Analysis	76.2	80.9	**85.0**	86.5	93.8	98.4	97.7
Total Budget	**286.0**	**304.1**	**306.9**	**290.1**	**300.1**	**301.9**	**301.2**
Change from FY 2021			**2.8**				
Percentage change from FY 2021			**0.9%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Models based on crevasse/rift analogues on Antarctic ice shelves can explain the presence of similar cracks on Europa and calculate how fast they grow. This image shows that due to the change in the orientation angle between two segments along the cusp (I and i-1), crack growth experiences dormant periods, caused by reorientation of the background tidal stress σ^n, at different orbital positions of Europa around Jupiter.

The Planetary Science Research program provides the scientific foundation for data returned from NASA missions exploring the solar system. It is also NASA’s primary interface with university faculty and graduate students in this field and with the research community in general. The program develops analytical and theoretical tools, as well as laboratory data, to support analyses of flight mission data. These capabilities allow Planetary Science to answer specific questions about, and increase the understanding of, the origin and evolution of the solar system. The research program achieves this by supporting research grants solicited annually and subjected to a competitive peer review before selection and award. The Planetary Science Research program focuses on five key research goals:

- Advance the understanding of how the chemical and physical processes in our solar system operate, interact, and evolve;
- Explore and observe the objects in the solar system to understand how they formed and evolve;
- Explore and find locations where life could have existed or could exist today;
- Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere; and
- Identify and characterize objects in the solar system that pose threats to Earth or offer resources for human exploration.

PLANETARY SCIENCE RESEARCH

EXPLANATION OF MAJOR CHANGES IN FY 2022

This budget request proposes additional funding for investments focused on Planetary Science's core Research and Analysis (R&A) program including implementation of a new access to facilities program element with a proactive emphasis on enabling more diverse groups of underrepresented researchers to have access in preparation for analyses of new samples from asteroids, the Moon, and Mars.

ACHIEVEMENTS IN FY 2020

Researchers developed a series of theoretical models to understand the presence of cycloids, crevasses with curved segments, on Jupiter's moon Europa. Based on terrestrial models for ice rift propagation, these models show that crevasses could evolve in a relatively short amount of time followed by long periods of dormancy. This improves our understanding of Europa and sets the stage for future cycloid propagation detection exploration missions like Europa Clipper. Further, the results from this study may help scientists predict changing features in the polar regions of Earth.

In 2008, Asteroid 2008 TC_3 disintegrated in the atmosphere and landed in Sudan as more than 700 individual stones. While 20-30 percent of the stones revealed that they were chondrites, meteorites consisting of individual grains remaining from the early stages of planet formation in our solar system, the remainder were ureilites, a type of achondrites. Achondrites are meteorites where individual grains have been processed through melting and recrystallization. Further examination showed that the observed properties of Asteroid 2008 TC_3 most closely matched that of fragment Almahata Sitta 91A, a hydrated carbonaceous chondrite. This helps shed light on potential formation mechanisms for asteroids in the early solar system and will be important for studying Bennu, the target of the Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-Rex) mission.

Ediacara Biota are some of the earliest macroscopic and complex organisms preserved in the fossil record. A research team located and identified one of the oldest fossils showing bilateral symmetry and characterized its age and transition from its progenitor. This organism was small and simple but provided a critical link between Ediacaran and Cambrian animals. This is significant for understanding the transition from simple to complex organisms, unraveling the evolutionary history of life on Earth, and determining how other planetary bodies might retain biosignatures. The search for biosignatures will be a key science component of current and future investigations of Mars, ocean worlds, and exoplanets.

At 9:30 Universal Time (UT) on March 12, 2020, a powerful and unexpected meteor shower outburst occurred in a toroidal region of the sky at a high southern ecliptic latitude, surrounding the South Pole. Data from the Southern Argentina Agile Meteor Radar Orbital System precisely located this activity, linking it to a parent asteroid (248590) 2006 CS, a large near-Earth object 1.24 miles in diameter that may have exhibited cometary activity in its distant past. The asteroid was 428 million miles from Earth at the time of the meteor shower outburst but as close as 28 million miles away in March 2021. The study of these meteor showers helps inform models of dust evolution within the Solar System while also preparing researchers for future meteor showers to better understand their strength and how they might change annually.

WORK IN PROGRESS IN FY 2021

In pursuit of fundamental science that guides planetary exploration, the Planetary Science Research program is continuing to select highly rated Research and Analysis (R&A) proposals that support

PLANETARY SCIENCE RESEARCH

planetary missions and goals. Planetary science will continue archiving and distributing relevant mission data to the science community and the public in a timely manner. The Planetary Science Research program is working with the other divisions of NASA's Science Mission Directorate to further research exoplanets by continuing and furthering the multi-division, multi-disciplinary approach to this topic. The Planetary Science Research program is supporting the Planetary Science and Astrobiology Decadal Survey process, which began in late FY 2020. Studies and discussions will continue throughout FY 2021.

While the range of scientific research supported by Planetary Science Division (PSD) is broad, of particular note this year is the selection and funding of eight new awards under the Interdisciplinary Consortia for Astrobiology Research Program. This program supports large teams of scientists with diverse backgrounds and experiences to look for novel and synergistic approaches to astrobiology. These teams also form the backbone for the Research Coordination Networks (RCNs), which support even broader community participation in these initiatives.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

In pursuit of fundamental science that guides planetary exploration, the Planetary Science Research program will continue to select highly rated R&A proposals that support planetary missions and goals. Planetary science will continue archiving and distributing relevant mission data to the science community and the public in a timely manner. During FY 2022, the PSD will also receive and provide an initial response to the Planetary Science and Astrobiology Decadal Survey.

In the Astromaterial Curation project, final preparation for return of OSIRIS-REx asteroid samples will culminate in FY 2022. With International Standards Organization 5 (ISO5) sample cleanroom construction and certification complete, and lab outfitting initiated, operational activities will include sample recovery planning and rehearsals at the Utah Test and Training Range. The project will conduct rehearsals for sample receiving and conduct the Touch and Go Sample Acquisition Mechanism head disassembly. The final outfitting of the cleanrooms will be subsequently completed, and NASA will conduct an operational readiness review for the sample curation lab. NASA will receive the Hayabusa2 sample allocation from Japan Aerospace Exploration Agency (JAXA). Individual grains will be carefully secured into separate containers, photographed, and cataloged to be published online. Initial characterization will divide samples into organic rich or mineral dominant sub-groups for international sample investigation opportunities.

Program Elements

PLANETARY SCIENCE RESEARCH AND ANALYSIS (R&A)

Planetary Science R&A enhances the scientific return from on-going and completed spaceflight missions and provides the foundation for the formulation of new scientific questions and strategies for answering those questions. R&A develops new theories and instrumentation concepts that enable the next generation of spaceflight missions. R&A funds research tasks in areas such as astrobiology and cosmochemistry; the origins and evolution of planetary systems; the observation and characterization of extra-solar planets (i.e., exoplanets); and the atmospheres, geology, and chemistry of the solar system’s bodies other than the Earth or the Sun.

PLANETARY SCIENCE RESEARCH

Program Schedule

The Planetary Science Research Program solicits proposals as part of the Science Mission Directorate's annual Research Opportunities in Space and Earth Sciences (ROSES) research calls. The program issues solicitations every year. A Senior Review process assesses all missions in the extended operations phase every three years and all data archives every three or four years.

Date	Significant Event
Feb 2021	ROSES-2021 NASA Research Announcement (NRA) solicitation release
Q1 FY 2022	ROSES-2021 selection within six to nine months of receipt of proposals
Feb 2022	ROSES-2022 NRA solicitation release
Mar-Apr 2022	Senior Review Operating Missions
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Feb 2023	ROSES-2023 NRA solicitation release
Q1 FY 2024	ROSES-2023 NRA selection within six to nine months of receipt of proposals
Feb 2024	ROSES-2024 NRA solicitation release
Mar-Apr 2025	Senior Review Operating Missions
Q1 FY 2025	ROSES 2024 NRA selection within six to nine months of receipt of proposals
Feb 2025	ROSES-2025 NRA solicitation release
Q1 FY 2026	ROSES-2025 NRA selection within six to nine months of receipt of proposals

Program Management & Commitments

Program Element	Provider
R&A	Provider: NASA Lead Center: Headquarters (HQ) Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), Jet Propulsion Laboratory (JPL), Johnson Space Center (JSC), Langley Research Center (LaRC), Marshall Space Flight Center (MSFC), HQ Cost Share Partner(s): N/A

Acquisition Strategy

The R&A budget will fund competitively selected activities from the ROSES omnibus research announcement.

PLANETARY SCIENCE RESEARCH

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Planetary Science Advisory Committee (PAC)	2019	Review to assess progress against strategic objectives of Planetary Science.	Recommendation was to maintain a strong program consistent with the decadal survey.	2020
Quality	Planetary Science Advisory Committee (PAC)	2020	Review to assess progress against strategic objectives of Planetary Science.	Recommendation was to maintain a strong program consistent with the decadal survey.	2021
Quality	Planetary Science Advisory Committee (PAC)	2021	Review to assess progress against strategic objectives of Planetary Science.	TBD	2022
Relevance	Planetary Science Decadal Survey	2022	Provide recommendations on strategic direction for the Planetary Science Division	TBD	2032
Quality	Planetary Science Advisory Committee (PAC)	2022	Review to assess progress against strategic objectives of Planetary Science.	TBD	2023

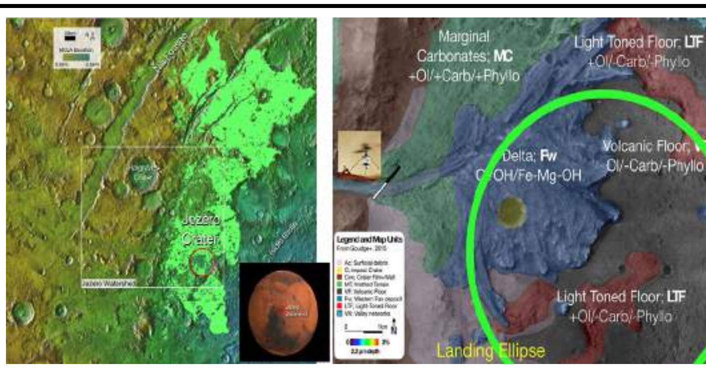
OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Advanced Multi-Mission Operation System	39.2	39.9	**40.5**	37.9	38.0	38.0	38.0
Planetary Science Directed R&T	0.0	0.0	**0.0**	8.3	15.6	19.7	19.5
Planetary Data System	19.2	24.1	**24.6**	24.2	23.8	24.3	23.7
Astromaterial Curation	11.2	12.9	**16.0**	12.1	12.4	12.4	12.4
Science Data & Computing	2.6	0.0	**0.0**	0.0	0.0	0.0	0.0
Robotics Alliance	4.0	4.0	**4.0**	4.0	4.0	4.0	4.0
Total Budget	**76.2**	**80.9**	**85.0**	**86.5**	**93.8**	**98.4**	**97.7**
Change from FY 2021			**4.1**				
Percentage change from FY 2021			**5.1%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



The location on the left is of Mars Jezero crater, the home of the Mars 2020 Rover named Perseverance. The location of the olivine-carbonate region is as mapped by Kremer et al. (2019) and Brown et al. (2020). On the right is a closer view of the Jezero delta and the landing ellipse of the rover over the geological map of the region, as mapped by Goudge et al. (2015).

Other Missions and Data Analysis includes activities and infrastructure that support NASA Planetary Science Research and missions, such as the Advanced Multi-Mission Operation System, Planetary Data System, and Astromaterial Curation.

Mission Planning and Other Projects

ADVANCED MULTI-MISSION OPERATION SYSTEM (AMMOS)

AMMOS provides multi-mission operations, navigation, design, and training tools and services for Planetary Science flight missions, as well as other Science Mission Directorate missions, and invests in improved communications and navigation technologies. The AMMOS project will continue to provide and develop multi-mission software tools for spacecraft navigation, command, control, assessment, mission planning, and data archiving. Utilizing the AMMOS common tools and services lowers

OTHER MISSIONS AND DATA ANALYSIS

individual mission cost and risk by providing a mature base for mission operations systems at significantly reduced development time. AMMOS also provides support to our international space agency partners on an as-needed basis. This support typically pertains to navigation assistance and scheduling of NASA's Deep Space Network (DSN) assets. AMMOS is a system of reusable software tools and services comprising a mission ground operations and ground data system that is used across multiple NASA missions.

Recent Achievements

AMMOS currently provides multi-mission operations tools and services to 71 missions. This is an increase of over 20 percent in the past year and includes support to planetary science, heliophysics, earth science, and astrophysics missions within NASA and critical operations services to 15 international missions.

Operating missions enabled by AMMOS include the Mars Rover 2020 rover named Perseverance, Parker Solar Probe, Chandrayaan-2, InSight, Origins Spectral Interpretation Resource Identification and Security-Regolith Explorer (OSIRIS-REx), Mars Atmosphere and Volatile EvolutioN (MAVEN), Chandra X-ray Observatory, among many others. Missions currently in development enabled by AMMOS include Europa Clipper, Volatiles Investigating Polar Exploration Rover, Janus, Psyche, Lucy, Lunar Trailblazer, NASA CubeSats Near-Earth Asteroid (NEA) Scout and Lunar Flashlight, and Argomoon, among others. The AMMOS has made major advancement in platform modernization including increased automated testing and deployment, continued its push towards software open source to increase its customer base and furthered adoption of cloud technology for operations. Significant accomplishments included successful delivery of a prototype of the initial phase of the new Reference Mission System. This system will enable significant cost savings to future missions by lowering the level of mission specific system adaptations.

PLANETARY SCIENCE DIRECTED RESEARCH AND TECHNOLOGY

This project funds the civil service staff that will work on emerging Planetary Science flight projects, instruments, and research.

PLANETARY DATA SYSTEM (PDS)

The PDS is an online data archive that furthers NASA's Planetary Science goals by efficiently collecting, archiving, and making accessible digital data produced by, or relevant to, NASA's planetary missions, research programs, and data analysis. This curated archive includes raw and fully calibrated orbital and surface observations from hundreds of NASA missions and instruments exploring the solar system planets, asteroids, and small bodies. The PDS archives now span more than 50 years of NASA-funded research and its holdings are now expanding to include ground-based observations of near-earth objects. The PDS archives are publicly available through the PDS website. NASA consolidated the Science Data and Computing project into the PDS, as it acts as the long-term stable archiving node for all planetary mission data, including PDS holdings.

Recent Achievements

The PDS received and released data from 11 active planetary missions since October 2019 and released enhanced legacy data from over a dozen past missions. The PDS Small Bodies Node is now receiving

OTHER MISSIONS AND DATA ANALYSIS

data from ground-based observations provided by the Minor Planets Center. The PDS supported data providers from over 300 NASA research program investigations, including archive support for data from ground-based observations, laboratory analyses, field observations, and the production of other higher order data sets. Migration of data from PDS3 to PDS4 standards continued for over 20 missions or projects, laying the cornerstone for the future user's enhanced and modern interaction with the PDS. As a result of these activities, the PDS archive grew in volume by approximately 150 terabytes to approximately 1.85 petabytes. Further, the PDS conducted its first community-wide survey to assess the present and future needs of its users and data providers.

ASTROMATERIAL CURATION

The Astromaterials Acquisition and Curation Office at JSC curates extraterrestrial material under NASA control. Curation is an integral part of sample return missions. Activities conducted by the Curation office include: (1) research into advanced curation techniques to support future missions; (2) sample return mission planning; (3) archiving of witness, engineering, and reference materials related to sample return missions; (4) recovery and transport of returned materials; (5) initial characterization of new samples; (6) preparation and allocation of samples for research; and (7) providing clean and secure storage for the benefit of current and future generations.

Materials currently curated include: Antarctic meteorites; cosmic dust; samples collected from the Moon; solar wind; samples from a comet and an asteroid; microparticle-impacted flight hardware; witness materials (small foils and plates placed in spacecraft assembly cleanrooms to collect molecules and particles); and, coupons (representative pieces of materials used in construction of spacecraft) for several past, present, and future sample return missions (e.g., Apollo, Genesis, Stardust, OSIRIS-REx, Mars 2020). Planning and research efforts are currently underway to develop the technologies and procedures for proper curation of samples from future missions to the moon (i.e., Artemis Program), asteroids (OSIRIS-REx and Hayabusa2), Mars, Mars' moons (Martian Moons eXploration, MMX), and comets. NASA plans to receive Hayabusa2 and MMX samples under international agreements with the Japan Aerospace Exploration Agency (JAXA). New laboratory space is being constructed and outfitted within the curation facility to prepare for receipt of the OSIRIS-REx and Hayabusa2 samples, as well as to do advanced cleaning and curation research.

Recent Achievements

The project maintains eight existing collections of astromaterials in pristine condition for scientific research within 22 cleanrooms at JSC and White Sands. In 2019, the team allocated more than 1,200 samples among the 400-plus registered principal investigators across 25 countries worldwide, before the facility had to close its doors in March 2020 due to the pandemic.

Construction is nearing completion on the facilities that will house the new OSIRIS-REx and Hayabusa2 samples, as well as advanced research labs to develop new technologies and handling procedures. Curation staff participates in construction activities to ensure that existing cleanrooms are not contaminated, that new lab construction materials adhere to curation and mission (OSIRIS-REx and Hayabusa2) requirements, and to archive construction materials for contamination knowledge.

The activities leading up to the recent successful OSIRIS-REx Touch-And-Go (TAG) maneuver in the Nightingale site on asteroid Bennu has driven accomplishments by curation scientists working on the mission and on asteroid sample-curation in general. This includes experimentation and testing of manipulation and remote handling techniques to optimize removal of astromaterial captured by the

OTHER MISSIONS AND DATA ANALYSIS

spacecraft's contact pads. TAG Sample Acquisition Mechanism head disassembly practice and rehearsal will optimize removal of the bulk sample. These initial tests and rehearsals will continue with flight-like hardware and the cleanroom environment in the coming years.

NASA is working to optimize future science return by ensuring proper sample handling for the Mars Sample Return and Artemis missions. As part of Mars Sample Return preparation, JSC is working with JPL to complete a benchmarking report on implementation strategies for receiving and processing future samples. The report assesses facility modalities and technologies for containing, protecting, and handling Mars samples. JSC Curation is actively receiving and curating items that record the background contamination environment for the Mars Rover 2020 spacecraft build. NASA refers to these items as contamination knowledge samples, and they include witness plates, witness items, and material coupons that record inorganic, organic, and biological contamination. These contamination knowledge samples will be part of the Mars sample collection and will be used to baseline contamination during analysis of the returned Martian samples.

JSC is transitioning back to onsite work after almost a year of mandatory telework. The immediate focus is to bring existing lab equipment back online safely followed by re-initiation of lab research and testing. With completion of facility construction, the project will conduct laboratory readiness reviews in FY 2021 to ensure labs are safe and technically ready to receive samples. Outfitting the newly renovated labs will be a major focus of FY 2021, including a benchtop X-ray fluorescence system to complement the recently installed scanning Raman spectrometer for non-destructive characterization of astromaterials. The team plans to certify the new Hayabusa2 cleanroom and conduct dress rehearsals to ensure readiness to secure samples gathered from the rendezvous mission with asteroid Ryugu in 2018.

ROBOTICS ALLIANCE PROJECT

The Robotics Alliance Project (RAP) goal is to increase interest in engineering, technology, science, and mathematics disciplines among youth in the United States. RAP's goal is to create an inspired, experienced, technical workforce for the aerospace community. Annual activities and events expose students to challenging applications of engineering and science. The RAP supports national robotic competitions in which high school students team with engineering and technical professionals from government, industry, and universities to gain hands-on experience and mentoring.

Recent Achievements

In FY 2020, RAP sponsored approximately 310 For the Inspiration and Recognition of Science and Technology (FIRST) Robotics Competition teams (approximately 8,000 students), 50 VEX robotics teams (approximately 500 students), and sponsored and/or supported four FIRST Robotics Competition events (affecting approximately 10,000 students). NASA cancelled the majority of the scheduled competition events due to the COVID-19 pandemic. As a result, the project redirected the RAP support typically provided for the 2020 competitions toward the 2021 programs and the development of virtual/remote, rather than in-person competitions.

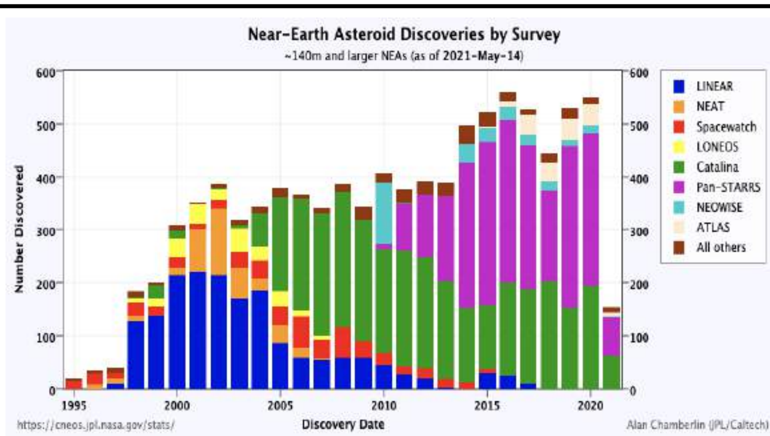
PLANETARY DEFENSE

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
DART	72.4	66.4	**11.1**	4.0	0.0	0.0	0.0
Other Missions and Data Analysis	77.6	84.6	**186.1**	216.7	226.5	224.2	170.6
Total Budget	**150.0**	**151.0**	**197.2**	**220.7**	**226.5**	**224.2**	**170.6**
Change from FY 2021			**46.2**				
Percentage change from FY 2021			**30.6%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Yearly progress in discoveries of near-Earth asteroids larger than 140 meters in size. Credit: NASA/JPL-Caltech.

The focus of planetary defense missions is to detect and provide follow-up observations for precision orbit determination and physical characterization of asteroids and comets with the potential to impact the Earth. This program also mounts efforts (from civil disaster response preparations to in-space object deflection or disruption missions) to mitigate the effects of an impending near-Earth object (NEO) impact event.

The Planetary Defense Coordination Office (PDCO) manages the Planetary Defense program. PDCO administers the Near-Earth Object Observations (NEOO) project, which funds and coordinates efforts to find, track, and characterize any asteroid or comet that could become an impact hazard to Earth. Scientists conduct these NEO observation efforts at observatories supported by NASA on the ground and in space, as well as by the National Science Foundation and space situational awareness facilities of the U.S. Space Force.

In addition to finding, tracking, and characterizing NEOs, NASA’s planetary defense goals include researching techniques for deflecting or disrupting, if possible, potentially hazardous objects (PHOs) that are determined to be on an impact course with Earth to provide options for U.S. government response to any detected impact threat. If deflection or disruption of the PHO is not possible due to insufficient time available before impact, the PDCO is responsible for providing expert input to other government agencies, such as the Federal Emergency Management Agency, for emergency response operations. The PDCO participates in implementing the U.S. National Near-Earth Object Strategy and Action Plan.

PLANETARY DEFENSE

For more information, go to: https://www.nasa.gov/sites/default/files/atoms/files/ostp-neo-strategy-action-plan-jun18.pdf

The PDCO responsibilities include:

- Managing NASA's Planetary Defense Program;
- Ensuring the early detection of PHOs, asteroids and comets whose orbit are predicted to bring them within 0.05 Astronomical Units, equal to about 5 million miles, of Earth's orbit, and of a size large enough to reach Earth's surface (i.e., at least 140 meters or greater in size, and perhaps greater than 30 to 50 meters);
- Tracking and characterizing PHOs and issuing warnings about potential impacts;
- Providing timely and accurate communications about PHOs; and
- Performing as a lead coordination node in U.S. Government planning for response to an actual impact threat (visit: https://www.nasa.gov/planetarydefense/overview).

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Budget increases funding to support a new Near-Earth Objects Surveyor spaceflight mission, which is in formulation.

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	40.6	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	40.6
Development/Implementation	120.9	72.4	65.0	**0.0**	0.0	0.0	0.0	0.0	0.0	258.3
Operations/Close-out	0.0	0.0	1.4	**11.1**	4.0	0.0	0.0	0.0	0.0	16.5
2021 MPAR LCC Estimate	**161.5**	**72.4**	**66.4**	**11.1**	**4.0**	**0.0**	**0.0**	**0.0**	**0.0**	**315.4**
Total Budget	**161.5**	**72.4**	**66.4**	**11.1**	**4.0**	**0.0**	**0.0**	**0.0**	**0.0**	**315.4**
Change from FY 2021				**-55.3**						
Percentage change from FY 2021				**-83.3%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The DART team prepares to integrate the spacecraft's panels, which house an array of hardware and wiring that technicians will tuck safely within the spacecraft structure. Credit: NASA/Johns Hopkins APL/Ed Whitman

The Double Asteroid Redirection Test (DART) is the first planetary defense mission demonstrating the kinetic impact technique to change the motion of an asteroid in space. The target asteroid for DART is the binary asteroid system Didymos. The Didymos system consists of the primary asteroid, Didymos A, which is about 780 meters (1/2 mile) across, and a "moonlet," Didymos B - now named Dimorphos. The DART spacecraft will demonstrate the kinetic impact deflection method by deliberately crashing into Dimorphos at a speed of approximately 13,000 miles per hour, with the aid of an onboard camera and sophisticated autonomous navigation software. The collision will change the period of the orbit of the moonlet around the main body by a fraction of one percent, but enough to be measured using telescopes on Earth. By targeting the small moonlet in a binary system, the DART mission plan makes this

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

demonstration possible without causing any detectable change to the orbit of the system about the Sun. The DART mission will demonstrate the effectiveness of the kinetic impact technique for deflecting a hazardous asteroid. NASA will use the mission to improve our understanding of the physics involved and our readiness to respond to an actual asteroid impact threat.

NASA's DART spacecraft has a launch readiness date of no later than February 2022. The targeted impact date with Dimorphos is late September to early October 2022, when the Didymos system is within 11 million kilometers of Earth, enabling subsequent observations of the change to the orbital period of the moonlet by ground-based telescopes, and possibly supplemented by planetary radar.

EXPLANATION OF MAJOR CHANGES IN FY 2022

Due to technical issues associated with the Didymos Reconnaissance and Asteroid Camera for Optical-navigation (DRACO) rework, Roll-Out Solar Arrays (ROSA) delivery, and COVID-19, the project will need additional funding. A replan is underway to accommodate COVID-19 impacts, the DRACO rework, and the ROSA delayed delivery. NASA expects this replan to be complete by this summer and offsets will be funded from within the Planetary Science Division.

PROJECT PARAMETERS

NASA plans to launch DART from Vandenberg Air Force Base no later than February 2022. DART carries a single instrument, the Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO), used by the DART Small-body Maneuvering Autonomous Real-Time Navigation (SMARTNav) system to guide the spacecraft to impact the moonlet of the double asteroid Didymos. DART will use X-Band communications through the NASA Deep Space Network to downlink the DRACO images prior to impact, which will allow the reconstruction of where on the moonlet the impact occurred. Researchers will measure the change in the orbital period of the moonlet caused by the impact during the 2022 Didymos double asteroid close approach to the Earth, using the world-wide network of optical and radio telescopes.

The DART spacecraft will enable the demonstration of the NASA Evolutionary Xenon Thruster – Commercial (NEXT-C) solar electric propulsion system as a new technology for in-space propulsion systems. The next-generation NEXT-C system, based on the Dawn spacecraft propulsion system, will provide significant flexibility in future mission timelines, including significantly widening the viable launch period (compared to most planetary missions), as well as decreasing the cost of the launch service.

ACHIEVEMENTS IN FY 2020

DART passed its integration readiness review in March 2020 and entered Phase D of development, the spacecraft integration and test phase.

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2021

DART will continue integration and test activities, complete comprehensive mission readiness tests, conduct the pre-ship readiness review, and prepare the spacecraft for shipment to the launch site.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The DART spacecraft will ship to the launch site and conduct its launch readiness review for final preparations for launch. After launch, DART will complete its on-orbit checkout activities prior to entry into Phase E mission operations. The spacecraft will spend most of FY 2022 in cruise to the targeted Didymos system, beginning terminal approach operations in September 2022.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
Formulation Authorization	Mar 2016 (Rev B)	Mar 2016 (Rev B)
MCR	May 2015	May 2015
SRR/MDR	Sep 2016	Sep 2016
KDP-B	Mar 2017	Mar 2017
PDR	Apr 2018	Apr 2018
KDP-C	Aug 2018	Aug 2018
CDR	Jun 2019	Jun 2019
KDP-D	Apr 2020	May 2020
ORR/FOR	Mar 2021	Sep 2021
MRR/FRR	May 2021	Oct 2021
Launch Readiness	Feb 2022	Feb 2022
KDP-E	Mar 2022	Mar 2022
Asteroid Impact/End of Flight Operations	Oct 2022	Oct 2022
End of Ground Observations and Data Analysis	Sep 2023	Sep 2023

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2019	258.3	70%	2021	258.3	0	LRD	Feb 2022	Feb 2022	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

NASA confirmed DART to proceed into implementation in August 2018. The NEXT-C electric propulsion technology demonstration system is funded by the Discovery Future project and is not included in the development cost of this mission.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**258.3**	**258.3**	**0**
Aircraft/Spacecraft	71.7	104.1	+32.4
Payloads	5.3	6.3	+1.0
Systems I&T	16.4	19.4	+3.0
Launch Vehicle	41.0	68.8	+27.8
Ground Systems	5.7	6.8	+1.1
Science/Technology	3.2	3.8	+0.6
Other Direct Project Costs	114.9	49.2	-65.7

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

Project Management & Commitments

The John Hopkins University/Applied Physics Laboratory (JHU/APL) has project management responsibility for DART.

Element	Description	Provider Details	Change from Baseline
DART Spacecraft	DART Project design and implementation, with the exception of subcontracted subsystems and the government-provided NEXT-C electric propulsion system	Provider: JHU-APL Lead Center: N/A Performing Center(s): JHU-APL Cost Share Partner(s): N/A	N/A
DRACO	The Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO)	Provider: JHU-APL Lead Center: N/A Performing Center(s): JHU-APL Cost Share Partner(s): N/A	N/A
NEXT-C	Government-furnished electric propulsion system not included in Life Cycle Cost (LCC)	Provider: Aerojet Lead Center: GRC Performing Center(s): GRC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Launch vehicle and all launch services	Provider: Space-X Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The SMARTNav autonomous guidance system used to guide the spacecraft during the final approach to impact is not sufficiently robust to variations in the observed binary system, Then: The spacecraft may not hit the target.	The project has developed, and is continuing to refine, a high-fidelity emulator of the end-to-end performance of the DRACO camera, image processing pipeline, and SMARTNav algorithms. The project is varying (in a Monte Carlo analysis) the characteristics of the Didymos system (e.g., size, shape, albedo of each body, orbit characteristics), the approach conditions, and the DRACO and spacecraft parameters to demonstrate the robustness of the design to the range of variations that DART may encounter when it arrives at Didymos.

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

Acquisition Strategy

NASA is acquiring the flight system for the DART mission from JHU/APL. NASA selected SpaceX to provide a dedicated Falcon-9 launch vehicle through a competitive Launch Service task order awarded by NASA's Launch Services Program. NASA is acquiring the NEXT-C propulsion system via the Glenn Research Center from Aerojet Rocketdyne.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Prime Contract, Mission Formulation, and Mission Implementation	JHU-APL	Laurel, MD
Launch Vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Institutional Review Team (IRT)	Sep 2016	System Requirements Review (SRR) to assess readiness for preliminary design and technology completion (Phase B)	After the SRR, NASA decided to establish the DART SRB and insert an SRB Status Review before approving KDP-B	PDR
Performance	Standing Review Board (SRB)	Feb 2017	SRB Status Review to assess SRR results, progress/ resolution of SRR actions, changes since the SRR, and to assess readiness for Phase B	Successful	PDR
Performance	SRB	Apr 2018	Preliminary Design Review (PDR) to assess readiness for final design and fabrication (Phase C)	Successful	CDR

DOUBLE ASTEROID REDIRECTION TEST

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Jun 2019	Critical Design Review (CDR) to assess readiness for to assess readiness for project to begin system assembly, integration, and test (start of Phase D)	Successful	ORR
Performance	SRB	Sep 2021	Operational Readiness Review (ORR) to assess readiness for system launch, checkout, (completion of Phase D), operations, and sustainment (Phase E)	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Near Earth Objects Surveyor	0.0	28.3	**143.2**	174.2	184.0	181.7	128.1
Near Earth Object Observations	77.6	56.3	**42.9**	42.5	42.5	42.5	42.5
Total Budget	**77.6**	**84.6**	**186.1**	**216.7**	**226.5**	**224.2**	**170.6**
Change from FY 2021			**101.5**				
Percentage change from FY 2021			**120.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Comet C/2020 F3 NEOWISE over NASA's Infrared Telescope Facility on Maunakea Kea, HI, on July 21, 2020. Credit: Mike Connelley/UH/IRTF.

Mission Planning and Other Projects

NEAR-EARTH OBJECT OBSERVATIONS (NEOO)

The NEOO project uses ground and space-based assets to look for Near-Earth Objects (NEOs) that have any potential to collide with Earth and characterizes them to assess if any could do significant damage to the planet. NEOs range in size from a few meters to approximately 34 kilometers. NEOs of one kilometer or larger in size are close to 1,000 in number, while those between 100 meters to one kilometer in size may number as much as 38,000.

The NEOO project supports a network of search and characterization observatories and the data processing and analysis required to understand the near-Earth population of small bodies. In accordance with the findings and recommendations of the National Academies studies on the NEO hazard in 2010 and on visible and infrared NEO survey capabilities in 2019, NASA continues to:

- Analyze the small body data collected by the reactivated Wide-field Infrared Survey Explorer (WISE) mission, now called NEOWISE, and support increased follow-up and analysis of this data;

OTHER MISSIONS AND DATA ANALYSIS

- Increase collection of NEO detection and characterization data by the Catalina Sky Survey, the Panoramic Survey Telescope and Rapid Reporting System (Pan-STARRS), and the United States Space Force's (USAF) Space Surveillance Telescope;
- Support the operation of the four small telescope wide field survey sites called the Asteroid Terrestrial-impact Last Alert System (ATLAS), designed to detect smaller asteroids as they approach the Earth and warn of any imminent impact, two of which will operate at southern hemisphere sites;
- Support the continued and enhanced operation of planetary radar capabilities at NASA's Goldstone Deep Space Network facility and support the processing and archiving of radar data from the now-decommissioned 305-meter telescope at the National Science Foundation's Arecibo Observatory;
- Support NEO research teams at multiple universities and space science institutes to observe and characterize the nature of asteroids and comets which can closely approach Earth; and
- Investigate both ground and space-based concepts for increasing capacity to detect, track, and characterize NEOs of all sizes.

Since NASA's search started in 1998, the program has found over 96 percent of these objects that are one kilometer and larger, and just over 38 percent of all those larger than 140 meters in size. NEOs discovered and characterized by the project may also be viable targets for future robotic and human exploration, and possible eventual candidates for asteroid resource utilization operations.

For more information on NEOO, go to:

https://www.nasa.gov/planetarydefense/overview

https://cneos.jpl.nasa.gov/about/search_program.html

The Infrared Telescope Facility (IRTF) is NASA's infrared-optimized three-meter telescope sited at an altitude of 13,600 feet on the extinct volcano Mauna Kea on the Big Island of Hawai'i. The NEOO project funds IRTF operations and IRTF is a primary NASA planetary defense asset for NEO physical characterization. IRTF continues its mission of strategic support of NASA flight missions and science goals in both planetary science and astrophysics while being on-call for rapid response observations of NEO targets of opportunity and potential threats.

For more information on IRTF, go to: http://irtfweb.ifa.hawaii.edu/

The NEOWISE mission uses the WISE spacecraft, a 40-centimeter (16-inch) diameter infrared telescope in Earth-orbit that continues an all-sky astronomical survey with its two detectors, which remain in non-cryogenic operations. NEOWISE capabilities and vantage point enable contribution to NEO discovery and, more significantly, understanding the physical properties of large numbers of NEOs, comets, main-belt asteroids, and other minor planets.

For more information on NEOWISE, go to:
https://www.nasa.gov/mission_pages/neowise/mission/index.html

Recent Achievements

In FY 2020, asteroid search teams funded by the NEO Observations project found another two near-Earth asteroids (NEAs) larger than one kilometer in size with orbits that come close to Earth's vicinity. Asteroid search teams also found 2,867 NEAs less than one km in size and observers found three additional Earth-approaching comets, bringing the total known population of NEOs to 23,819 NEAs and 113 Earth-approaching comets as of September 30, 2020. The high-precision orbit predictions computed by the

OTHER MISSIONS AND DATA ANALYSIS

Center for Near-Earth Object Studies at JPL show that none of these objects is likely to strike the Earth in the next century. However, as of September 2020, there are 2,126 near-Earth asteroids (of which 158 are larger than one km in diameter) with 113 found in FY 2020, in orbits that could become a hazard in the more distant future and warrant continued monitoring.

Researchers studied asteroids in detail during their close approaches to Earth, characterizing small or potentially hazardous asteroids and yielding important new near-Earth asteroid discoveries. During FY 2020, 98 asteroids - all less than 50 meters is size - passed Earth within the distance to our Moon. Seven of the smaller asteroids (less than 10 meters in size) passed within the distance of the orbiting geosynchronous satellites. All 98 asteroids were discovered in the days either just prior to or just following closest approach. Researchers discovered a very small asteroid, 2020 QG, just as it approached at only about 1800 miles above the southern Indian Ocean on Sunday, August 16, 2020. NASA estimates the asteroid to be only 10 to 18 feet in size and is the closest known pass to Earth without having impacted the atmosphere.

WORK IN PROGRESS FY 2021

The NEOWISE spacecraft orbit has been moving away from the ideal sun synchronous orbit alignment since the end of prime operations in 2010. In FY 2021, it will complete a seventh year of operations since reactivation and engineers will continue to monitor closely the temperature on the spacecraft. Excessive heat would effectively blind the infrared detectors, terminating the useful life of the spacecraft. NEOWISE has no orbital maintenance thrust capability; therefore, it cannot compensate for this natural orbital movement.

The United States Space Force’s (USSF) Space Surveillance Telescope is in the process of test and commissioning in Australia. NASA continues to coordinate with USSF Space Command on a logistical and funding path for transferring the data from Australia to the United States. Researchers will use the USSF data for asteroid detection and tracking. The Lincoln Near-Earth Asteroid Research team continues to prepare the data processing pipeline for the data.

The Asteroid Terrestrial-impact Last Alert System (ATLAS) team identified partners and sites in South Africa and Chile and will continue the component procurements and the development of the two new ATLAS observatory stations in those locations.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

NASA will continue to support a network of search and characterization observatories and the data processing and analysis required to understand the near-Earth population of small bodies and detect any threats for impacting Earth.

NEAR EARTH OBJECTS SURVEYOR

The Near Earth Objects (NEO) Surveyor mission addresses NASA’s objective to find, track, and characterize the asteroids and comets that could potentially impact Earth and cause significant damage. NEO Surveyor is a system that consists of ground-and space-based segments searching the sky for significant potential impact hazards. The segments include continued flight operations of NEOWISE until

OTHER MISSIONS AND DATA ANALYSIS

its end-of-mission is declared, the NEO Surveyor space telescope flight project, and the associated data processing and analysis needed to meet the mission level requirements.

The mission will make significant progress toward the objective to detect, track, catalog, and characterize at least 90 percent of NEOs equal to or larger than 140 meters in size in Public Law 109-155 Sec. 321, the George E. Brown, Jr. Near-Earth Object Survey Act.

The mission is a key priority of NASA's Planetary Defense Coordination Office tasked with detecting, quantifying, and responding to the hazard of asteroid and comet impacts. A 2019 National Academy of Sciences report concluded that a space-based infrared mission was the most effective option for completing the survey of NEOs equal to or larger than 140 meters in size. The mission also responds to the findings of the National Academy of Sciences report Defending Planet Earth: Near-Earth Object Surveys & Hazard Mitigation Strategies (2010) and the objectives of the U. S. National Near-Earth Object Preparedness Strategy and Action Plan (June 2018).

Recent Achievements

The NEO Surveyor mission completed Phase A formulation and technology development of the required infrared detector arrays.

WORK IN PROGRESS FY 2021

NEO Surveyor is working toward Key Decision Point-B (KDP-B) and entering the Phase B preliminary design phase.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

NEO Surveyor will continue to mature the preliminary design, with a target to complete Phase B in 2023.

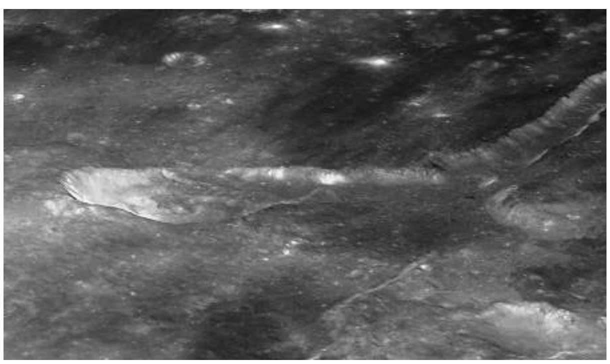
LUNAR DISCOVERY AND EXPLORATION

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
VIPER	54.9	99.1	**107.2**	102.0	30.6	0.0	0.0
Other Missions and Data Analysis	245.1	344.4	**390.1**	399.3	427.7	458.3	458.3
Total Budget	**300.0**	**443.5**	**497.3**	**501.3**	**458.3**	**458.3**	**458.3**
Change from FY 2021			**53.8**				
Percentage change from FY 2021			**12.1%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



LRO image of the CLPS Task Order 2 awardee Intuitive Machines lunar landing site in the Aristarchus plateau, a location noted for its rich array of geologic features.

NASA's exploration strategy will provide an innovative and sustainable approach to scientific and human exploration with commercial and international partners to enable human expansion across the solar system and bring new knowledge and opportunities back to Earth. The Agency will achieve these accomplishments through public-private partnerships with emerging commercial capabilities and innovative approaches to achieving human and science exploration goals, including the return of humans to the Moon.

The Lunar Discovery and Exploration Program (LDEP) in the Science Mission Directorate is a key component of the Agency's exploration strategy. It includes establishing commercial contracts for lunar payload delivery and other related services; continuing operations of the Lunar Reconnaissance Orbiter (LRO); and developing SmallSats, instruments, and other payloads that serve lunar science, long-term exploration, and utilization needs. LDEP will provide innovative investigations, evolved strategies to enhance lunar exploration and science by developing technical capabilities, and increased commercialization of an expanded range of lunar services. NASA is prioritizing capabilities that support lunar resource analysis and prospecting to inform future human space flight objectives.

In partnership with private industry and the scientific community, the program is developing lunar surface payloads (and supporting orbital payloads) along with cost-effective ways to deliver and provide services for these payloads. These payloads and services address the nation’s lunar exploration, science, and technology demonstration goals, many of which are outlined in the National Academies of Sciences 2011 Decadal Survey: Vision and Voyages for Planetary Sciences in the Decade 2013-2022, the National

LUNAR DISCOVERY AND EXPLORATION

Research Council 2007 Report: The Scientific Context for the Exploration of the Moon, and the NASA Strategic Knowledge Gaps.

For more information, go to: https://www.nasa.gov/exploration/library/skg.html

NASA purchases transportation services to the Moon for NASA instruments and technology demonstration payloads. These transportation or delivery services include needed "utilities" from the commercial systems, such as power, communications, and thermal control, during launch integration, launch, and cruise phase, and in most cases, operations at the lunar destination. In other cases, these services culminate in deployment of a NASA asset such as a rover to fulfill its own mission. In addition, NASA will pursue the purchase of science or engineering data provided by contractor systems, as well as the possibility of returning payloads and/or samples to the Earth.

LDEP makes these lunar services available to the exploration and technology directorates, in addition to developing science-driven payloads and instrument suites to deliver to the Moon.

One area of focus will be instrumentation to advance the knowledge and technologies for the use of local resources, such as lunar water ice. Working with the science and human exploration communities, our international partners, and U.S. industry, NASA will refine the goals and objectives for a robust and sustainable lunar exploration and science program.

EXPLANATION OF MAJOR CHANGES IN FY 2022

There are three new projects in this budget. The Development and Advancement of Lunar Instrumentation (DALI) and Payloads and Research Investigations on the Surface of the Moon (PRISM) activities are instrument selection elements previously executed within the Lunar Instruments and Lunar Future projects. Lunar Trailblazer is a new project in development selected as a SmallSat in the recent Small Innovative Missions for Planetary Exploration (SIMPLEx) call in the Discovery Program.

ACHIEVEMENTS IN FY 2020

The program added five companies to the Commercial Lunar Payload Services (CLPS) portfolio in FY 2020. NASA awarded task orders to Masten Space Systems and Astrobotic for deliveries in 2022 and 2023. NASA proceeded with in-house development of 12 payloads under the internal NASA-Provided Lunar Payload (NPLP) call, externally awarded 12 additional payload developments under the Lunar Surface Instrument and Technology Payload (LSITP) call, and kicked-off a new procurement process and series of projects known as Payloads and Research Instruments on the Surface of the Moon (PRISM) for Principal Investigator-led instrument suites building a robust pipeline of payloads to deliver via CLPS.

NASA continued LRO into its 11th year of operations. LRO provides a treasure trove of lunar data that helps to characterize and conduct detailed surveys of potential landing sites for commercial missions.

NASA selected one SIMPLEx research announcement in support of planetary science investigations as a prospective investigation of the Moon. In addition, several teams of scientists awarded grants through the Apollo Next Generation Sample Analysis research announcement continued their research. These teams are analyzing specially curated lunar samples including an Apollo 17 lunar sample that has been sealed since its return to Earth in 1972.

LUNAR DISCOVERY AND EXPLORATION

The Volatiles Investigating Polar Exploration Rover (VIPER) development continued, and the project held the preliminary design review (PDR) in August 2020.

WORK IN PROGRESS IN FY 2021

Final development of CLPS early-delivery payloads continues in FY 2021. NASA will use the new PRISM initiative to solicit and award two Principal Investigator (PI)-led payload suites for two CLPS deliveries. Funding for future instrument development through the DALI research call continues. Lunar Trailblazer completed its PDR in October 2020. NASA awarded a CLPS task order to deliver the Polar Resources Ice Mining Experiment-1 (PRIME-1) drill experiment to the lunar south pole in FY 2023 and awarded another task order for delivery of seven payloads to Crisium Basin, bringing the total number of active CLPS lunar deliveries to six.

NASA continues to engage with the science community, NASA's international exploration partners, and U.S. industry to refine the exploration, scientific, and technology objectives in support of LDEP.

NASA will continue to operate LRO in support of scientific research and future science and exploration mission planning. NASA will provide LRO landing site characterization capabilities to international partners for future lunar lander missions when requested.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The first two CLPS deliveries to the lunar surface will occur in early FY 2022, with the next two working toward delivery in FY 2023 (CY 2022).

Plans for the delivery of more capable scientific, exploration, and technology payloads will continue across the NASA mission directorates, utilizing the CLPS providers to deliver these payloads to the lunar surface.

The VIPER rover will complete its critical design review.

NASA will competitively select additional robotic lunar surface payloads through future PRISM requests for information and will fly on CLPS-provided launch and landing services to the lunar surface.

NASA will continue operations of LRO and offer LRO landing site characterization capabilities to international and commercial partners upon request.

Program Schedule

Date	Significant Event
FY 2021	Award PRIME-1 lunar polar delivery task order
FY 2021	Award task order for delivery of payloads to Crisium Basin
FY 2021	Deliver NASA-developed payloads for integration into CLPS providers for delivery to the lunar surface.
FY 2021	First PRISM selections and awards

LUNAR DISCOVERY AND EXPLORATION

Date	Significant Event
FY 2022	VIPER CDR
FY 2022	Scheduled* delivery of payloads by Astrobotic through CLPS
FY 2022	Scheduled* delivery of payloads by Intuitive Machines through CLPS
FY 2022	Deliver NASA-funded LSITP payloads for integration into CLPS deliveries to the lunar surface.
FY 2023	Deliver VIPER to Astrobotic for delivery to lunar south polar region.
FY 2023	Scheduled* delivery of payloads to Crisium Basin by Firefly Aerospace through CLPS
FY 2023	Scheduled* delivery of PRIME-1 drill to southern lunar pole region by Intuitive Machines
FY 2023	Scheduled* delivery of payloads to lunar south polar region by Masten

**NASA does not manage the launch vehicle portion of the CLPS effort and does not ultimately control final launch schedules of the selected partners that will deliver NASA and other partner-provided payloads. NASA will work with the CLPS vendors to ensure timely and successful launch and delivery of all science and technology payloads.*

Program Management & Commitments

Program Element	Provider
Lunar Reconnaissance Orbiter	Lead Center: Goddard Space Flight Center (GSFC) Performing Center(s): GSFC, Applied Physics Laboratory (APL), Jet Propulsion Laboratory (JPL) Cost Share Partner(s): N/A
Lunar Instruments	Lead Center: Various Performing Center(s): N/A Cost Share Partner(s): N/A
Commercial Lunar Payload Services	Lead Center: Johnson Space Center (JSC) Performing Center(s): N/A Cost Share Partner(s): N/A
VIPER	Lead Center: Ames Research Center (ARC) Performing Center(s): ARC, JSC, KSC Cost Share Partner(s): N/A
DALI	Lead Center: Headquarters Performing Center(s): ARC, GRC, GSFC Cost Share Partner(s): N/A

LUNAR DISCOVERY AND EXPLORATION

Program Element	Provider
PRISM	Lead Center: Headquarters Performing Center(s): TBD Cost Share Partner(s): N/A
Lunar Trailblazer	Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
Lunar Management	Lead Center: HQ Performing Center(s): MSFC Cost Share Partner(s): N/A

Acquisition Strategy

LDEP uses flexible contract mechanisms, such as indefinite-delivery-infinite-quantity (IDIQ) contracts, to enable the flexible and rapid procurement of commercial transportation services to deliver NASA scientific, exploration, and technology development payloads to the surface of the Moon, and potentially to lunar orbit. NASA may expand lunar service requirements to include more capabilities, such as mobility or sample return.

In parallel, NASA uses its established solicitation mechanisms, such as the Research Opportunities in Space and Earth Science (ROSES) NASA Research Announcement (NRA) and the Stand Alone Missions of Opportunity (SALMON) Announcement of Opportunity (AO) processes, to select and develop exploration, scientific, and technology development payloads for delivery to the Moon. In some cases, NASA may direct a NASA center to develop a lunar capability or surface payload when it is in the Government's best interest, such as when that capability supports multiple NASA applications or when a commercial entity or international partner identifies a near-term opportunity for a lunar surface mission on a timeframe that does not support competitive selection. However, to the maximum extent possible, NASA will leverage commercial efforts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Commercial Lunar Payload Services	Astrobotic Technology	Pittsburgh, PA
Commercial Lunar Payload Services	Intuitive Machines	Houston, TX
Commercial Lunar Payload Services	Firefly Aerospace	Cedar Park, TX
Lunar SmallSats - Lunar Trailblazer	California Institute of Technology	Pasadena, CA
Commercial Lunar Payload Services	Masten Space Systems	Mojave, CA

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

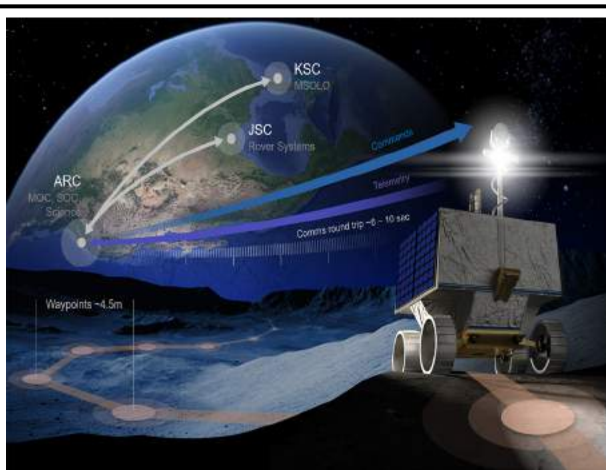
Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	39.7	40.4	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	80.1
Development/Implementation	0.0	14.5	99.1	**107.2**	102.0	13.5	0.0	0.0	0.0	336.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	17.2	0.0	0.0	0.0	17.2
2021 MPAR LCC Estimate	**39.7**	**54.9**	**99.1**	**107.2**	**102.0**	**30.6**	**0.0**	**0.0**	**0.0**	**433.5**
Total Budget	**39.7**	**54.9**	**99.1**	**107.2**	**102.0**	**30.6**	**0.0**	**0.0**	**0.0**	**433.5**
Change from FY 2021				**8.1**						
Percentage change from FY 2021				**8.2%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



VIPER rover operating in a Lunar polar region (artist concept).

PROJECT PURPOSE

The Volatiles Investigating Polar Exploration Rover (VIPER) is a robotic lunar rover that will explore the relatively nearby, but extreme environment of the Moon, in search of water ice and other potential volatile resources. The suite of instruments will also address high priority science questions by providing information about the origin and distribution of water on the Moon and across the solar system. NASA will use the data the rover collects to determine where the Moon’s water ice is most likely to be found and easiest to access, making VIPER the first-ever resource mapping mission on another celestial body. NASA can then use these maps in the decision process for future lunar human space exploration, and beyond. The first water maps of the Moon will mark a critical step forward in NASA’s Artemis Program to establish a sustainable human presence on the surface of the Moon.

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2022

The increase in the VIPER mission budget profile supports the project requirements identified at its confirmation into the development phase.

PROJECT PARAMETERS

VIPER is a 100 Earth-day mission to cover three cycles of lunar day/night over some selected regions at the South Pole with a scheduled late 2023 arrival. VIPER is a remotely commanded golf-cart sized rover that will be delivered onto the Moon's surface via NASA Commercial Lunar Payload Services (CLPS) provided launch vehicle and lander. The CLPS project funds all costs associated with launch and landing.

VIPER will explore a selected landing zone in a polar region and will venture into the semi-permanent and permanently shadowed regions, to survey different ice-stability regions to detect and assess volatiles distributions and concentrations. To achieve its scientific goals, the rover will carry three instruments and a 3.28-foot (one meter) drill to detect and analyze various lunar soil environments at a range of depths and temperatures.

The VIPER drill, The Regolith and Ice Drill for Exploring New Terrain (TRIDENT), will excavate using the auger/percussion approach, which utilizes a hammering action in conjunction with a rotary motion, to extract down to a depth of 1-meter and deliver lunar regolith in small (10 centimeter) segments.

The Neutron Spectrometer System (NSS) instrument will prospect for and map the distribution of hydrogen-rich materials while roving. NSS will be located on the front of the rover to have an unobstructed view of the lunar surface.

The Near InfraRed Volatiles Spectrometer System (NIRVSS) instrument will operate during roving or while drilling. The instrument will look for near real-time changes in the properties of the materials exposed. Using different wavelengths of light to illuminate the surface, the team will use NIRVSS to provide an additional means of surveying the surface and immediate excavation site for water and other volatiles, providing surface and regolith mineral context.

The Mass Spectrometer observing lunar operations (MSolo) instrument will operate during roving or while drilling. MSolo will identify low-molecular weight volatiles on the surface or from subsurface excavations. Working in concert with the NIRVSS instrument, the instruments will analyze volatiles as it delivers materials by the drill bit from the depth of up to one meter.

ACHIEVEMENTS IN FY 2020

VIPER passed a Sync Point Review (SPR) on April 30, 2020. The SPR was a snapshot review focused on the alignment of project goals, requirements, and the team's proposed technical approach. The VIPER Review Team (VRT) conducted the independent review timed to occur prior to the Preliminary Design Review (PDR), a key project life-cycle gate review. The project successfully completed its preliminary design review in August 2020. In June 2020, NASA selected Astrobotic as the CLPS vendor to launch and deliver VIPER to a lunar pole.

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2021

The project continues its design and technology efforts. The project conducted a successful Key Decision Point-C in February and has entered the final design and fabrication phase. Subsystem developments including instrument payloads are ongoing and the entire team is preparing for the mission critical design review planned for late in calendar year 2021.

The team is actively engaging with the VIPER CLPS provider, Astrobotic, to further define and capture interface requirements that will inform Astrobotic lander/launch vehicle development and payload accommodation approach.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The VIPER project will complete its Critical Design Review (CDR) and System Integration Review (SIR), Key Decision Point-D (KDP-D) review, and assembly in FY 2022 and begin the integration and test phase of development.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
KDP-C	Feb 2021	Feb 2021
CDR	Nov 2021	Nov 2021
SIR	May 2022	Jul 2022
Ship to CLPS Provider	Jul 2023	Jul 2023
Launch Readiness	Nov 2023	Nov 2023
Initial Operational Capability	Nov 2023	Nov 2023
Start Phase E	Nov 2023	Nov 2023

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

Development Cost and Schedule

The confidence level developed for VIPER confirmation is the result of a combination of analysis between an independent cost estimate and an independent schedule estimate.

Base Year	Base Year Develop-ment Cost Estimate ($M)	CL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2021	433.5	70	2021	336.2	-	IOC	Nov 2023	Nov 2023	-

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

This report is the first report of development costs for this mission. The CLPS project funds all costs associated with launch and landing. Launch vehicle costs reported here are for VIPER integration requirements.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**336.2**	**336.2**	**0**
Aircraft/Spacecraft (Rover)	92.2	92.2	0
Payloads	22.8	22.8	0
Systems I&T	15.7	15.7	0
Launch Vehicle	1.8	1.8	0
Ground Systems	37.1	37.1	0
Science/Technology	7.2	7.2	0

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Other Direct Project Costs	159.4	159.4	0

Project Management & Commitments

Ames Research Center (ARC) manages the VIPER mission and provides systems engineering, project science, real-time rover surface operations, and flight software.

Element	Description	Provider Details	Change from Baseline
Project Office and Mission Management including Science, System Engineering, Safety & Mission Assurance	Overall mission planning and project management functions.	Provider: NASA Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Rover	Develop, design, build, system integration and testing of the rover mobility platform including integration of instrument payloads, and qualification testing.	Provider: NASA Lead Center: ARC Performing Center(s): JSC Cost Share Partner(s): N/A	N/A
TRIDENT	Drilling instrument	Provider: Honeybee Robotics Lead Center: ARC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A
NSS	Neutron Spectrometer instrument	Provider: NASA Lead Center: ARC Performing Center(s): ARC Cost Share Partner(s): N/A	N/A

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
NIRVSS	Near infrared spectrometer instrument	Provider: NASA Lead Center: ARC Performing Center(s): ARC Cost Share Partner(s): N/A	N/A
MSolo	Mass spectrometer instrument	Provider: NASA Lead Center: ARC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A
Lander and Launch Vehicle	CLPS-provided lander and launch vehicle (not included in VIPER baseline)	Provider: Astrobotic Lead Center: JSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: COVID-19 restrictions continue, Then: The lack of in-person interaction and work will impact overall efficiency, extend schedules, and likely increase the cost to complete tasks.	Project continues to use innovative remote work approaches and follows all protocols for center access to laboratories, fabrication, and test facilities for necessary hands-on work. VIPER technical team members will continue to create new capabilities to facilitate teaming in accomplishing development, design, analysis, and simulation during the current remote-work environment.
If: VIPER is required to make unexpected design changes to enable payload accommodation with the CLPS vendor, Then: This could increase its life cycle cost and schedule.	The VIPER project, CLPS office staff, and Astrobotic are in regular contact to develop interfaces requirements while maximizing system success.

Acquisition Strategy

NASA is designing, developing, building, integrating, and testing most of the elements of VIPER at NASA centers. The VIPER rover at Johnson Space Center (JSC), the NSS and NIRVSS instruments at

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

ARC, and MSolo at Kennedy Space Center (KSC) are all NASA in-house developments. The TRIDENT drill was competed and awarded to Honeybee Robotics.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	VIPER Review Team (VRT)	Apr 2020	Prior to PDR, an alignment review focused on VIPER's mission goals, and the connections to recently approved L1-requirements	VRT provided positive assessment; project is working on a well-understood approach to meet mission goals and objectives and is on path toward PDR.	PDR
Performance	VRT	Aug 2020	Preliminary design review	Project design was deemed sufficiently mature to proceed	CDR
Performance	VRT	Nov 2021	Critical Design Review	TBD	SIR
Performance	VRT	Jul 2022	Systems Integration Review	TBD	ORR
Performance	ARC	Nov 2023	Operational Readiness Review	TBD	N/A

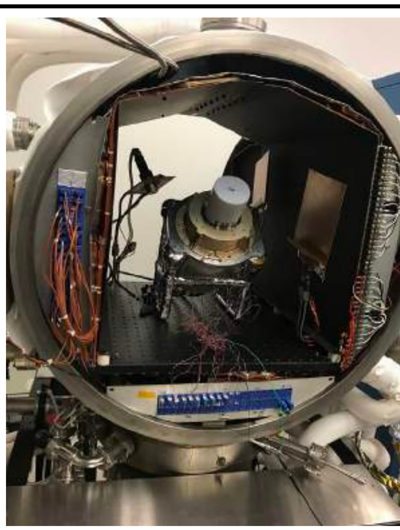
OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Development and Advancement of Lunar Instrumentation (DALI)	0.0	20.4	**14.7**	15.0	15.0	15.0	15.0
Lunar Trailblazer	0.0	23.2	**17.5**	1.2	4.3	3.4	1.8
Payloads and RI on Surface of the Moon	0.0	21.0	**25.4**	21.5	8.5	0.0	0.0
Lunar Future	4.3	6.3	**19.6**	26.9	45.1	85.1	86.7
Lunar Instruments	34.2	13.7	**32.7**	54.6	69.2	74.4	74.5
Commercial Lunar Payload Services	184.6	233.4	**254.0**	254.0	254.0	254.0	254.0
Lunar International Mission Collaboration	0.0	0.5	**0.5**	0.5	0.5	0.5	0.5
Lunar Management	0.0	3.7	**3.5**	3.5	9.0	3.8	3.8
Lunar Reconnaissance Orbiter (LRO)	22.0	22.2	**22.1**	22.0	22.0	22.0	22.0
Total Budget	**245.1**	**344.4**	**390.1**	**399.3**	**427.7**	**458.3**	**458.3**
Change from FY 2021			**45.7**				
Percentage change from FY 2021			**13.3%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



The Surface and Exosphere Alterations by Landers (SEAL) lunar payload installed in a thermal vacuum chamber at GSFC. SEAL was one of 13 NPLP instruments selected in 2019 to fly on a CLPS provider.

Mission Planning and Other Projects

Other Missions and Data Analysis includes mission planning, mission development, instrument and technology development, operating missions, international collaborations, management activities, and funding for future instrument and mission selections.

DEVELOPMENT AND ADVANCEMENT OF LUNAR INSTRUMENTATION (DALI)

DALI focuses on advancing the development of spacecraft-based instruments that show promise for use in future lunar missions including expected commercial ventures. The goal of the effort is to develop and demonstrate lunar science instruments to the point where principal investigators may propose their use in response to future announcements of flight opportunity without additional extensive technology

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development. The technology readiness levels (TRLs) that DALI supports are TRL four through six.

Recent Achievements

NASA released the DALI 2019 NRA in March 2019 and the five instruments that NASA selected for funding in November 2019 continue to be developed. NASA released the DALI 2020 NRA in February 2020 and expects to make five additional selections. To date, NASA has awarded 15 DALI technology development efforts.

LUNAR TRAILBLAZER

NASA selected a SmallSat called Lunar Trailblazer from the recent Small Innovative Missions for Planetary Exploration (SIMPLEx) call. Trailblazer will spend one year orbiting the Moon at an altitude of 100 kilometers to generate a high-resolution map, at 100 meters per pixel, that charts the form, abundance, and distribution of water while also collecting information about the environments where that water exists, including within shadowed craters. Lunar Trailblazer will carry two instruments: a shortwave imaging spectrometer to search for the signature of water, either in the form of ice or bound to minerals, and a multispectral thermal imager to map the temperature, physical properties, and composition of regions where the spectrometer detects water. These data will fill in gaps of our understanding of the distribution and composition of lunar volatiles as well as contribute to mission planning for future human exploration.

Recent Achievements

Lunar Trailblazer recently completed its Preliminary Design Review, entering its development phase. Lunar Trailblazer is planned as a rideshare on the Interstellar Mapping and Acceleration Probe (IMAP) launch, launching no-earlier-than February 2025 on a SpaceX Falcon 9 rocket.

PAYLOADS AND RESEARCH INVESTIGATIONS ON THE SURFACE OF THE MOON (PRISM)

As the NASA Provided Lunar Payloads (NPLP) and Lunar Surface Instrument and Technology Payloads (LSITP) instruments are completed, the PRISM instrument selections will continue to help NASA develop science-driven payloads for manifesting on future CLPS deliveries and on international flight opportunities. PRISM calls are for investigations utilizing suites of instruments (as opposed to individual payloads acquired under NPLP and LSITP) manifested on CLPS deliveries. The PRISM-1 selections will launch to two high science-value locations with deliveries to the lunar surface expected as early as December 2023: the Reiner Gamma albedo swirl on the lunar nearside and Schrödinger Basin impact melt on the lunar far side. This innovative approach for soliciting science investigations and technology demonstration payloads for future deliveries by CLPS providers will enable decadal caliber science at the Moon and support the Artemis Program.

Recent Achievements

NASA released the PRISM-1 Request for Information (RFI) in April 2020 and released the PRISM-1 solicitation as a ROSES NRA element in November 2020 with at least two selections planned for spring 2021.

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LUNAR FUTURE

Lunar Future supports a variety of activities with a strategic focus that helps NASA achieve human and science exploration goals, including the return of humans to the Moon.

NASA is also studying future lunar mission capabilities, including options for technologies to survive and operate during the long, cold lunar night, which would enable long-duration mobility and science investigations. NASA is also assessing possible future orbiters that would acquire new key data sets to inform science investigations and support future landed robotic and human exploration missions.

Recent Achievements

NASA awarded several grants through the Apollo Next Generation Sample Analysis NASA research announcement to analyze specially curated lunar samples, including one Apollo 17 lunar sample sealed since its return to Earth in 1972. The purpose of keeping these samples in pristine condition was to take advantage of the new analysis capabilities that have developed over the last four decades.

LUNAR INSTRUMENTS

NASA is developing instruments and technology payloads to manifest on both CLPS and international lunar lander missions. These instruments come from U.S. academia and industry, as well as from NASA centers. These activities include NPLP and LSITP, which NASA manifests on CLPS deliveries and will be completed and launched in or by 2025. It also includes funding for future instrument selections, which will become new PRISM projects.

Recent Achievements

NASA is progressing with the development of payloads awarded in February and May of 2019. The 12 internally developed NPLP payloads and 12 academic and industry developed LSITP payloads are on-track for five of the first seven CLPS deliveries to the surface of the Moon. More than half the payloads for the first two deliveries in FY 2022 are already complete and are ready for integration into the commercial transportation systems. Funding for future instrument development through DALI research has moved to its own project line.

COMMERCIAL LUNAR PAYLOAD SERVICES (CLPS)

CLPS is opening competition to United States commercial providers of space transportation services, with the strategic goal of supporting affordable commercial operations on and near the Moon, consistent with the National Space Transportation Policy and Commercial Space Act. CLPS consists of a multi-vendor catalog, a 10-year indefinite-delivery-indefinite-quantity (IDIQ) contract. NASA manages it through task order competition for specific lunar surface transportation services of payloads with NASA being one of several customers.

Recent Achievements

The program added five companies to the CLPS portfolio in FY 2020, bringing the roster of providers to 14. NASA also awarded three task orders for lunar polar deliveries, two in FY 2020 to Masten Space Systems and to Astrobotic and one in early FY 2021 to Intuitive Machines. Combined with the two lunar delivery task orders initially issued to Astrobotic and Intuitive Machines and the recent non-polar delivery task order to Firefly Aerospace, CLPS now has six commercial deliveries actively in work that will all

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occur between FY 2022 and FY 2024. These commercial missions are also delivering payloads provided by customers other than NASA. See the list of commercial service company awardees in the Major Contract/Awards table of the Lunar Discovery and Exploration Program section.

LUNAR INTERNATIONAL MISSION COLLABORATION

In developing collaborations with our international partners, NASA funds U.S. participating science investigators and provides international collaborators with lunar landing site characterization data, as well as navigation and data relay services, in exchange for United States participation. NASA is providing science instruments to fly on international missions as well as manifesting international payloads on CLPS landers in exchange for rights to the data and placement of U.S. scientists on the international science teams.

Recent Achievements

NASA is prepared to provide two contributions to a Japan Aerospace Exploration Agency (JAXA) mission for: 1) flying a small Laser Retroreflector Array for lunar orbital ranging on their Smart Lander for Investigating Moon and 2) providing a Neutron Spectrometer on a rover system, which will be delivered to the lunar surface by the Indian Space Research Organisation. NASA is also prepared to partner with European Space Agency (ESA) to fly two payloads via CLPS to the lunar surface: 1) a large Lunar Retroreflector for Earth-based ranging and 2) a volatiles characterization payload to fly to the lunar pole. NASA is also planning to collaborate with the Canadian Space Agency to provide an instrument on a lunar rover, as well as with the Korea Astronomy and Space Science Institute, the Swiss Space Office, and the Luxembourg Space Office on other potential partner contributions.

LUNAR MANAGEMENT

The Planetary Missions Program Office (PMPO) at the Marshall Space Flight Center manages Planetary Science flight projects that are not part of the Mars Exploration Program, including certain elements of the LDEP portfolio, such as the contracts selected through LSITP for lunar delivery by CLPS landers, PRISM-1 awards, and the Lunar Trailblazer. Lunar Management includes support outside of PMPO for the day-to-day efforts of relevant mission elements, as well as establishing review boards and external technical support as needed. The budget also includes other management activities at Headquarters and other NASA centers.

Operating Missions

LUNAR RECONNAISSANCE ORBITER (LRO)

The LRO mission continues to conduct priority science investigations and acquire valuable data sets that provide critical support for commercial lunar deliveries under the CLPS project as well as for human exploration. LRO has contributed to a new understanding of the Moon and its evolution, which provides a foundation for understanding all other objects in our Solar System, as well as solar systems beyond our own. LRO's investigations include a focus on lunar volatiles (e.g., ice, water): what the volatiles are,

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where they come from, how they move about on the lunar surface, and where they collect. LRO has also been characterizing the thermal history of the Moon by identifying unusual volcanic features that may be geologically young, as well as tectonic features that reflect the continued gravitational pull from the Earth. Such features are targets for all seven instruments as the mission works to use multiple datasets to investigate the Moon. Scientists use the instrument suite on LRO to characterize the rate at which volatiles move across the surface, the development of the regolith on different terrains, and the location and composition of unusual rock types on the surface.

LRO will continue supporting characterization of the lunar surface, which ultimately enables and reduces risk associated with commercial and human exploration initiatives. Over the upcoming year, LRO will continue characterizing areas on the Moon that may contain volatiles at or near the surface and will characterize landing sites in support of the upcoming U.S. commercial lunar lander missions. LRO is also providing data products in support of current and future Artemis missions.

Recent Achievements

LRO, now in its 11th year of operation, has provided over 1.3 petabytes of lunar data to the planetary data system, which comprises over two-thirds of all planetary data ever acquired. The extended baseline of LRO observations allows us to understand the rate of change in the regolith over human timescales, something no other lunar mission has ever accomplished. Continued observations allow us to test hypotheses for how the surface changes in multiple datasets, informing our understanding of how the lunar regolith evolves over time. The LRO radiation detector has created an invaluable measure of the radiation environment in cis-lunar space, which enables us to understand how humans will respond to both solar and galactic cosmic radiation. With this dataset, we can estimate the allowable human exposure to radiation at the Moon and help characterize how shielding will protect future explorers. Such characterization leverages data from all instruments to identify not just safe landing sites but also ones that maximize the scientific return from a landed mission.

LRO data has helped scientists understand the rate of crater formation on Earth. The LRO team discovered that the rate of large crater formation on the Moon has been two to three times higher over approximately the last 290 million years than it had been over the previous 700 million years. This discovery indicates that the Earth has fewer older craters on its most tectonically stable regions because the impact rate was lower about 290 million years ago and not because of erosion erasing them as had been previously thought.

DISCOVERY

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Lucy	208.6	143.6	**77.3**	18.0	20.2	24.5	41.7
Psyche	214.0	169.6	**139.7**	28.7	29.0	32.0	32.0
Other Missions and Data Analysis	86.1	138.1	**147.8**	180.8	254.6	472.9	676.8
Total Budget	**508.7**	**451.3**	**364.8**	**227.6**	**303.8**	**529.4**	**750.5**
Change from FY 2021			**-86.5**				
Percentage change from FY 2021			**-19.2%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

NASA's InSight lander retracted its robotic arm on October 3, 2020, revealing the spot where the self-digging "mole" is attempting to burrow into the planet's surface. It is currently below the surface several centimeters and not visible in this image. Attached to the mole is the copper-colored ribbon, which is laden with temperature sensors designed to measure the heat flow within Mars.

NASA’s Discovery program supports competitively selected, investigator-led planetary science missions to explore the planets, their moons, and small bodies such as comets and asteroids. With a lower mission cost cap than NASA's other planetary missions, Discovery provides scientists the opportunity to propose innovative ways to unlock the mysteries of the solar system.

The Discovery program has one operational mission, the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight); and three missions in development, Lucy, Psyche and Janus.

The Discovery program also supports the development of instruments that NASA deploys on foreign-led missions, such as the Start from a ROtating FIeld mass spectrOmeter (STROFIO) instrument on the BepiColombo mission to Mercury. A joint mission of the European Space Agency and Japanese Aerospace Exploration Agency (JAXA), BepiColombo is currently executing Venus fly-bys and plans to enter Mercury's orbit and begin observations in 2025. NASA also has a partnership with JAXA for two

DISCOVERY

contributions to its Martian Moons eXploration (MMX) mission, planned for launch in 2024. These include the Mars-moon Exploration with Gamma rays and Neutrons (MEGANE) instrument, a competitively selected neutron and gamma-ray spectrometer to map surface composition, and P-Sampler, a pneumatic sampler included as a technology demonstration to return samples of the moon's surface.

EXPLANATION OF MAJOR CHANGES IN FY 2022

Due to other missions being in peak development and COVID-related challenges in the broader Planetary Science Division portfolio, NASA the funding requirements for the next Discovery selection. However, remaining funding is enough to select up to two missions from the current Announcement of Opportunity (AO) with planned launches no earlier than 2028. Selected Discovery missions will be in Phase B in FY 2022 after down-select in FY 2021.

ACHIEVEMENTS IN FY 2020

Psyche passed its Critical Design Review in May 2020 and entered final fabrication phase.

Lucy passed Key Decision Point-D (KDP-D) in August 2020, progressing into the assembly, system integration, and test phase of development.

Janus passed Key Decision Point-C (KDP-C) in September 2020, entering its final design and fabrication phase of development.

NASA selected four missions from the 2019 Discovery AO to develop concept study reports, which involves development of the mission concept through Phase A.

WORK IN PROGRESS IN FY 2021

The Lucy project will complete the assembly and test phase and ship the spacecraft to the launch site at Cape Canaveral.

Psyche completed its KDP-D gate review in January 2021 and began assembly, integration, and testing of flight hardware.

Janus will complete its system integration review and prepare for its KDP-D gate review for authorization to begin the assembly, integration, and testing phase of development.

Lunar Trailblazer passed its KDP-C gate review in November 2020 and is in the Lunar Development and Exploration program for 2022 and beyond.

InSight will complete its prime mission and propose an extended mission through the established senior review process.

In November 2020, NASA received the concept study reports for the four missions selected from the 2019 Discovery AO. Planetary Science will evaluate these reports through spring 2021, at which point NASA plans to select up to two missions to proceed into formulation.

DISCOVERY

KEY ACHIEVEMENTS PLANNED FOR FY 2022

NASA plans to launch Lucy, Psyche, and Janus in FY 2022. Lucy ground-based observation campaigns will begin to study the shapes and orbits of its targets, focusing on the first encounter with the Queta and Eurybates satellites.

The new Discovery flight project(s) down selected in 2021 will be in formulation phase.

Program Schedule

Date	Significant Event
Q3, FY 2021	Down-select mission(s) from 2019 Discovery concept study reports
Q1, FY 2022	Lucy Launch
Q4, FY 2022	Psyche and Janus Launch
2023	Release 2023 Discovery AO solicitation
2024	Select 2023 Discovery AO proposals for concept study reports
2025	Down-select up to two missions from 2023 Discovery concept study reports

Program Management & Planned Cadence

The Discovery Program is a multiple-project program, with responsibility for implementation assigned to the Planetary Missions Program Office, located at the Marshall Space Flight Center (MSFC).

The Discovery Program has an objective to launch a flight mission an average of once every 36 months, with a goal of one every 24 months, commensurate with the availability of adequate funding. The present cadence, calculated from 1992 through 2022, is 24 months, with variations in the mean time between launches from five to 81 months. The last Discovery AO cost cap for the Principal Investigator was $500 million.

This budget provides for launches of Lucy, Psyche, and Janus in FY 2022 and the next Discovery launch will be pending down-select in FY 2021.

Acquisition Strategy

NASA competitively selects new Discovery missions, releasing AO's when available funding allows.

DISCOVERY

INDEPENDENT REVIEWS

NASA will schedule the Discovery Program's next Program Implementation Review (PIR) when recommended by the primary stakeholders.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PIR	Standing Review Board (SRB)	Aug 2016	Review implementation of program	Passed	TBD

LUCY

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	94.7	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	94.7
Development/Implementation	209.7	208.6	143.6	**52.3**	0.0	0.0	0.0	0.0	0.0	614.2
Operations/Close-out	0.0	0.0	0.0	**25.0**	18.0	20.2	24.5	41.7	150.8	280.2
2021 MPAR LCC Estimate	**304.4**	**208.6**	**143.6**	**77.3**	**18.0**	**20.2**	**24.5**	**41.7**	**150.8**	**989.1**
Total Budget	**304.4**	**208.6**	**143.6**	**77.3**	**18.0**	**20.2**	**24.5**	**41.7**	**150.8**	**989.1**
Change from FY 2021				**-66.3**						
Percentage change from FY 2021				**-46.2%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Lockheed Martin Space facility personnel integrating major components of the Lucy spacecraft in Littleton, Colorado, November 2020.

PROJECT PURPOSE

Lucy will investigate the Trojan asteroids, which scientists consider the fossils of planet formation. The mission's name honors Australopithecus afarensis, the human ancestor fossil named Lucy, for its role in advancing understanding of the evolution of our species. The Lucy mission supports the goals of advancing the knowledge of our planetary origin and expanding our knowledge of the formation and evolution of our solar system.

The Lucy spacecraft will execute six fly-by encounters to investigate eight asteroids: one in the main asteroid belt, and seven primitive bodies in the Trojan groups that orbit the Sun at the distance of Jupiter. Two of Lucy’s Trojan targets are binary systems: Patroclus and Menoetius are two similar-sized asteroids in orbit around each other, a configuration never seen up close; Eurybates is an asteroid that scientists discovered in this past year to have a small moon, named "Queta". Scientific evidence indicates that

LUCY

Formulation	Development	Operations

Trojans are primitive, volatile, and organic rich bodies and leftover building blocks of the giant outer planets. Researchers believe giant planets played a key role in getting water to Earth, which is essential for life as we know it. Lucy will be the first mission to visit the Jupiter Trojan asteroids.

EXPLANATION OF MAJOR CHANGES IN FY 2022

NASA rephased some funding in FY 2021 and FY 2022 based on mission needs and added funds to mission student collaboration for increased support during operations.

PROJECT PARAMETERS

NASA selected the Lucy mission in December 2016 from the Discovery Program's 2014 Announcement of Opportunity (AO). Lucy is planned to launch in November 2021, will reach its first Trojan in 2027, and will have its final Trojan asteroid encounter in 2033. In 2025, Lucy will fly by 52246 Donald Johanson, an object in the Main Asteroid Belt between Jupiter and Mars and use that encounter as a training exercise for operations and science data collection. During its planned 12-year lifetime, Lucy will perform three Earth gravity assists and six fly-by encounters, investigating one main belt asteroid and seven Trojan asteroids, closely studying these fascinating and never-before explored objects.

Lucy's instrument payload includes a panchromatic and color visible imager (L'Ralph), a high-resolution visible imager (L'LORRI), and a thermal infrared (IR) spectrometer (L'TES). In addition, Lucy will perform Doppler mass determinations using its radio subsystem. The Lucy spacecraft will have a heliocentric trajectory and perform all its flybys in a period of 11.6 years. Lucy will fly by and for the first time will study several different taxonomic classes of Jupiter Trojans, plus a main belt asteroid binary. A fortuitous orbital alignment that is unlikely to recur soon enables this comprehensive tour.

ACHIEVEMENTS IN FY 2020

Lucy successfully completed its system integration review and Key Decision Point-D (KDP-D) and continued final design, fabrication, and risk reduction activities throughout FY 2020.

WORK IN PROGRESS IN FY 2021

Lucy conducted its mission operations review in October 2020 and is planning for a KDP-E in September 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

Lucy will launch in November 2021, followed by its on-orbit checkout and initial flight operations, prior to the first Earth gravity assist in early FY 2023.

LUCY

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
KDP-C	Nov 2018	Nov 2018
CDR	Oct 2019	Oct 2019
SIR	Jul 2020	Jul 2020
KDP-D	Aug 2020	Aug 2020
Operations Readiness Review (ORR) / Flight Readiness Review (FRR)	Aug 2021	Aug 2021
Launch	Nov 2021	Nov 2021
Start Phase E	Nov 2021	Nov 2021

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2019	622.2	70%	2021	614.2	-1.3%	Launch Readiness Date (LRD)	Nov 2021	Nov 2021	0

Note: The confidence level (CL) estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other CLs reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

LUCY

Formulation	Development	Operations

Development Cost Details

NASA confirmed Lucy to proceed into implementation in October 2018.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**622.2**	**614.2**	**-8.0**
Aircraft/Spacecraft	161.3	224.2	+62.9
Payloads	43.2	82.0	+38.8
Systems I&T	30.7	25.6	-5.1
Launch Vehicle	161.2	149.4	-11.8
Ground Systems	17.2	24.3	+7.1
Science/Technology	14.3	16.1	+1.8
Other Direct Project Costs	194.3	92.6	-101.7

Project Management & Commitments

The principal investigator for Lucy is from the Southwest Research Institute (SwRI). Goddard Space Flight Center (GSFC) manages the Lucy mission and will provide systems engineering, safety and mission assurance, project scientists, flight dynamics, payload management, and mission system management.

Element	Description	Provider Details	Change from Baseline
Spacecraft	Spacecraft bus and propulsion system	Provider: Lockheed Martin Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

LUCY

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Panchromatic Visible Imager and IR Spectrometer (L'Ralph = Multi-spectral Visible Imaging Camera + Linear Etalon Imaging Spectral Array)	Provides color and near IR images to discriminate between and map compositional units	Provider: GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
High-Resolution Visible Imager (L'LORRI)	Provides high resolution images to determine shape, geology, and albedo of the Trojans asteroids	Provider: Johns Hopkins University (JHU)/Applied Physics Laboratory (APL) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Thermal Emission Spectrometer (L'TES)	Provides thermal inertia maps of the Trojans' elemental composition	Provider: Arizona State University (ASU) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Radio Science	Utilizes the X-band radio telecommunications system to measure the Trojans' mass	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Launch Vehicle (Atlas V)	Launch vehicle and related launch services	Provider: United Launch Alliance Lead Center: Kennedy Space Center (KSC) Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

LUCY

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The pandemic continues to limit face-to-face interaction or access to facilities and Lucy resources Then: There is a possibility the Lucy LRD of November 2021 could slip.	The team is executing mitigations for resources needed for Launch and Early Operations (LEO) to enable the team to perform more of those activities through remote work.

Acquisition Strategy

NASA competitively selected the Lucy mission through a competitive Discovery 2014 AO and a down-selection in FY 2017. All major acquisitions are in place. The major elements of the mission and spacecraft are as proposed for the AO. NASA competitively selected the launch vehicle through the NASA Launch Services Program.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft, System Integration and Test, Launch Operations, Mission Operations	Lockheed Martin	Denver, CO
PI, Co-Is, Science Team, Science Operations, Payload Management	SwRI	Boulder, CO
Launch Vehicle	United Launch Alliance	Centennial, CO
L'TES spectrometer instrument	ASU	Tempe, AZ
L'LORRI Infrared spectrometer	APL	Laurel, MD

LUCY

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Sep 2018	PDR	Successful	CDR
Performance	SRB	Oct 2019	CDR	Successful	SIR
Performance	SRB	Jul 2020	SIR	Successful	ORR
Performance	SRB	Aug 2021	ORR	TBD	None

PSYCHE

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	143.7	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	143.7
Development/Implementation	122.8	214.0	169.6	**139.7**	0.0	0.0	0.0	0.0	0.0	646.1
Operations/Close-out	0.0	0.0	0.0	**0.0**	28.7	29.0	32.0	32.0	49.1	170.8
2021 MPAR LCC Estimate	**266.5**	**214.0**	**169.6**	**139.7**	**28.7**	**29.0**	**32.0**	**32.0**	**49.1**	**960.6**
Total Budget	**266.5**	**214.0**	**169.6**	**139.7**	**28.7**	**29.0**	**32.0**	**32.0**	**49.1**	**960.6**
Change from FY 2021				**-29.9**						
Percentage change from FY 2021				**-17.6%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Assembly of the Psyche spacecraft chassis at the Maxar facilities in Palo Alto, CA. The team powered on the Psyche spacecraft for the first time in the factory and began reading telemetry.

PROJECT PURPOSE

The Psyche mission will explore one of the most intriguing targets in the main asteroid belt, a giant metal asteroid known as 16 Psyche. This asteroid measures approximately 140 miles in diameter, and unlike most other asteroids that are rocky or icy bodies, is likely comprised mostly of metallic iron and nickel, similar to Earth's core. Scientists theorize that Psyche may be the exposed core of an early planet that could have been as large as Mars but lost its rocky outer layers due to a number of violent collisions billions of years ago. The mission will help scientists understand how planets and other bodies separated into their layers, including cores, mantles, and crusts, early in their histories.

PSYCHE

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

PROJECT PARAMETERS

NASA plans to launch the mission in August 2022 for arrival at 16 Psyche in January 2026, where the spacecraft will spend 21 months in four different orbits. Each orbit will be successively closer to the asteroid to study its shape and magnetic field, topography and spectral characteristics, gravitational field, and elemental compositions. Each orbit provides knowledge and constraints needed to guide one or more future orbits, and operators have ample time to update the models, plans, and sequences. Psyche's instrument payload includes a multispectral imager, a gamma ray and neutron spectrometer, and a magnetometer. Psyche will use the X-band radio telecommunications system to measure 16 Psyche's gravity field. The mission will aid in our understanding of iron cores and the formation of planets. It will provide insight into terrestrial planets, including Earth, by directly examining what scientists theorized was once the interior of a differentiated body. In addition, it will allow us to explore a world not made of rock or ice, but of metal. Psyche will also carry the flight terminal for the Deep Space Optical Communications (DSOC) technology demonstration, a project funded by the Space Technology Mission Directorate (STMD) and the Human Exploration and Operations Mission Directorate (HEOMD) to help mature the use of lasers to communicate with spacecraft beyond low-Earth orbit.

NASA selected the Psyche mission in December 2016 from the Discovery Program's 2014 Announcement of Opportunity (AO).

ACHIEVEMENTS IN FY 2020

Psyche completed its critical design review (CDR) in May 2020. The project continued to make progress in the final design and the fabrication phase (Phase C) through FY 2020.

WORK IN PROGRESS IN FY 2021

Psyche continues final design and fabrication and held its system integration review in December 2020. Psyche successfully passed its Key Decision Point-D (KDP-D) gate review in January and in February began the assembly, integration, and testing phase (Phase D) of the flight hardware, which will continue through FY 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

Psyche will complete its Operations Readiness Review (ORR) in May 2022 and will launch in August 2022.

PSYCHE

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
KDP-C	May 2019	May 2019
CDR	Apr 2020	May 2020
System Integration Review (SIR)	Dec 2020	Dec 2020
KDP-D	Jan 2021	Jan 2021
Operations Readiness Review (ORR)	May 2022	May 2022
Launch	Aug 2022	Aug 2022
Phase E Start	Oct 2022	Oct 2022

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2020	681.9	70%	2021	646.1	-5.3%	Launch Readiness Date (LRD)	Aug 2022	Aug 2022	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

The reduction in the Development cost estimate was mainly due to the selection of the SpaceX Falcon Heavy as the launch vehicle for the mission.

PSYCHE

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**681.9**	**646.1**	**-35.8**
Aircraft/Spacecraft	199.9	266.3	+66.4
Payloads	49.6	71.2	+21.6
Systems I&T	19.2	19.6	+0.4
Launch Vehicle	154.3	112.7	-41.6
Ground Systems	16.1	18.1	+2.0
Science/Technology	9.3	9.1	-0.2
Other Direct Project Costs	233.5	149.1	-84.4

Project Management & Commitments

The Principal Investigator is from Arizona State University (ASU) and leads the management of the mission. The Jet Propulsion Laboratory (JPL) serves as the development center for the Psyche mission and provides systems engineering; mission assurance; spacecraft design, build, and test; mission and science operations; navigation; and ground data systems.

Element	Description	Provider Details	Change from Baseline
Solar Electric Propulsion Chassis	Spacecraft bus and propulsion system	Provider: Maxar Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Psyche Multispectral Imager	Provides high-resolution images using filters to discriminate between 16 Psyche's metallic and silicate constituents	Provider: ASU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Magnetometer	Detects and measures the remnant magnetic field of 16 Psyche	Provider: University of California, Los Angeles (UCLA) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	Removed from the mission

PSYCHE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Magnetometer	Detects and measures the remnant magnetic field of 16 Psyche	Provider: Technical University of Denmark (DTU) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	Yes, replacement magnetometer
Gamma Ray and Neutron Spectrometer	Detects, measures, and maps 16 Psyche's elemental composition	Provider: APL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Gravity Science	Utilizes the X-band radio telecommunications system to measure 16 Psyche's gravity field	Provider: Massachusetts Institute of Technology (MIT) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Launch Vehicle	Launch vehicle and launch services	Provider: Space Exploration Technologies Corp. (SpaceX) Lead Center: Kennedy Space Center (KSC) Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Deep Space Optical Communications (DSOC)	Demonstrates DSOC technology's capabilities	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): NASA HEOMD/STMD	N/A

Project Risks

Risk Statement	Mitigation
If: The COVID-19 pandemic places additional restrictions on onsite work at JPL and partnering organizations, Then: Project could incur additional cost.	Monitor impacts due to COVID-19 pandemic and release additional project reserves as necessary to mitigate increased costs.

PSYCHE

Formulation	Development	Operations

Acquisition Strategy

NASA selected the Psyche mission through a competitive Discovery 2014 AO and a down selection in FY 2017. All major acquisitions are in place. The major elements of the mission and spacecraft are as proposed for the AO. NASA competitively selected the launch vehicle through the NASA Launch Services program.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft	Maxar	Palo Alto, CA
PI, Co-Is, Imager, Science Data Center	ASU	Tempe, AZ
Launch Vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Mar 2019	PDR	Successful	CDR
Performance	SRB	May 2020	CDR	Successful	SIR
Performance	SRB	Dec 2020	SIR	Successful	ORR
Performance	SRB	May 2022	ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Janus	0.0	23.7	**15.3**	1.2	0.6	0.6	1.1
Venus Technology	0.0	4.9	**7.9**	8.9	8.2	1.5	0.0
InSight	13.6	14.9	**8.8**	8.8	9.0	9.0	9.0
Strofio	1.3	1.3	**1.0**	0.9	1.0	1.8	1.2
International Mission Contributions (IMC)	9.4	12.9	**16.6**	20.1	19.2	38.1	69.1
Planetary Management	11.1	22.0	**17.8**	24.0	24.1	24.1	18.7
Discovery Future	20.2	29.8	**53.7**	103.5	179.9	383.6	562.1
Discovery Research	6.9	8.4	**9.5**	9.7	10.0	11.5	12.5
Planetary SmallSats	15.6	7.9	**9.3**	0.9	0.1	0.0	0.0
Mars-moon Exploration with GAmma Rays an	8.1	12.2	**7.9**	2.8	2.6	2.8	3.2
Total Budget	**86.1**	**138.1**	**147.8**	**180.8**	**254.6**	**472.9**	**676.8**
Change from FY 2021			**9.7**				
Percentage change from FY 2021			**7.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

BepiColombo images acquired of Venus during close approach on October 15, 2020. Credit: ESA/BepiColombo/MTM.

Discovery Other Missions and Data Analysis funds research and analysis; management activities; operations of active missions; small projects and international collaborations; and funding for future mission selections.

Mission Planning and Other Projects

JANUS

Janus is a planned dual space probe that will visit two binary asteroids, (175706) 1996 FG3 and (35107) 1991 VH, to study the formation of small "rubble pile" asteroids. The mission will launch in

OTHER MISSIONS AND DATA ANALYSIS

August 2022 as a secondary payload with the Psyche spacecraft and arrive at the two binary asteroids in 2026. The intention is to perform a flyby to collect data in infrared and visible light. It will be the world's first flyby and close-up observation system of a binary asteroid pair.

Recent Achievements

The Janus mission conducted its Preliminary Design Review (PDR) in July 2020 and passed its Key Decision Point-C (KDP-C) review in September 2020 to enter its final design and fabrication phase (Phase C).

VENUS TECHNOLOGY

The surface of Venus is an extreme environment with high temperatures and an acidic atmosphere that presents unique challenges to robotic missions. Therefore, the Venus Technology project focuses on developing and advancing technologies that future missions will use to explore Venus and other worlds. Some developments currently being studied in Venus Technology include: the Hot Operating Temperature Technology (HOTTech) activity which supports development of technologies for high-temperature environments such as Venus, Mercury, and the deep atmospheres of the gas giant planets; the Glenn Extreme Environment Rig (GEER) which is a pressure vessel capable of simulating the temperature, pressure and atmospheric gas mix of many extreme environments in the Solar System and beyond; and the Long-Lived In-Situ Solar System Explorer (LLISSE) which is an exploration module designed to support scientific observations in extreme environments.

Recent Achievements

HOTTech recently demonstrated low-light intensity, high-temperature solar cells that could power missions to the surface of Venus, as well as diamond and silicon-carbide based semiconductors that can operate over 1,000 degrees Celsius temperature spans. GEER is currently involved in water vapor studies relevant to interpreting data for NASA's Juno mission to Jupiter and developing chemical systems to improve the ability to recreate the Venus atmosphere. The LLISSE team successfully developed part of a new communications system as well as new batteries for future Venus missions' operations.

INTERNATIONAL MISSION CONTRIBUTIONS (IMC)

There are more scientifically interesting destinations across the solar system than any one country's program can quickly undertake. NASA works closely with other space agencies to find opportunities to participate in each other's missions. These opportunities complement NASA-led planetary missions and address additional Decadal Survey priorities when appropriate. Under the International Mission Contributions, NASA funds instruments and scientific investigators and will provide navigation and data relay services in exchange for participation. International missions include the Japanese Space Agency's Hayabusa2 and Akatsuki (Venus Climate Orbiter) missions.

Recent Achievements

The Akatsuki mission is in orbit around Venus and will continue to investigate the planet for at least the next four years. Hayabusa2 arrived at the Ryugu asteroid in June 2018, successfully deployed Japanese and European rovers in 2019, touched down, and collected samples for return to Earth. The spacecraft journeyed back to Earth and landed in December 2020 in Australia. NASA deployed two aircraft to support the Hayabusa2 sample return capsule's reentry to aid in locating its landing area and to obtain data

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on capsule heating in the atmosphere useful to planning future entry, descent, and landing systems on Earth and other worlds. Sample analysis is just beginning and will involve NASA scientists. NASA is currently collaborating with ESA on a potential Venus Mission Concept (EnVision) as part of ESA's M5 competition (selection June 2021) as well as continuing to study a Venus flagship mission concept (Venera-D) with the Russian Space Research Institute (IKI)/Roscosmos.

PLANETARY MANAGEMENT

The Planetary Missions Program Office (PMPO) at Marshall Space Flight Center manages all Planetary Science flight projects that are not part of the Mars Exploration Program, including the competed Discovery and New Frontiers missions, the Jupiter Icy moons Explorer (JUICE), the Double Asteroid Redirection Test (DART), Europa Clipper, the PI-led CubeSats, and SmallSat missions. The PMPO includes support for the day-to-day efforts of the mission managers and business office, as well as standing and independent review boards and external technical support as needed for the projects. It also funds the Science Office for Mission Assessments at Langley Research Center to support the mission selection process, including the development of Announcements of Opportunity (AO) and the formation and operations of independent review panels to evaluate mission proposals. The budget also includes other management activities at Headquarters.

DISCOVERY FUTURE

Discovery Future funds new missions selected through the AO process, specific technology investments to enable future missions, and small missions of opportunity.

Recent Achievements

NASA selected missions from the 2019 Discovery AO to develop concept study reports in FY 2020 and received the reports in November 2020. NASA is currently evaluating the concept study reports and will down select up to two missions to proceed into formulation in FY 2021.

NASA plans to release the next Discovery AO in 2023 with mission selection planned in 2025.

DISCOVERY RESEARCH

Discovery Research funds analysis of archived data from Discovery missions and supports participating scientists for the InSight mission. Discovery Research gives the research community access to samples and data and allows research to continue for many years after mission completion. NASA solicits planetary research proposals from the U.S. planetary science community and evaluates them for selection through competitive peer review. Discovery Research also funds the analysis of samples returned to the Earth by the Stardust and Genesis missions as well as the development of new analysis techniques for samples returned by future missions.

The Discovery Data Analysis Program element (DDAP) has provided support for continued analysis of spacecraft data from the Near Earth Asteroid Rendezvous (NEAR)-Shoemaker, Stardust, Genesis, Deep Impact, Mercury Surface, Space Environment, Geochemistry and Ranging (MESSENGER), Dawn, and Kepler missions. The supported projects conduct new scientific inquiries and regularly obtain new and unexpected scientific results, using data sets to go beyond the work conducted by the original mission

OTHER MISSIONS AND DATA ANALYSIS

teams. The Rosetta Data Analysis Program element (RDAP) has provided additional support targeted for analysis of data from Rosetta, an ESA-led mission with NASA participation, to explore and land on Comet 67P/Churyumov-Gerasimenko.

Recent Achievements

Data from NASA's MESSENGER mission yielded surprising results, especially through expanded use of the topographic measurements from its laser altimeter. Detailed studies of Mercury's cratered surface, including using altimeter data to identify hidden basins, showed that half of Mercury's crater record is missing with the oldest craters obliterated by later events; quite different from the Earth's moon, which has some craters nearly as old as the moon itself. This research also supports the existence of only one population of impactors, in contrast to the theory of at least two populations including a late, heavy bombardment. Another study showed that when one uses topography to correct the brightness measurements from MESSENGER's Wide-Angle Camera, scientists can effectively map volatile organic compounds in and around Mercury's craters. This work constrains the thermal conditions, and hence identity, of these low-reflectance volatiles in Mercury's polar deposits and will contribute to understanding their origin and processing on the surface. This work will also inform the observational strategy for the BepiColombo mission that will enter Mercury's orbit in 2025. Finally, another study based on MESSENGER data improved our understanding of solar wind-magnetosphere-exosphere coupling at Mercury by showing that "flux ropes" dominate flux transfer between Mercury's dayside and nightside magnetosphere.

Images from the Extrasolar Planet Observation and Characterization (EPOCh) and Deep Impact eXtended Investigation (DIXI) (EPOXI) mission to Comet 103P/Hartley 2 showed how heterogeneous the comet's surface is regarding H2O and CO2. As a hyperactive comet, this study was able to characterize plumes of material erupting from the surface and map these to variations in surface composition.

PLANETARY SMALLSATS

NASA established the Small Innovative Missions for Planetary Exploration (SIMPLEx) program element to develop and operate targeted science investigations that exploit the unique attributes of small spacecraft to conduct compelling science. These small satellite missions take advantage of available launch capacity on larger missions to reduce the overall costs of launching multiple missions, provide a means to mature technologies for future missions, and serve as additional opportunities to provide flight experience to the workforce.

In June 2019, NASA announced the selection of three small satellite missions under the Small Innovative Missions for Planetary Exploration (SIMPLEx) Program: Janus, Escape and Plasma Acceleration and Dynamics Explorers (EscaPADE), and Lunar Trailblazer.

NASA plans to launch Lunar Trailblazer with the Interstellar Mapping and Acceleration Probe Heliophysics mission in 2024 and will directly detect and map water on the surface of the Moon to determine how its form, abundance, and location relate to geology. NASA transferred this mission from the Discovery Program to the Lunar Discovery and Exploration Program.

EscaPADE is a twin-spacecraft mission that will orbit Mars to study how its atmosphere responds to the constant outflow of the solar wind. NASA transferred management of this mission to the Heliophysics Division Explorers program. Access to space for EscaPADE is to be determined.

Other Missions and Data Analysis

Recent Achievements

Lunar Trailblazer passed its KDP-C review in November 2020 to enter its final design and fabrication phase (Phase C).

MEGANE

The Mars-moon Exploration with Gamma rays and Neutrons (MEGANE, also Japanese for "eyeglasses") instrument is a gamma-ray and neutron spectrometer currently in development by the Johns Hopkins University Applied Physics Laboratory, as a contribution to Japan Aerospace Exploration Agency's (JAXA) Martian Moons eXploration (MMX) mission. Planned for launch in 2024, MMX will operate near the Martian moons Phobos and Deimos for approximately three years and return a sample from Phobos to Earth in 2029. MEGANE will measure the bulk composition of the near-surface materials on Phobos for a set of eight elements to constrain theories for the origin of the moons. It will also map the near-surface materials on Phobos to enable the study of surface processes and support MMX sample site selection.

Recent Achievements

MEGANE conducted its Preliminary Design Review in March 2020 and passed its Key Decision Point-C (KDP-C) review in May 2020 to enter its final design and fabrication phase (Phase C).

Operating Missions

InSight

InSight is a robotic lander investigating the deep interior of Mars--including its crust, core, and tectonic processes--to improve our understanding of the formation and evolution of the terrestrial planets. The mission launched on May 5, 2018 and landed on the surface of Mars at Elysium Planitia on November 26, 2018. The InSight lander is equipped with instruments to conduct Mars' first "physical" in its 4.5 billion year history; measuring its pulse by recording its seismic activity, taking its temperature by measuring the flow of heat from its interior, and testing its reflexes by studying how the planet wobbles due to the gravitational pull of its moons and the Sun. The science payload has two major instruments: The Seismic Experiment for Interior Structure (SEIS) and the Heat Flow and Physical Properties Package (HP3). SEIS is making precise measurements of marsquakes to determine the planet’s structure and infer its history. HP3 is a self-penetrating heat flow probe designed to burrow up to five meters below the surface to measure how much heat is coming from Mars’ interior. In addition, the Rotation and Interior Structure Experiment (RISE) uses the spacecraft's communication system to measure planetary rotation precisely, while the surface of the lander hosts other instruments to measure atmospheric pressure, wind speed, and magnetic field intensity.

The InSight prime mission ends in November 2021, and will transition to extended operations, as approved via the Senior Review process.

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Recent Achievements

InSight is different from previous Mars missions in that its science is, by its very nature, slow to reveal itself. Scientists expect to need a full Mars year to acquire enough data to be able to answer the key questions that engineers designed InSight to address. However, InSight has produced some important early results. As of October 2020, SEIS has detected 486 events, approximately 52 of which are Marsquakes large enough to be useful in studying Mars's interior. The team's preliminary estimates of the global seismic activity of Mars appear to be close to, and somewhat higher than, pre-landing predictions for quakes smaller than approximately magnitude 4.0. InSight detected fewer larger quakes than expected. Importantly, the InSight project has been able to locate the epicenters of three Marsquakes. All are near Cerberus Fossae, a region known from orbital imaging to have geologically recent (a few million years or less) volcanic and tectonic activity. To date, InSight has confirmed predictions of the level of Martian seismic activity, approximately 1,000 times lower than Earth. It obtained detailed analysis of landing site geology, inferred geologic history, and implications for future seismic measurements on Mars. SEIS has been able to measure the thickness of the crust for the first time, yielding a thickness of either approximately 25 km (2-layer model) or approximately 40 km (3-layer model). Scientists expect additional seismic data to allow discrimination between these values. In addition, InSight obtained the first observations of Mars magnetic field at surface, approximately 10 times larger than seen from orbit.

InSight's pressure and wind sensors are providing surprising new observations of atmospheric dynamics. InSight's instruments have detected thousands of convective vortices (dust devils), even though there has not been a single visual sighting with the cameras. Researchers are using this data, along with concurrent data from SEIS, to determine the stiffness of the Martian regolith. InSight observed weather phenomena with unprecedented resolution and used hundreds of dust devils to study boundary layer turbulence and constrain subsurface ground structure. InSight has detected thousands of atmospheric vortices with the pressure sensor, Temperature and Wind for InSight (TWINS) and SEIS, but has not seen a single dust devil with its cameras despite thousands of images.

STROFIO

STROFIO (Start from a ROtating FIeld mass spectrOmeter) is a unique mass spectrometer that is part of the suite of instruments flown onboard the joint European Space Agency (ESA) and JAXA BepiColombo spacecraft, launched on October 20, 2018 and planned to enter Mercury orbit and begin observations in 2025. STROFIO will study and characterize the chemical composition and dynamics of Mercury's thin atmosphere (exosphere). Eight NASA-funded scientists serve as interdisciplinary scientists, guest investigators, or instrument co-investigators on the BepiColombo Science Team. These investigators collaborate with the BepiColombo team on a variety of projects that will improve understanding of both Mercury and Venus, as well their surrounding space environments.

Recent Achievements

The BepiColombo mission is currently in its cruise phase and recently completed two successful 'flyby' gravity-assist maneuvers, one of Earth (April 10, 2020) and one of Venus (October 15, 2020). A second Venus flyby will take place in August 2021 before a series of six Mercury flybys and then Mercury orbit insertion in December 2025. Optimization of the STROFIO sensors continues while the spacecraft travels to Mercury. One of the NASA-funded guest investigators is leading a Venus-focused project. The guest investigator combines observations from BepiColombo's Probing of Hermean Exosphere by Ultraviolet

OTHER MISSIONS AND DATA ANALYSIS

Spectroscopy spectrometer taken during the first, and upcoming, Venus flybys with telescopic observations from Earth to investigate the atmosphere and climate of Venus.

NEW FRONTIERS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Dragonfly	41.0	86.0	**201.1**	370.3	411.4	332.3	257.2
Other Missions and Data Analysis	95.8	74.0	**70.6**	76.5	89.0	162.6	115.1
Total Budget	**136.8**	**160.0**	**271.7**	**446.8**	**500.4**	**494.9**	**372.3**
Change from FY 2021			**111.7**				
Percentage change from FY 2021			**69.8%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

OSIRIS-REx Touch-And-Go (TAG) sample collection event on October 20, 2020 the moment the spacecraft touched down on asteroid Bennu's surface. The sampling event brought the spacecraft all the way down to sample site Nightingale, and the team on Earth received confirmation of successful touchdown at 6:08 pm EDT. Credit: NASA/Goddard/University of Arizona.

The New Frontiers program explores our solar system with medium-to-large-class spacecraft missions. Within the New Frontiers program, possible mission destinations and the science goals for each competitive opportunity are limited to specific science targets. These science objectives are announced for the competition and aligned with the scientific goals of the Planetary Science Decadal Survey.

The program currently includes one mission in formulation, Dragonfly, and three missions in operations: New Horizons; Juno; and Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx).

The New Horizons mission is helping us understand worlds at the edge of the solar system. Having completed the first-ever reconnaissance of Pluto and its moons, the spacecraft recently conducted a flyby of a newly discovered body, Arrokoth, in the Kuiper Belt.

Juno is a mission to Jupiter that is significantly improving our understanding of the origin and evolution of the gas giant planet. Juno is completing the first ever pole-to-pole exploration of the largest planet in our Solar System, revealing important insights into the formation of planets and the origins of our solar system.

NEW FRONTIERS

After its successful sample collection effort in October 2020, OSIRIS-REx remains on plan to return the first NASA sample recovery of a pristine, carbon-rich asteroid (Bennu) to study and analyze on Earth. This mission will increase our understanding of the role that primitive bodies, such as Bennu, played in planet formation and the origin of life. In addition to its science objectives, OSIRIS-REx will improve our knowledge of how to operate human and robotic missions safely near a large Near-Earth Object (NEO). This knowledge will provide significant insight for potential planetary defense strategies.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The FY 2022 budget request supports a launch readiness date of no earlier than June 2027 for Dragonfly. The New Frontiers 5 Announcement of Opportunity will be delayed by two years to the first quarter of FY 2025 due to other missions being in peak development and COVID-related challenges in the broader Planetary Science Division portfolio.

ACHIEVEMENTS IN FY 2020

In January 2019, the New Horizons mission successfully completed a flyby of a small Kuiper Belt object designated 2014 MU69 (now known as Arrokoth). In FY 2020, the team downloaded the data and the analysis began. New Horizons has conducted remote observations of several additional Kuiper Belt objects and together with the studies of Arrokoth, is giving us new insight into the building blocks of the solar system.

The Juno mission completed additional polar orbits of Jupiter in FY 2020 for a current total of 29 science passes since arriving at Jupiter. Juno has now completed more than three-quarters of its prime mission. Juno has made significant progress in understanding the complex structure of the southern pole of Jupiter and has nearly completed the 32-pass grid necessary to characterize the interior magnetic structure of Jupiter. Juno's measurements have shown that observed surface structures penetrate significantly deeper in the atmosphere than previously thought.

In FY 2020, NASA selected its final two sample collection sites for OSIRIS-REx (a primary called Nightingale, located high in a crater in Bennu's northern hemisphere and a backup called Osprey) and completed the reconnaissance overflights to confirm the safety and suitability of the sites. OSIRIS-REx conducted a series of progressively closer rehearsals in preparation for sample acquisition. In September 2020, Bennu moved far enough away from the Sun in its orbit to ensure the sample would not be compromised by overheating after sample acquisition.

The Dragonfly project continued in its preliminary design and technology completion phase (Phase B) throughout FY 2020 and successfully completed an internal system requirements review in August 2020. The project also completed key mobility motor/rotor testing in the NASA Langley Research Center (LaRC) wind tunnel and parachute dynamics testing in the LaRC Vertical Spin Tunnel.

WORK IN PROGRESS IN FY 2021

The New Horizons mission will continue to downlink data and collect light curve measurements of distant Kuiper Belt objects. The mission is also characterizing the environment of this distant portion of the solar system.

NEW FRONTIERS

Juno will complete the 32 planned science passes that constitute a full spacing grid of magnetic field measurements. These measurements will allow Juno to characterize the interior magnetic structure of Jupiter and enable a better understanding of the density and composition structure. Juno will continue science operations, including atmospheric observations of the Northern pole, which is coming into better view in orbit around Jupiter in FY 2021. The Juno mission will complete its prime science mission and deliver a Senior Review proposal for its extended mission phase.

In October 2020, the OSIRIS-REx mission successfully completed its rendezvous with Bennu and prepared to gather the sample for return to Earth. OSIRIS-REx proceeded with the Touch-and-Go sample acquisition, confirmed acquisition of the sample, and stowed the sample in the Sample Return Capsule. OSIRIS-REx will remain near Bennu until the orbital alignment between Bennu and the Earth is favorable for beginning the cruise back to Earth.

Dragonfly will continue its preliminary design, technology completion, and risk reduction activities throughout FY 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The New Horizons mission will continue making science measurements and prepare a Senior Review proposal for its second mission extension phase.

If approved, the Juno mission will begin an extended mission, which may continue to study not only Jupiter, but also some of its important moons.

OSIRIS-REx will continue its cruise back to Earth and will arrive in in 2023.

Dragonfly will continue its preliminary design and technology completion activities in preparation for Key Decision Point-C (KDP-C).

PROGRAM SCHEDULE

Date	Significant Event
Q1 FY 2025	Release of New Frontiers 5 Announcement of Opportunity (AO) solicitation
Q3 2027	Select fifth New Frontiers mission

PROGRAM MANAGEMENT & PLANNED CADENCE

The New Frontiers Program is a multiple-project program, with responsibility for implementation assigned to the Planetary Missions Program Office, located at the Marshall Space Flight Center (MSFC). The New Frontiers Program AO cadence is approximately every five to six years.

ACQUISITION STRATEGY

NASA competitively selects New Frontiers missions, releasing AOs when available funding allows.

NEW FRONTIERS

INDEPENDENT REVIEWS

NASA will schedule the New Frontier's next Program Implementation Review (PIR) when recommended by the primary stakeholders.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Implementation Review (PIR)	MSFC	2016	PIR	Successful	TBD

DRAGONFLY

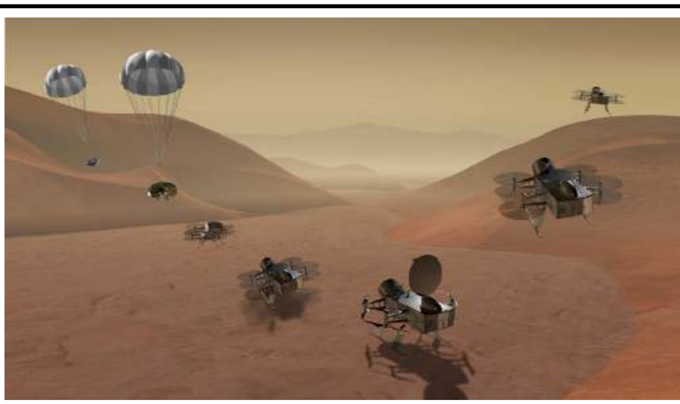
Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**41.0**	**86.0**	**201.1**	**370.3**	**411.4**	**332.3**	**257.2**
Change from FY 2021			**115.1**				
Percentage change from FY 2021			**133.8%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Dragonfly mission concept illustration on the surface of Titan.

PROJECT PURPOSE

Dragonfly is a mission to study Titan, the largest moon of Saturn, using a rotorcraft carrying an advanced set of instruments to characterize the surface, atmosphere, and interior from different locations. Titan is a unique world that potentially harbors an interior ocean. Its surface, layered with organic snow on an icy crust possibly shaped by wind and fluvial processes, is important to study because it may be like the early Earth, where carbon and nitrogen interacted with water and energy to form life. Through measurements at diverse locations across Titan, Dragonfly will characterize the habitability of Titan's environment; investigate how far pre-biotic chemistry has progressed; and search for chemical signatures indicative of water-based and/or hydrocarbon-based life.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The FY 2022 budget request supports a launch readiness date of no earlier than June 2027. The date was changed due to COVID 19 impacts and other priorities within the Planetary Science Division and launching later will not affect Dragonfly's science return or capabilities once at Titan.

DRAGONFLY

Formulation	Development	Operations

PROJECT PRELIMINARY PARAMETERS

Dragonfly will launch no earlier than 2027 and upon landing on Titan, will fly to dozens of locations looking for prebiotic chemical processes common on both Titan and Earth. Dragonfly, which has eight rotors and flies like a large drone, marks the first time NASA will fly a multi-rotor vehicle for science on another body. It will take advantage of Titan's dense atmosphere (four times denser than Earth's) and low gravity (one seventh that on Earth) to become the first vehicle ever to fly its entire science payload to multiple sites for repeatable and targeted access to surface materials. It is a scientifically diverse mission that includes an assortment of instruments: the Dragonfly Camera Suite (DragonCam) is a set of microscopic and panoramic cameras to image Titan's terrain and scout for scientifically interesting landing sites; Dragonfly Gamma-Ray and Neutron Spectrometer (DraGNS) consists of a deuterium-tritium Pulsed Neutron Generator and a set of a gamma-ray and neutron spectrometers to identify the surface composition under the lander; the Dragonfly Mass Spectrometer (DraMS) is an advanced mass spectrometer to identify chemical components in surface and atmospheric samples, especially those relevant to biological processes; and the Dragonfly Geophysics and Meteorology Package (DraGMet) is a suite of meteorological sensors including a seismometer.

Titan is an analog to the very early Earth and can provide clues to how life may have begun on our planet. During its nearly 3-year baseline mission, Dragonfly will explore diverse environments from organic dunes to the floor of an impact crater where liquid water and complex organic materials, key to life, once existed together, possibly for tens of thousands of years. Its instruments will study how far prebiotic chemistry has progressed. They also will investigate the moon's atmospheric and surface properties and its potential subsurface ocean and liquid reservoirs. Instruments will search for chemical evidence of past or extant life. A multi-mission radioisotope thermoelectric generator will power the Dragonfly rotorcraft.

ACHIEVEMENTS IN FY 2020

The Dragonfly project continued to make progress in its preliminary design and technology completion phase (Phase B) throughout FY 2020, which culminated in the successful completion of an internal system requirements review in August 2020. In addition, the project completed key mobility motor/rotor testing in the Langley Research Center wind tunnel as well as parachute dynamics testing in the LaRC Vertical Spin Tunnel.

WORK IN PROGRESS IN FY 2021

Dragonfly will continue preliminary design, technology completion, and risk reduction activities throughout FY 2021, which will include finalizing major science requirements, completing the required environmental assessment process, and continuing work on interface definitions.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

Dragonfly will complete subsystem and instrument level Preliminary Design Reviews (PDRs) in preparation for the mission level PDR, expected to occur no earlier than late FY 2022/early FY 2023.

DRAGONFLY

Formulation	Development	Operations

ESTIMATED PROJECT SCHEDULE

Dragonfly's project schedule is currently under review and based upon a June 2027 launch readiness date.

Milestone	Formulation Authorization Document	FY 2022 PB Request
Preliminary Design Review	N/A	NET Aug 2022
Key Decision Point-C (KDP-C)	N/A	NET Oct 2022
KDP-D	N/A	TBD
KDP-E	N/A	TBD
Launch	N/A	Jun 2027

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows the PDR.

KDP-B Date	Estimated Life Cycle Cost Range ($)	Key Milestone	Key Milestone Estimated Date Range
Jun 2019	$2.1B - 2.5B	Launch	Jun 2027

Project Management & Commitments

The Principal Investigator is from the Johns Hopkins University Applied Physics Laboratory (APL). APL has project management responsibility for Dragonfly.

Element	Description	Provider Details	Change from Formulation Agreement
Dragonfly Mass Spectrometer	Provides detailed analysis of organic chemistry	Provider: Goddard Space Flight Center (GSFC) Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

DRAGONFLY

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Dragonfly Gamma-Ray and Neutron Spectrometer	Determines bulk near-surface composition and layering	Provider: APL Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Dragonfly Geophysics and Meteorology Package	Measures atmospheric conditions, seismicity, and surface/subsurface properties	Provider: APL Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Dragonfly Camera Suite	Documents landforms and processes, provides context for samples, and performs aerial imaging to scout landing sites	Provider: Malin Space Science Systems Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Drill for Acquisition of Complex Organics Sampling System	Provides pneumatic transfer system and sample acquisition drill	Provider: Honeybee Robotics Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Multi-Mission Radioisotope Thermoelectric Generator	Provides power to the Dragonfly lander	Provider: Department of Energy Lead Center: GRC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Cruise Stage	Propulsion stage to get Dragonfly to Titan	Provider: Lockheed Martin Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Entry, Descent, and Landing Assembly	Includes aeroshell, parachutes, and support equipment	Provider: Lockheed Martin Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Dragonfly Lander	Flight system to carry and support the science instruments	Provider: APL Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

DRAGONFLY

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Dragonfly lander mass exceeds the 825 kilogram not to exceed (NTE) value, Then: Additional design modifications will be required to meet the Dragonfly Level 2 requirements.	The lander integrated mechanical-thermal-mobility structure continues to evolve and the project is continuing work on final a preliminary design. The project has established an Engineering Advisory Board to help evaluate this design in order to determine a minimum mass point. Meanwhile, the landing loads, lander finite-element model, and mobility performance models are being refined. A lander system-wide survey of mass-reduction opportunities is also being conducted, along with a refinement of all allocated contingencies

Acquisition Strategy

NASA competitively selected the mission through the New Frontiers 4 Announcement of Opportunity (AO) and the final down selection was in June 2019. The major elements of the mission and spacecraft are as proposed to the AO.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
PI, Science Co-Is, Mission Management, Lander Development, DraGMet, DraGNS, System I&T, Science Operations, Mission Operations	APL	Laurel, MD
Cruise Stage, Entry, Descent, and Landing (EDL) Assembly, I&T Support	Lockheed Martin	Denver, CO

DRAGONFLY

Formulation	Development	Operations

INDEPENDENT REVIEWS

All dates are preliminary.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Aug 2022	PDR	TBD	Critical Design Review (CDR)
Performance	SRB	TBD	CDR	TBD	System Integration Review (SIR)
Performance	SRB	TBD	SIR	TBD	Operations Readiness Review (ORR)
Performance	SRB	TBD	ORR	TBD	Launch Readiness Review (LRR)
Performance	SRB	TBD	LRR	TBD	N/A

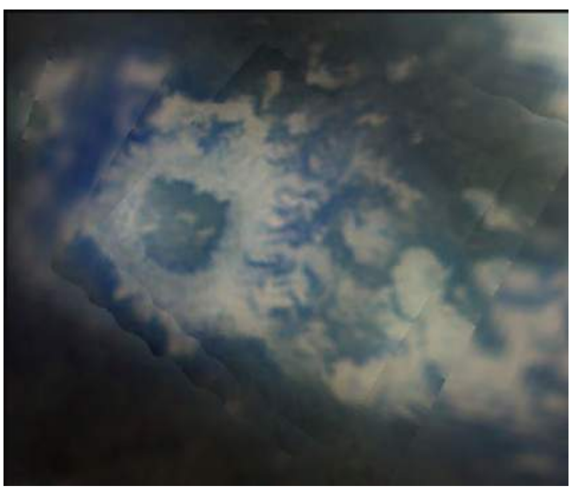
OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
New Frontiers Future Missions	1.7	4.3	**1.5**	2.4	11.9	90.8	60.3
New Frontiers Research	5.9	6.9	**10.4**	10.5	10.5	9.3	9.3
Origins Spectral Interpretation Resource	37.1	19.5	**17.2**	26.1	29.1	25.0	20.0
New Horizons	17.3	12.5	**9.5**	12.5	12.5	12.5	12.5
Juno	33.8	30.9	**32.0**	25.0	25.0	25.0	13.0
Total Budget	**95.8**	**74.0**	**70.6**	**76.5**	**89.0**	**162.6**	**115.1**
Change from FY 2021			**-3.4**				
Percentage change from FY 2021			**-4.6%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Scientists have used Cassini data to provide the best analysis to date of the composition of Selk Crater on Titan, which indicates it is composed purely of organic material, bolstering the selection of the crater as the destination for the Dragonfly mission. Scientists will be able to use Dragonfly's in situ instruments to determine what types of organic material are present, and if they could provide one of the four ingredients needed to support life.

New Frontiers Other Missions and Data Analysis includes support for three operating missions: New Horizons; Juno; and Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx), analysis of data from these missions, and preparation for future missions.

Mission Planning and Other Projects

NEW FRONTIERS FUTURE MISSIONS

New Frontiers Future Missions supports technology development for future missions and provides the funding required for the next announcement of opportunity (AO). The New Frontiers program expects to begin the competition to select the fifth mission in the first quarter of FY 2025.

OTHER MISSIONS AND DATA ANALYSIS

NEW FRONTIERS RESEARCH

New Frontiers Research funds analysis of archived data from New Frontiers missions as well as participating scientists and selected members of the research community, who augment and enhance the science teams of New Frontiers missions. New Frontiers Research provides the research community access to data and samples, enabling research to continue for many years after mission completion. Participating scientists bring new ideas to mission teams and frequently provide a pathway for early career investigators to gain experience with planetary missions. This program supports efforts to maximize science return from each of the missions. NASA solicits planetary research proposals from the U.S. planetary science community and evaluates them for selection through competitive peer review. NASA will select new research in FY 2021 using the New Horizons mission data returned from Pluto and Arrokoth (previously known as 2014 MU69), Juno mission data returned from Jupiter, and OSIRIS-REx mission data returned from the asteroid Bennu.

Recent Achievements

The New Frontiers Data Analysis program element competitively selected and awarded 15 new science investigations. These investigations use data provided by all New Frontiers missions to expand the scientific results generated by the mission science team. Some investigations pursue topics never envisioned by the missions. For example, one investigation is using calibration data acquired by New Horizons during its Jupiter flyby to better understand volcanism on Io, a moon of Jupiter.

Operating Missions

NEW HORIZONS

New Horizons is the first scientific investigation to obtain close observations of Pluto and its moons, Charon, Nix, Hydra, Kerberos, and Styx (scientists discovered the last four moons after the spacecraft's launch in 2006). Scientists aimed to find answers to basic questions about the surface properties, geology, interior makeup, and atmospheres of these bodies, and their relationship to Solar System formation.

New Horizons launched on January 19, 2006. It successfully encountered Pluto on July 14, 2015 and completed downloading all the primary science observations of the Plutonian System in October 2016. The mission is currently in extended operations through September 2022.

Recent Achievements

The mission continues gathering data on the plasma environment of the Kuiper Belt and obtaining light curves of distant Kuiper Belt Objects. As part of its extended mission, researchers downloaded spacecraft data on the Kuiper Belt Object Arrokoth (2014 MU69) and have started publishing the results of their analysis on the origin and structure of this object. Arrokoth is one of the small and primitive icy bodies in the region approximately two billion miles beyond Pluto’s orbit.

Recent findings and research from the New Horizons mission include some evidence that Pluto's many surface colors are attributable to the abundance and particle size of tholins (organic compounds produced when sunlight, cosmic rays, and energetic particles irradiate methane and nitrogen molecules in Pluto's atmosphere). The evidence also showed that Arrokoth (2014 MU69) formed through a gentle, low speed merger of two objects that spiraled towards each other as they orbited one another. New Horizons

OTHER MISSIONS AND DATA ANALYSIS

continues to have a fully functioning instrument suite and will reach 50 Astronomical Units (AU) from Earth in mid-April 2021, which is more than 4.5 billion miles.

JUNO

Juno has transformed our view of Jupiter, the most massive planet in the solar system, through major discoveries about its interior, structure, origin, and evolution. Juno launched on August 5, 2011 and entered Jupiter's orbit on July 4, 2016. Juno's state-of-the-art instruments are gathering information from deep in Jupiter's atmosphere, enabling scientists to understand planetary formation and early evolution of the solar system, and exploration of its interior, rings, radiation environment, and moons Io, Europa, and Ganymede. While Juno's prime mission ends in September of 2021, the mission has recently been approved for extended operations through September of 2025.

Recent Achievements

Juno is currently in a 53-day orbit and has successfully completed 29 science orbits of Jupiter. During its science operations, Juno has been sampling Jupiter's full range of latitudes and longitudes during polar orbits. Juno is capturing details no other mission has captured. For instance, the novel combination of close observation distance, camera sensitivity, and the spin of the Juno spacecraft (two revolutions per minute) enabled the discovery of "shallow lightning" (1.4 and 1.9 bar) at a higher resolution than previously possible (Becker et al. 2020, Nature). Lightning on Earth originates in water-bearing clouds, while clouds made up of ammonia and water produce shallow lightning. Juno also has an onboard camera, JunoCam, that is producing a new view of Jupiter and its moons and providing unique opportunities to engage the next generation of scientists through citizen science, an effort that promotes collaborations between scientists and interested members of the public.

Juno has contributed imaging, gravity, and magnetic field data to a community-wide effort to understand the shrinking of Jupiter's great red spot, which has diminished in width by one third since the time of the Voyager flybys in 1979.

OSIRIS-REX

OSIRIS-REx will be the first U.S. mission to bring a sample from an asteroid back to Earth. The OSIRIS-REx spacecraft traveled to (101955) Bennu, a near-Earth carbonaceous asteroid formerly designated 1999 RQ36, to study the asteroid in detail and bring a sample (at least 60 grams or 2.1 ounces) back to Earth. Analysis of this sample by current and future generations of scientists will yield insight into planet formation and address questions we have not thought of yet. The data collected at Bennu will aid in further understanding asteroids that could collide with Earth. In addition, the mission will measure the Yarkovsky effect on a potentially hazardous asteroid and determine the asteroid properties that contribute to this effect. The Yarkovsky effect is a small force on an asteroid caused by the Sun as the asteroid absorbs sunlight and re-emits that energy into space as heat.

OSIRIS-REx launched on September 8, 2016 and arrived at Bennu on December 3, 2018. The mission globally mapped the surface from distances of less than half a mile to about three miles. The spacecraft cameras and instruments photographed the asteroid and measured its surface topography, composition, and thermal emissions. Radio science provided mass and gravity field maps. This information helped the mission team select the most promising locations to collect a sample of pristine asteroid material.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The OSIRIS-REx spacecraft spent its first year in orbit around Bennu identifying the four best candidate sites for acquisition of a sample to return to Earth in late 2023. Reconnaissance observations of the four sites was completed, and in December 2019 NASA selected its final primary sample collection site Nightingale, and a backup, Osprey. Because of the need to target smaller-than-expected sample sites, the project team used a new method utilizing natural feature tracking, called "bullseye TAG" (Touch-And-Go) sample collection to guide the spacecraft down to the sample site.

On October 20, 2020, the spacecraft successfully descended to the surface of Bennu, contacted the surface, collected a sample, and backed away. To deliver the sample to Earth, OSIRIS-REx has a capsule similar to the one that returned the sample of Comet 81P/Wild on the Stardust spacecraft. Following analysis of the sampling head, NASA determined that adequate material was very likely collected, and the sample was stowed for secure return to earth. The project has scheduled the capsule, with its pristine sample from Bennu, to land at the Utah Test and Training Range on September 24, 2023. NASA will transport the capsule containing the sample to Johnson Space Center (JSC) for processing, analysis, and curation at a dedicated research facility. NASA JSC will make subsamples available for research to selected members of the worldwide science community.

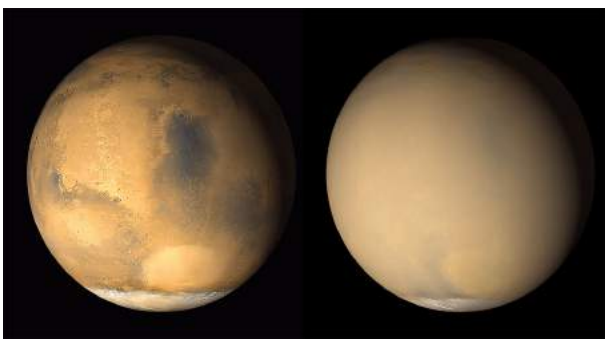
MARS EXPLORATION

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Other Missions and Data Analysis	565.7	334.8	**267.8**	251.9	249.1	228.1	229.8
Total Budget	**565.7**	**334.8**	**267.8**	**251.9**	**249.1**	**228.1**	**229.8**
Change from FY 2021			**-67.0**				
Percentage change from FY 2021			**-20.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



In 2018, Mars orbiters and rovers on the surface measured a global dust storm. This unprecedented combination of measurements is still providing tremendous insight into the effects of dust on the atmosphere. Dust heats and expands the atmosphere and boosts the loss of water into space. The global dust storm blotted out sunlight on the surface and ended the solar powered Opportunity rover mission, which had been operating for over 14 years.

The Mars Exploration Program seeks to understand when Mars may have had habitable conditions for microbial life, whether Mars has supported microbial life in the past or today, and the extent to which Mars could be a habitable world for humans in the future. As the most Earth-like planet in the solar system, Mars has a landmass approximately equivalent to the Earth's, as well as ancient remnants of many of the same geological features, such as riverbeds, river deltas, and volcanoes. Mars also has many of the same "systems" that characterize Earth, such as air, water, ice, and geology that all interact to produce the Martian environment. Mars also has fundamental differences from Earth including the lack of a global magnetic field and chaotic changes in the orientation of its spin axis over tens of millions of years, which have affected its environment.

Individual orbital and landed robotic missions have progressively built on the discoveries of each mission, all collectively guided by four broad, overarching goals for Mars Exploration:

- Determine if life ever arose on Mars;
- Characterize the climate of Mars;
- Characterize the geology of Mars; and,
- Prepare for human exploration.

MARS EXPLORATION

Today, our robotic scientific explorers are paving the way. Together, humans and robots will pioneer Mars and the solar system.

EXPLANATION OF MAJOR CHANGES IN FY 2022

This budget transfers the Mars Sample Return budget from Mars Future to a separate program. It establishes a separate project, Mars Ice Mapper, an international cooperation mission that will study and profile the near-surface (3-15 meters) water ice.

The budget for the Mars Rover 2020 mission incorporates cost growth in the Phase E prime mission operations due to delayed surface operations capability development and COVID-19 inefficiencies. It includes budget for extended operations from 2024-2026.

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FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Mars Ice Mapper	0.0	7.2	**15.0**	40.0	40.0	30.0	30.0
Mars Organic Molecule Analyzer (MOMA)	7.3	5.1	**4.9**	7.3	6.5	3.0	0.0
Mars Rover 2020	353.0	150.0	**95.7**	60.0	60.0	60.0	60.0
ExoMars	1.9	2.2	**2.0**	2.0	2.0	2.0	2.0
Mars Program Management	11.2	11.2	**12.5**	10.9	9.6	13.2	15.3
Mars Future Missions	65.5	23.3	**7.5**	5.8	15.0	13.0	15.0
Mars Mission Operations	5.9	6.7	**6.7**	5.5	5.5	5.5	5.6
Mars Research and Analysis	9.9	14.0	**15.0**	15.7	15.7	15.7	15.7
Mars Technology	3.7	8.5	**3.2**	5.0	6.0	6.0	6.0
2011 Mars Science Lab	47.0	47.5	**45.0**	40.0	30.0	20.0	20.0
Mars Reconnaissance Orbiter 2005 (MRO)	26.9	27.0	**26.0**	25.5	24.5	24.5	25.0
Mars Odyssey 2001	11.7	11.0	**11.0**	11.0	11.0	11.0	11.0
Mars Express	1.1	0.0	**0.3**	0.3	0.3	0.3	0.3
Mars Atmosphere & Volatile EvolutioN	20.5	21.0	**23.0**	23.0	23.0	24.0	24.0
Total Budget	**565.7**	**334.8**	**267.8**	**251.9**	**249.1**	**228.1**	**229.8**
Change from FY 2021			**-67.0**				
Percentage change from FY 2021			**-20.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

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Scientists can use ultraviolet emissions from the nightside of Mars to infer circulation patterns in the middle atmosphere. More than two years of nightglow observations from NASA's MAVEN spacecraft reveal that the middle atmospheric circulation is controlled by Martian season and strongly modified by atmospheric tides. The image shows the strongest peak brightening after sunset due to enhanced downward winds.

Other Missions and Data Analysis includes mission planning and other projects, such as NASA's contribution to the Mars Organic Molecule Analyzer (MOMA) for the European Space Agency (ESA) Exobiology on Mars (ExoMars) 2022 rover, Mars Program Management, Mars Mission Operations, Mars Research and Analysis, Mars Technology, Mars Ice Mapper, Mars Future Missions, and Mars operating projects. The operating projects include Mars Science Laboratory (MSL), Mars Reconnaissance Orbiter 2005 (MRO), Mars Odyssey 2001, Mars Express, Mars Atmosphere and Volatile Evolution (MAVEN), and Mars Rover 2020.

Mission Planning and Other Projects

MARS ORGANIC MOLECULE ANALYZER (MOMA)

The ExoMars Rover mission is the second of the ESA ExoMars missions and will carry the "Rosalind Franklin" rover to the surface of Mars. MOMA is the core astrobiology instrument on the ESA ExoMars Rosalind Franklin rover, and it addresses the top ExoMars science goal of seeking signs of past or present life on Mars. NASA provided the MOMA-Mass Spectrometer (MOMA-MS), a subsystem of MOMA. It is primarily a dual-source mass spectrometer, including laser desorption capability, used to detect a wide-range of organic molecules in Martian samples. Organic structure and distribution can be indicators of past or present life.

Recent Achievements

The NASA-provided MOMA-MS has been completed, delivered, and integrated into the ExoMars rover. Due to technical development issues unrelated to MOMA, ESA has made the decision to move the launch date for the ExoMars rover mission from July 2020 to September 2022.

EXOMARS

The ESA ExoMars program is a series of two missions designed to understand if life ever existed on Mars. The first mission in the ExoMars program is the 2016 ExoMars Trace Gas Orbiter (TGO), which launched in March 2016 and began its science and relay operations phase in March 2018, starting with the observations of the global dust storm. For this mission, NASA contributed two Electra ultra-high frequency (UHF) telecommunication radios, identical to those used successfully on NASA’s MRO and MAVEN. The Electra radio acts as a communications relay and navigation aid for surface assets and support navigation, command, and data-return needs for landers and rovers. Furthermore, two instruments, the Stereo Surface Imaging Systems and the Nadir and Occultation for Mars Discovery have significant contributions from U.S. co-Investigators.

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Recent Achievements

ESA's ExoMars Trace Gas Orbiter has detected glowing green oxygen in Mars's atmosphere. The atmospheres of planets including Earth and Mars glow constantly during both day and night as sunlight interacts with atoms and molecules within the atmosphere. Slightly different mechanisms cause dayglow and nightglow: nightglow occurs as broken-apart molecules recombine, whereas dayglow arises when the Sun's light directly excites atoms and molecules such as nitrogen and oxygen. Scientists have predicted this kind of emission existed at Mars for approximately 40 years, but this is the first time that scientists observed it around a planet other than Earth.

The ExoMars TGO, using the contributed NASA Electra radio, is relaying over 50 percent of the science data from NASA's Curiosity rover and InSight lander.

MARS PROGRAM MANAGEMENT

Mars Program Management provides for the broad-based implementation and programmatic management of the Mars Exploration program. Mars Program Management also supports independent review panels, studies regarding planetary protection, advanced mission studies and program architecture, program science, and telecommunications coordination and integration.

MARS FUTURE MISSIONS

Mars Future Missions funds the planning of future robotic missions to Mars that build on scientific discoveries from past missions and incorporate the lessons learned from previous missions. Mars Future supports planning and studies for future capabilities for handling returned samples in the early 2030s.

MARS MISSION OPERATIONS

Mars Mission Operations provides management and leadership for the development and operation of Mars multi-mission systems for operations. Mars Mission Operations supports and provides common operational systems and capabilities at a lower cost and risk than having each Mars project produce systems individually.

MARS RESEARCH AND ANALYSIS (R&A)

Mars R&A provides funding for research and analysis of Mars mission data to understand how geologic, climatic, and other processes have worked to shape Mars and its environment over time, as well as how they interact today. The project has invested in Mars data analysis capabilities to analyze archived data collected on Mars missions, as well as critical products that provide data and analyses for the safe arrival, aero-maneuver, entry, descent, and landing on Mars.

Data analysis through Mars R&A enables a much broader and objective analysis of the data and samples. It also allows research to continue for many years after the mission completion. These research projects increase our scientific understanding of Mars's past and present environments, disseminating the results through the scientific publications. By using data collected by spacecraft, researchers can make scientific discoveries and test hypotheses about the Martian environment.

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Recent Achievements

Recently published papers have provided significant new information on:

- The influence of solar tides on variability over space and time of the upper atmosphere of Mars and its impact on aerobraking because of thermosphere density variability.
- Diurnal variations of dust during the recent 2018 global dust storm, the same dust storm responsible for the loss of the Opportunity rover.
- The nature and formation mechanisms of the sedimentary deposits indicating that mechanisms other than flowing water are required to account for the majority of sediments transported into Gale Crater, where the Curiosity rover is operating.
- The possible presence of relatively shallow water-ice at latitudes as low as 35 degrees North, which has implications for resource use by crewed missions and the habitability of Mars.

MARS TECHNOLOGY

Mars Technology focuses on technological investments that lay the groundwork for successful future Mars missions, such as: entry, descent, and landing capabilities; Mars ascent vehicle components; sample handling and processing technologies; and surface-to-orbit communications improvements.

Recent Achievements

Recent investments in Mars technology enabled development of the Mars 2020 Perseverance sample caching system. It consists of three robotic components that work in concert to collect samples of rock and regolith (broken rock and dust), seal them in sample tubes, and deposit those tubes on the surface of Mars for retrieval by a future mission. The Ingenuity Mars helicopter technology demonstration successfully performed the first powered, controlled aerodynamic flight on another planet. In addition, the infusion of Terrain Relative Navigation (TRN) into the Mars 2020 entry, descent, and landing system enabled a safe landing at Jezero Crater on Feb 18, 2021. This was the first demonstration of this technology on a space mission and TRN technology will be critical for future robotic and human missions to the Moon and Mars.

MARS ICE MAPPER

Mars Ice Mapper supports NASA participation in an international ice-mapping mission that would detect near-surface (top 5-10 meters) water ice on Mars using a Synthetic Aperture Radar (SAR). Detecting and eventually accessing water ice supports both science and future human exploration. International collaboration with Canada, Japan, and Italy, along with potential commercial contributors, enables this mission. In January 2021, the four potential partners signed a Statement of Intent (SOI) outlining the planned contributions of the agencies. Per the SOI, NASA would serve as the systems architect and mission lead.

Knowing where to find abundant water ice close to the surface is a critical knowledge gap in Mars exploration. Water ice on Mars could provide critical raw materials for human exploration, such as hydrogen and oxygen as a component of methane-based rocket fuel for the return trip to Earth. Water ice is also central to understanding the history of environmental change on Mars and whether the planet ever was home to microbial life or still might be today. Characterizing near-surface water ice would also

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complement science results from other Mars radar instruments that have probed deeper into the subsurface, providing near-global coverage of a yet unseen part of Mars. Water ice will inform the site selection for the first human landing site, as well as the scientific investigations astronauts will likely pursue there, including ice-core samples that preserve a record of climate, habitability, and potential life.

Operating Missions

MARS ROVER 2020

NASA's Mars Rover 2020 Perseverance rover will advance one of the top scientific priorities detailed in the National Research Council's Planetary Science Decadal Survey for 2013-2022, initiating the first leg of a round trip to Mars to return samples to Earth for further study. Perseverance will characterize the planet's geology and past climate, search for signs of ancient microbial life on Mars, collect and store carefully selected rock and sediment samples, and test new technology to benefit future robotic missions and pave the way for future human exploration of Mars. Subsequent NASA missions, in cooperation with ESA (European Space Agency), would send spacecraft to Mars to retrieve the sealed samples collected by Perseverance from the surface of Mars and return them to Earth for in-depth analysis.

The Perseverance rover is carrying a competitively selected science and technology instrument payload of seven instruments. NASA chose five of those instruments to provide the clearest possible measurements for seeking possible signs of ancient life (potential "biosignatures") on Mars over its long, 4.6 billion-year history. NASA chose the remaining two instruments to assess environmental hazards and resources for future human exploration. Perseverance is also ferrying a high-risk, high-reward technology demonstration to the surface of Mars, a helicopter named Ingenuity, the first aircraft to attempt powered, controlled flight on another planet. The Mars 2020 mission incorporates new capabilities developed through investments by NASA's Space Technology Mission Directorate, Human Exploration and Operations Mission Directorate (including the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) and Terrain Relative Navigation technology), and payload contributions from international partners.

Recent Achievements

The Mars Rover 2020 mission successfully launched on July 30, 2020, and safely landed the Perseverance rover on the surface of Mars at Jezero Crater on February 18, 2021. Improvements in entry, descent, and landing capabilities, including the infusion of Terrain Relative Navigation enabled the landing at the scientifically compelling, yet challenging terrain of Jezero Crater. Initial surface operations have begun, with science instrument and payload commissioning and successful completion of the flight test campaign by the Ingenuity helicopter.

2011 MARS SCIENCE LAB (MSL)

MSL and its Curiosity rover, which successfully landed in August 2012, completed its prime mission exploration activities. The Curiosity rover is exploring and quantitatively assessing regions on Mars as potential past habitats for life and has determined that Mars, at least at one point in time, was able to support microbial life. The Curiosity rover is collecting Martian soil and rock samples and analyzing them

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for organic compounds and environmental conditions that could have supported microbial life, and measuring the Martian atmosphere, the radiation environment, and the weather. MSL is the first planetary mission to use guided entry landing techniques, steering itself toward the Martian surface. This landing method enabled the rover to land in an area less than 12 miles in diameter, about one-sixth the size of previous landing zones on Mars and this successful system is the basis of the system architecture of the Mars 2020 mission. The successful use of guided entry by MSL, along with newer improvements, enabled the targeting of more challenging terrain in Jezero carter by Mars 2020 and its successful landing in February 2021.

Curiosity is the first planetary rover to make use of a nuclear power source, which gave the rover the ability to travel up to 12 miles during the two-year primary mission. This international partnership mission uses components provided by the space agencies of Russia, Spain, France, and Canada.

Recent Achievements

Curiosity has traveled over 14 miles (23km) and has been exploring the lower reaches of Mt. Sharp, the prime science target of the mission, and is now in its third extended mission period. Since landing on Mars in 2012 in Gale Crater, the Curiosity rover has consistently detected low levels of methane in the atmosphere, which varies seasonally and punctuated occasionally by transient spikes. The variation in methane has remained a mystery, with plausible theories for both the sources and sinks. One clue has been that the methane increases at night, perhaps trapped by the atmospheric boundary layer that forms overnight. This suggests that the methane is local and not transported from outside the crater. Repeated observations of this phenomenon will continue to produce insight into Mars's methane climate and point to the potential geological and/or biological processes that could produce its variations.

Curiosity is completing its investigation of a clay-bearing area at the foot of Mount Sharp inside of Gale Crater, where the rover has found an array of complex organic compounds. Rock samples that the rover has drilled here have revealed diverse organic molecules in the clay-bearing rocks warranting the first use of a different type of wet chemistry experiment. The rover will soon reach the change from clay to sulfate-bearing layers of Mount Sharp that represents a major transition as Mars became the drier planet we see today. In addition, Curiosity has monitored over three Mars years of local weather and radiation environments, quantifying the radiation shielding of the atmosphere and of the surrounding rocks.

MARS RECONNAISSANCE ORBITER 2005 (MRO)

MRO, currently in its fifth extended operations phase, carries the most powerful camera ever flown on a planetary exploration mission: The High-Resolution Imaging Science Experiment (HiRISE). This capability provides a more detailed view of the geology and structure of Mars and is critical in identifying obstacles that could jeopardize the safety of future landers and rovers. A second camera, The Context Camera (CTX), acquires medium-resolution images that provide a broader geological context for the more detailed observations from higher-resolution instruments; it has covered most of the planet and searches for new phenomena, such as new impact craters, revealing subsurface ice. MRO also carries a radar sounder to find subsurface water ice, an important consideration in selecting scientifically worthy landing sites for future exploration.

MRO carries a high-resolution imaging spectrometer, the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), which can map minerals at unprecedented spatial resolution. A wide-angle camera, the Mars Color Imager (MARCI), provides daily global weather maps, and the Mars Climate Sounder (MCS) shows how the Martian atmosphere transports dust and water vapor. MRO will

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follow up on recent discoveries of an increasingly diverse array of ancient aqueous environments and buried carbon dioxide ice that, if released, would double the present atmospheric pressure. MRO will extend mapping of the three-dimensional structure and content of the polar ice deposits, characterize the episodic nature of great dust storms, expand coverage of surface changes, and monitor possible seasonal surface color changes suggestive of liquid water flow on Mars today. MRO characterized the landing sites for the Mars 2020 Rover and the 2022 ESA ExoMars Rover.

As it explores Mars, MRO also serves as a major element of an "interplanetary Internet," as a relay communications orbiter relaying commands to and data from the Curiosity and Mars 2020 Perseverance rovers and InSight lander to Earth. In FY 2021, MRO will continue to characterize phenomena on the surface of Mars, such as the Recurring Slope Lineae and dust storms. In addition, MRO relayed to Earth the entry, descent, and landing telemetry from Mars 2020 during its landing in February of 2021.

Recent Achievements

In its fifth Extended Mission (FY 2020-22), MRO imaged locales where previous CRISM infrared spectra indicated episodic alteration of ancient rocks on Mars by liquid water. CTX re-imaged intriguing regions to support digital terrain mapping. HiRISE digital maps are covering smaller areas at higher resolution. CRISM covered 70 percent of Mars at approximately 100 m/pixel at visible-near infrared (IR) wavelengths to reveal key details of the mineralogy of ancient landforms. CTX continues to identify new impact craters (greater than 1,000 since 2013), confirmed as such by follow-up HiRISE images. The Shallow Radar (SHARAD) team applied 3-D analysis techniques to expanded coverage of subsurface ice deposits and of the polar cap interior layering. Indications of subsurface water ice at nonpolar latitudes support studies of possible in situ resources for future human explorers.

MCS finished the first phase of a campaign to detect seasonal changes in surface temperatures due to very shallow subsurface ice. MARCI and MCS have characterized the Mars weather following the 2018 planet-encircling dust event. In the observations to date, Mars is following a three-storm pattern typical of Mars years without a planet-encircling event. However, researchers observed an unusual, relatively short-lived regional dust event in the northern spring. MRO detected regional dust storms and provided data on them and their exported dust hazes to landed assets, such as the solar-powered InSight lander. MRO continues to provide relay for landed assets and covered Mars 2020/Perseverance rover's arrival in February 2021.

MARS ODYSSEY 2001

Mars Odyssey, currently in its eighth extended mission operations phase, continues in orbit to explore Mars with its powerful set of instruments, and provides a key element of the communications infrastructure for landed assets. It sends information to Earth about Martian geology, climate, and mineralogy. Measurements by Odyssey enable scientists to create maps of minerals and identify regions with near-surface water associated with hydrated minerals or ice. Observations that measure the surface temperature provide spectacular images mapped onto Martian topography. Mars Odyssey will continue critical, long-term longitudinal studies of the Martian climate. Odyssey has served as an essential link in communications between Earth and NASA's surface assets on Mars for more than a decade. Starting in November 2018, Odyssey has provided crucial relay support for the InSight lander.

Other Missions and Data Analysis

Recent Achievements

From its unique morning orbit, Odyssey's Thermal Emission Imaging System (THEMIS) is observing frost, clouds, and fogs that no other orbiter can see. Odyssey team scientists are studying the details of Martian weather and climate, revealing the current cycles of water and dust, and mapping terrains that once were potentially hospitable to life. The surface geophysical observatory InSight relies on daily contacts with Odyssey to conduct its search for Mars quakes and studies of the interior structure of the planet. In addition, Odyssey is continuing its THEMIS observing campaign of the Martian moon Phobos. Thermal emission data provides information about the surface texture, structure, and composition of surface materials. Phobos is a target of the Japanese Mars Moons Exploration (MMX) sample return mission, on which NASA is a partner. Results from the THEMIS observing campaign will aid selection of sampling sites on Phobos.

Mars Express

Mars Express, currently in its eighth extended mission operations phase, is an ESA mission that provides an understanding of Mars as a “coupled” system: from the ionosphere and atmosphere down to the surface and sub-surface. This mission addresses the climatic and geological evolution of Mars as well as the potential for life on the planet. NASA contributed components for the Mars Advanced Radar for Subsurface and Ionospheric Sounding and Analyzer of Space Plasmas and Energetic Atoms instruments aboard Mars Express and participates in the scientific analysis of mission data.

Recent Achievements

Mars Express continued to measure atmospheric loss and characterize the Mars ionosphere and its interaction with the solar wind and conducted a series of radio science investigations to gather data on lower atmosphere dynamics. Due to the prioritization of other Mars science investigations, NASA directed that the NASA participation in the Mars Express mission conclude at the end of FY 2020. The team is calibrating the data acquired during the active Agency involvement with the mission and placing it into the Planetary Data System. The current budget supports the Deep Space Network costs to continue communications for the ESA-operated instruments.

Mars Atmosphere and Volatile Evolution (MAVEN)

MAVEN, now in its fourth extended mission, launched in 2013 and successfully completed its primary mission in November 2015. MAVEN is providing a comprehensive picture of the Mars upper atmosphere, ionosphere, solar energetic drivers, and atmospheric losses, to determine how the Mars atmosphere evolved through time. The mission is answering long-standing questions regarding the loss of the Mars atmosphere, climate history, liquid water, and habitability. MAVEN is the first mission devoted to studying Mars's upper atmosphere, with the most comprehensive measurements ever taken to address key scientific questions about Mars's evolution. It is exploring the upper atmosphere, ionosphere, interactions with the Sun and solar wind, and the resulting loss of gas from the atmosphere to space. Scientists are using MAVEN data to determine the role that loss of volatile compounds (e.g., carbon dioxide, water) from the Mars atmosphere to space has played through time, and the importance of this loss in changing the Mars atmosphere and climate through time.

As with all Mars Exploration Program orbiters, MAVEN carries an Electra radio for communications with rovers and landers on the Martian surface. MAVEN has been carrying out relay activities at a low

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level for the past three years but in FY 2019, the spacecraft positioned to a more relay efficient orbit. This will allow MAVEN to increase its relay support to landed assets.

Recent Achievements

MAVEN recently completed six years of orbiting Mars. This extended period of measurements allowed MAVEN researchers to develop a complete picture of the global electric current system around Mars. Scientists have known the basic current system in Earth's magnetosphere for decades and that it is strongly tied to Earth's permanent magnetic field. Unlike the Earth, Mars does not have a permanent, global magnetic field. The global current system observed by MAVEN reveals differences from the current system at Earth and demonstrates the energy transfer between the solar wind and Mars that drives atmospheric escape. These results for Mars have implications for understanding other similar magnetospheres such as Venus and Titan.

MAVEN used ultraviolet emission measurements from the night side of Mars to infer circulation patterns in the middle atmosphere. Observed nightglow emissions at Mars are due to the chemical and dynamic processes that produce nitric oxide from carbon dioxide and nitrogen. When nitric oxide forms, it emits ultraviolet light. MAVEN can detect the ultraviolet light and scientists have determined it is an effective tracer of middle atmospheric circulation patterns. More than two years of nightglow observations from MAVEN reveal that the seasons on Mars control the middle atmospheric circulation. Atmospheric tides also strongly modify the middle atmospheric circulation. Researchers couple these observations with observations of circulation at both lower and higher altitudes to understand more fully the atmospheric motions at Mars.

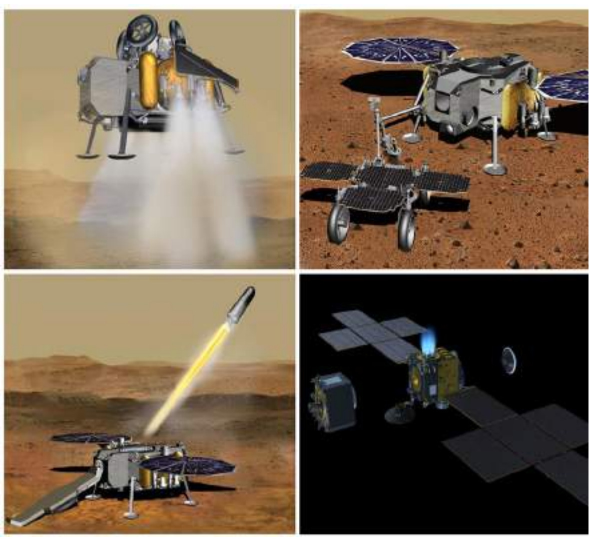
Mars Sample Return

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**0.0**	**246.3**	**653.2**	**772.3**	**800.0**	**700.0**	**600.0**
Change from FY 2021			**406.9**				
Percentage change from FY 2021			**165.2%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Retrieving Mars samples and returning them to Earth will expand our capability in space and significantly contribute to scientific knowledge. Back on Earth, the samples will be available to the world's best laboratories for intensive analysis to pursue answers to some important science questions about extraterrestrial life and planetary evolution.

The Mars Sample Return (MSR) Program is a joint mission with the European Space Agency (ESA). MSR will bring scientifically selected samples from Mars to Earth that will accomplish a solar system exploration goal that has been a priority since 1980 and the last two Planetary Decadal Surveys. The scientific driver of sample return is exploration of an ancient river-delta thought to present the best location for collecting samples that will reveal the early evolution of Mars, including the potential for life.

The MSR Program consists of two coordinated flight-elements that the program plans to launch as early as 2026: 1) NASA's Sample Retrieval Lander (SRL), carrying the Mars Ascent Vehicle (MAV) and ESA's Sample Fetch Rover (SFR); and 2) ESA's Earth Return Orbiter (ERO) carrying NASA's Capture, Containment, and Return System (CCRS), which includes the Earth Entry System (EES). Mars Rover 2020 is the first step in the sample return campaign and its Perseverance rover landed on Mars in February 2021 and will identify, sample, and cache samples on the Martian surface. The program will deploy new capabilities developed through investments made by NASA and will leverage significant contributions from international partners.

The MSR Program will return the stored samples as early as 2031, making them available for analysis by the most advanced instrumentation on Earth. The sample return will advance human exploration of Mars by demonstrating the first round-trip to another planet and furthering our understanding of planetary protection risks. Additionally, MSR's Sample Retrieval Lander (SRL) will utilize "advanced precision-

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landing" technology, an advancement of the Terrain Relative Navigation (TRN) successfully used in the Mars Rover 2020/Perseverance landing. This technology applies directly to safely landing robotic precursors, humans, and equipment, including in situ resources, near each other on the Martian surface.

EXPLANATION OF MAJOR CHANGES IN FY 2022

NASA established MSR as a new program early in mission formulation.

ACHIEVEMENTS IN FY 2020

MSR pre-formulation activities in FY 2020 included: establishing the desired system architecture, early mission concepts, system-level requirements drafts, performance, cost, schedule feasibility assessment, potential technology needs and associated scope, and preliminary risk reduction activities.

WORK IN PROGRESS IN FY 2021

Following an assessment by an Independent Review Board (IRB), and a successful Mission Concept Review, the Agency approved the mission to enter Phase A in the first quarter of FY 2021. The IRB, commissioned by SMD, was the earliest such a group has been engaged with a program or project. As formulation efforts begin, MSR will continue refining requirements, technology development efforts, and risk-reduction activities. Planned reviews include a Standing Review Board (SRB) assessment associated with the System Requirements Review (SRR), and a Key Decision Point-B (KDP-B) gate review.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The program will complete early technology development and risk-reduction activities in preparation for Preliminary Design Review (PDR) and KDP-C.

Program Elements

MARS SAMPLE RETURN (MSR)

MSR will consist of two separate launches carrying four NASA components, one ESA launch for the ERO, and one NASA launch for the Sample Retrieval Lander. The goal of the program is to bring selected samples cached by Perseverance back to Earth. The ESA-provided Sample Fetch Rover will bring selected samples to the orbiting sample container in the Mars Ascent Vehicle. The Mars Ascent Vehicle will launch from Mars and inject the orbiting sample into Mars orbit. The ESA ERO, using the Capture/Containment and Return System, will capture the orbiting sample and place it in the Earth Entry System itself, also contained within the Capture/Containment and Return System. The ESA ERO will return to Earth and deliver the Earth Entry System into a ballistic entry orbit and land on Earth.

MARS SAMPLE RETURN

The NASA-provided portion of the Mars Sample Return Campaign consists of four components; the Sample Retrieval Lander (SRL), the Capture/Containment and Return System (CCRS), the Mars Ascent Vehicle (MAV) and the Earth Entry System (EES).

The first component, SRL, launched by NASA, carries NASA's Mars ascent vehicle, the ESA-provided sample fetch rover and the sample transfer arm, which are part of the sample transfer system. The sample transfer system, operated by NASA, will retrieve the sample tubes from the sample fetch rover and/or the Perseverance rover and place them into the orbiting sample container in the Mars ascent vehicle. The Mars ascent vehicle, launched from the sample return lander, will inject the orbiting sample into Mars orbit for capture by the ERO /Capture Containment and Return System. The sample return lander notional launch readiness date is 2026.

The second component, CCRS, is the primary payload on the ESA ERO. The ERO will rendezvous with the orbiting sample, then the CCRS will capture and encapsulate the orbiting sample to “break the chain” of contact with Martian material to satisfy planetary protection requirements and to ensure the samples pose no risk to Earth. The CCRS's Robotic Transfer Arm (RTA) will place the orbiting sample into the EES. The ERO will deliver the Earth entry system to an Earth entry trajectory, and the EES will execute a ballistic entry and land at a selected U.S. landing site.

The third component, MAV, carried by the SRL, is the first rocket that NASA will launch from the surface of another planet. It will launch the orbiting sample container from Mars and place it in a stable orbit 400km above the surface. The MAV is a two-stage launch vehicle that utilizes two separate solid rocket motors for propulsion. Prior to its own launch from Mars, the MAV must survive Earth launch, a cruise phase to Mars, atmospheric entry; and over 400 sols (Martian days), or 411 Earth days, of time on the Martian surface.

The fourth component, EES, is a passive entry capsule developed by NASA to return Mars samples safely back to Earth and consists of an Earth Entry Vehicle (EEV) and the orbiting sample container necessary to protect the orbiting sample during Earth entry and impact. The CCRS processes the orbiting sample, encapsulating it within the primary and secondary containment vessels, and loads it into EEV. The containment assurance module lid closes on the EEV to form the final EES. The EES is a fully passive aerodynamic design for entry and landing designed for maximum reliability.

Program Schedule

Date*	Significant Event
Oct 2020	Mission Concept Review (MCR)
Dec 2020	Key Decision Point-A
Aug 2021	System Requirements Review
Sep 2021	Key Decision Point-B
Aug 2022	Preliminary Design Review (PDR)
Sep 2022	Key Decision Point-C
Sep 2023	Critical Design Review (CDR)

MARS SAMPLE RETURN

Date*	Significant Event
Jul 2024	Key Decision Point-D
Jul 2026	Sample Retrieval Lander (SRL) Launch
Aug 2026	Earth Return Orbiter (ERO) Launch

**Consistent with as early as 2026 SRL Launch Readiness Date*

Program Management & Commitments

The MSR Program Director at NASA Headquarters has overall responsibility for the MSR Program and reports directly to the Science Mission Directorate Associate Administrator. The Program Director is responsible for planning and implementing the program consistent with top-level policies, requirements, and funding. JPL is the lead Center for the MSR Program. The JPL MSR Program Manager is responsible for executing the program and reports to the SMD MSR Program Director.

NASA has established the MSR Campaign System Engineering and Integration (SE&I) team to support and report to the MSR Program Manager. The Campaign SE&I, which includes ESA membership, will oversee the development and control of campaign requirements, inter-project interfaces, planetary protection, sample integrity and other campaign level system engineering functions. The MSR Program Office will also interface with the Mars Rover 2020/Perseverance rover during its surface operation phase to coordinate sample acquisition and caching, and the program office is responsible for the science integrity of the samples throughout the MSR mission sequence. The future NASA Sample Receiving Project, funded in the Mars Exploration Program, will coordinate handoff of the samples upon their safe arrival on Earth.

Program Element	Provider
Sample Retrieval Lander (SRL)	Provider: Jet Propulsion Laboratory (JPL) Lead Center: JPL Performing Center(s): GRC, MSFC, LaRC, ARC, JPL Cost Share Partner(s): European Space Agency (ESA)
Capture/Containment & Return System (CCRS)	Provider: Goddard Space Flight Center (GSFC) Lead Center: GSFC Performing Center(s): JPL, LaRC, ARC Cost Share Partner(s):
Mars Ascent Vehicle (MAV)	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC, JPL, LaRC Cost Share Partner(s):

MARS SAMPLE RETURN

Program Element	Provider
Earth Entry System (EES)	Provider: LaRC Lead Center: LaRC Performing Center(s): LaRC, ARC, GSFC, JPL Cost Share Partner(s):

Acquisition Strategy

NASA conducted an Acquisition Strategy Meeting (ASM) in July 2019 and made center roles/responsibilities assignments (depicted in the previous Table). NASA plans to award several long-lead SRL and CCRS contracts. NASA anticipates competitive selections of the long-lead contracts led by the performing centers.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
MAV Propulsion	Northrop Grumman Systems Corp.	Elkton, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	IRB	2020	Program Feasibility	Completed	MCR
Performance	SRB	2020	Program MCR	TBD	SRR
Performance	SRB	2021	Program SRR	TBD	PDR
Performance	SRB	2022	Program PDR	TBD	TBD
Performance	SRB	2024	SRL SIR	TBD	ORR
Performance	SRB	2026	SRL ORR	TBD	N/A

OUTER PLANETS AND OCEAN WORLDS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Jupiter Europa	592.6	434.8	**472.1**	305.0	240.0	110.1	90.1
Other Missions and Data Analysis	39.4	27.7	**22.7**	26.2	25.5	25.6	25.6
Total Budget	**632.0**	**462.5**	**494.8**	**331.2**	**265.5**	**135.7**	**115.7**
Change from FY 2021			**32.3**				
Percentage change from FY 2021			**7.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

An icy shelf riddled with cracks and complex geology covers Europa's probable vast subsurface ocean. Many of these cracks show evidence of a reddish-brown material spilling from them, suggesting that the cracks release compositionally complex water from the subsurface.

The Outer Planets and Ocean Worlds program enables the exploration of worlds in our solar system possessing vast expanses of liquid water. These liquid reservoirs provide insight into some of the most fundamental questions about life and the evolution of the solar system. The exploration of ocean worlds has the highest relevance and potential in the search for extant life and its habitable environments beyond Earth, one of NASA’s strategic objectives.

NASA missions have revealed a surprising number of ocean worlds in our solar system while at the same time providing enticing, though limited, details about these unexpected oceans. Not far underneath its icy crust, Jupiter's moon Europa contains a global liquid water ocean holding twice as much water as all of Earth’s oceans. Recent observations suggest active water plumes erupting from the surface of Europa. Scientists detected a similar, though smaller, global ocean on Enceladus, a small moon orbiting Saturn, which also emanates active plumes. Other moons (such as Ganymede, Titan, and perhaps Callisto) and possibly even Pluto also possess oceans deep beneath their surfaces. Unlike Europa and Enceladus, whose oceans have a rocky bottom; these oceans are sandwiched between ice layers. Titan also possesses huge lakes of liquid methane on its surface, the only place beyond Earth with lakes exposed to an atmosphere. Titan's lakes and atmosphere can reveal much about the exotic chemistry that ultimately led to life on Earth.

Astrobiology research, along with the exploration of Earth's oceans and the aforementioned discoveries, has demonstrated the pervasiveness of life given the proper conditions and environment. Research and

OUTER PLANETS AND OCEAN WORLDS

spacecraft measurements have increased our confidence that these ocean worlds possess at least some of the conditions necessary for extant life: long-lived oceans providing liquid water and a stable habitat, hydrothermal activity and other chemical sources providing energy, and the basic elements along with organics providing the necessary materials, among others. In fact, Europa and Enceladus may possess all these conditions necessary for life. Thus, ocean worlds are the most likely places to search for currently habitable environments in the solar system and the life forms that could exist in those environments.

The Outer Planets and Ocean Worlds program enables science investigations spanning the diversity of worlds hosting large liquid bodies in the outer solar system. The unexpected discoveries of the first ocean worlds provided by large strategic missions such as Galileo and Cassini have enabled the definition of more focused scientific questions. The missions enable more focused scientific questions than smaller and less complex missions in the New Frontiers and Discovery programs can pursue.

EXPLANATION OF MAJOR CHANGES IN FY 2022

This budget request includes $5 million per year within the Icy Satellites Surface Technology project for technology efforts in support of a future Ocean Worlds lander mission. The long-term goal of Ocean Worlds exploration is accessing the deep subsurface and ultimately the oceans themselves. NASA has identified a small number of technologies to enable this exploration, but they require sustained investment to develop.

The Europa Clipper project's established baseline lifecycle cost (LCC) estimate was set at $4.25 billion in August 2019. The FY 2022 budget request adds $47 million to the Europa Clipper LCC to mitigate COVID-19 impacts.

Europa Clipper will launch on a Commercial Launch Vehicle (CLV) utilizing a Mars-Earth Gravity Assist (MEGA) trajectory by November 2024. The procurement of the CLV is currently in process, consistent with the FY 2021 Consolidated Appropriations Act (P.L.160-260). A project replan is underway to accommodate COVID-19 impacts, as well as assembly, test, and launch operations (ATLO) requirements, the updated schedule plan, and Phase E costs. NASA expects this replan and CLV selection to be complete in early CY 2022.

EUROPA CLIPPER

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	1,219.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	1,219.0
Development/Implementation	349.3	592.6	434.8	**472.1**	305.0	240.0	0.0	0.0	0.0	2,393.8
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	110.1	90.1	484.0	684.2
2021 MPAR LCC Estimate	**1,568.3**	**592.6**	**434.8**	**472.1**	**305.0**	**240.0**	**110.1**	**90.1**	**484.0**	**4,297.0**
Total Budget	**1,568.3**	**592.6**	**434.8**	**472.1**	**305.0**	**240.0**	**110.1**	**90.1**	**484.0**	**4,297.0**
Change from FY 2021				**37.3**						
Percentage change from FY 2021				**8.6%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Scientists reexamined Galileo data over 20 years old and found evidence that the spacecraft passed through a water plume erupting from the surface. This offers an independent dataset, in addition to observations from Hubble, indicating the presence of this activity on Europa.

PROJECT PURPOSE

Jupiter’s moon Europa has the largest known ocean in the solar system and is one of the most likely places to find current life beyond our Earth. NASA developed concepts to explore Europa and determine if it is habitable based on characteristics of its vast oceans (twice the size of all of the Earth's oceans combined); the ice surface-ocean interface; the chemical compositions of the intriguing, irregular brown surface areas; and the current geologic activity providing energy to the system. After a thorough investigation of concept options, NASA directed a multiple flyby mission (Europa Clipper) that delivers the most science for the least cost and risk of all the concepts studied. The Europa Clipper mission takes advantage of solar power and requires no new technology development, despite the harsh radiation environment that the spacecraft will encounter during the

EUROPA CLIPPER

Formulation	Development	Operations

flybys. The Clipper mission will explore Europa and investigate its habitability.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Europa Clipper project's established baseline lifecycle cost (LCC) estimate was set at $4.25 billion in August 2019. The FY 2022 budget request adds $47 million to the LCC to mitigate COVID-19 impacts.

Europa Clipper will launch on a Commercial Launch Vehicle (CLV) utilizing a Mars-Earth Gravity Assist (MEGA) trajectory by November 2024. The procurement of the CLV is currently in process, consistent with the FY 2021 Consolidated Appropriations Act (P.L.160-260). A project replan is underway to accommodate COVID impacts, as well as assembly, test, and launch operations (ATLO) requirements, the updated schedule plan, and Phase E costs. NASA expects this replan and CLV selection to be complete in early CY 2022.

PROJECT PARAMETERS

NASA formulated the Europa Clipper mission in response to the planetary science Decadal Survey (Vision and Voyages for Planetary Science in the Decade 2013-2022), which identified a strategic mission to Europa as the second-highest priority for planetary science flagship missions. This mission will leverage the competitively selected payload of investigations to characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of the surface-ice ocean exchange. It will also seek to understand the habitability of Europa’s ocean through composition and chemistry of the surface and exosphere; understand the formation of surface features, including sites of recent or current activity; and identify and characterize high science interest localities. This will be the first NASA mission explicitly designed to explore an ocean world.

The Europa Clipper mission will spend four years in orbit around Jupiter, conducting its scientific observations by completing approximately 44 close fly-bys of Europa, minimizing the spacecraft's exposure to the harsh radiation environment near Europa.

ACHIEVEMENTS IN FY 2020

During FY 2020, the Europa Clipper project worked to mature its system design. Every major subsystem and each instrument underwent a Critical Design Review (CDR), demonstrating their progress to independent boards. Development and testing of prototype hardware are nearing completion and fabrication of flight hardware is underway.

WORK IN PROGRESS IN FY 2021

The project conducted the mission-level CDR in early FY 2021. Determination of the launch vehicle type (Space Launch System or Commercial Launch Vehicle) was finalized in January 2021. A replan is underway to accommodate COVID-19 impacts, as well as assembly, test, and launch operations (ATLO)

EUROPA CLIPPER

Formulation	Development	Operations

requirements and updated Phase E costs and schedule impacts. Flight hardware delivery, including instruments, begins in spring 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The project will complete its System Integration Review (SIR) and Key Decision Point-D (KDP-D) review in FY 2022 and the spacecraft assembly, integration, and testing phase (Phase D) will begin.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
KDP-C	Aug 2019	Aug 2019
CDR	Dec 2020	Dec 2020
SIR	Oct 2021	Nov 2021
KDP-D	Nov 2021	Dec 2021
ORR	May 2024	May 2024
Launch Readiness Date	Sep 2025	Nov 2024
Phase E Start	Nov 2025	Nov 2025

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2020	2412.8	69%	2021	2393.8	-0.8	LRD	Sep 2025	Nov 2024	-10

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

EUROPA CLIPPER

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**2,412.8**	**2,393.8**	**-19**
Aircraft/Spacecraft	818.7	855.9	+37.2
Payloads	168.7	300.3	+131.6
Systems I&T	63.2	53.4	-9.8
Launch Vehicle	432.0	432.0	0
Ground Systems	104.8	136.7	+31.9
Science/Technology	24.8	33.4	+8.6
Other Direct Project Costs	800.6	582.1	-218.5

Project Management & Commitments

Responsibility for Europa Clipper project management resides at Jet Propulsion Laboratory (JPL).

Element	Description	Provider Details	Change from Baseline
Spacecraft	TBD	Provider: JPL Lead Center: JPL Performing Center(s): JPL, APL, GSFC, MSFC, JSC, KSC Cost Share Partner(s): N/A	N/A
Europa UVS Instrument	Ultraviolet Spectrograph	Provider: SwRI Lead Center: JPL Performing Center(s): Cost Share Partner(s): N/A	N/A
MASPEX	Time-of-Flight Mass Spectrometer	Provider: SwRI Lead Center: JPL Performing Center(s): Cost Share Partner(s): N/A	N/A

EUROPA CLIPPER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Europa Imaging System (EIS)	Narrow Angle and Wide-Angle cameras	Provider: APL Lead Center: JPL Performing Center(s): Cost Share Partner(s): N/A	N/A
SUDA	Dust Analyzer; Mass Spectrometer	Provider: LASP - CU Lead Center: JPL Performing Center(s): Cost Share Partner(s): N/A	N/A
E-THEMIS	Thermal Imager	Provider: ASU Lead Center: JPL Performing Center(s): Cost Share Partner(s): N/A	N/A
ICEMAG	Magnetometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL, Cost Share Partner(s): N/A	Terminated
ECM	Magnetometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL, Cost Share Partner(s): N/A	Facility instrument to replace ICEMAG functionality
PIMS	Plasma Instrument - Faraday Cups	Provider: APL Lead Center: JPL Performing Center(s): Cost Share Partner(s): N/A	N/A
MISE	Infrared Spectrometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL, Cost Share Partner(s): N/A	N/A
REASON	Sounding Radar	Provider: Univ. of Texas Lead Center: JPL Performing Center(s): JPL, Cost Share Partner(s): N/A	N/A

EUROPA CLIPPER

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: COVID-19 mitigations slow the progress at delivering organizations and / or subcontractors, Then: Hardware deliveries to ATLO will be delayed, resulting in delays in ATLO progress and potentially an impact to Clipper's LRD.	1) Tracking cost and schedule impacts to hardware and software deliverables on a biweekly / monthly basis. 2) Documenting and communicating status monthly in Monthly Management Reviews and quarterly in Science Mission Directorate (SMD) Quarterlies. 3) NASA approved JPL, GSFC, and MSFC on-site access to perform selected tasks. Activities are progressing at JPL, GSFC, and MSFC but slower than planned due to safe-at-work practices. 4) Will replan impacted hardware delivery dates to ATLO as part of MEGA 2024 LRD replan.
If: Existing Europa Clipper Integrated Pump Assembly (ECIPA) design cannot be manufactured and operated to meet the thermal performance and life requirements, Then: Significant redesign would be necessary, resulting in consumption of project cost and schedule reserve.	1) Subject Matter Expert peer review of ECIPA pump design, analysis, and assumptions. Closure of Request for Actions from peer reviews prior to start of pump manufacturing. 2) Investigation of Mars Program pump life-test hardware. Teardown and detailed inspection / analysis of heritage pump design that has demonstrated long life (12 years without radiation, 3.5 years with radiation). 3) Augment analysis tools to better correlate wear model with life test results and life test predictions. 4) Conduct a comprehensive test program to contribute to the life requirements verification. 5) Investigate alternate operation of ECIPA hardware during Clipper mission cruise phase. Limited use of individual pumps may extend life but the project must trade that against any performance reduction in the Thermal Control System.

Acquisition Strategy

The Europa Clipper spacecraft is a JPL "in-house" build with each subsystem doing its internal make/buy assessment, with competed industry contracts where appropriate. JPL has entered a partnership with Applied Physics Laboratory (APL) for this build, leveraging each other's strengths as well as those of other NASA centers. As a result, APL is responsible for the propulsion module and the telecom subsystem, and Goddard Space Flight Center will be providing the propulsion subsystem. The Europa Clipper payload is comprised of nine investigations, each competitively selected via a Science Mission Directorate Announcement of Opportunity.

EUROPA CLIPPER

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Telecom and Propulsion Subsystems	APL	Laurel, MD
EIS instrument	APL	Laurel, MD
PIMS instrument	APL	Laurel, MD
REASON instrument	University of Texas University of Iowa	Austin, TX Iowa City, IA
MISE instrument	APL	Laurel, MD
SUDA instrument	LASP - University of Colorado	Boulder, CO
MASPEX instrument	SWRI	San Antonio, TX
UVS instrument	SWRI	San Antonio, TX
E-THEMIS instrument	ASU Ball Aerospace Raytheon Vision Systems	Tempe, AZ Boulder, CO Goleta, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Jan 2017	Europa SRR and MDR	Successful	PDR
Performance	SRB	Aug 2018	PDR	Successful	Delta-PDR
Performance	SRB	Jun 2019	Delta-PDR	Successful	CDR
Performance	SRB	Dec 2020	CDR	Successful	SIR
Performance	SRB	Oct 2021	SIR	TBD	ORR
Performance	SRB	May 2024	ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Icy Satellites Surface Technology	14.2	14.2	**10.0**	15.0	15.0	15.0	15.0
JUICE - Jupiter Icy Moons Explorer	18.2	3.7	**2.8**	1.4	0.8	0.8	0.8
Outer Planets Research	7.0	9.8	**9.8**	9.8	9.8	9.8	9.8
Total Budget	**39.4**	**27.7**	**22.7**	**26.2**	**25.5**	**25.6**	**25.6**
Change from FY 2021			**-5.0**				
Percentage change from FY 2021			**-18.1%**				

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FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Other Missions and Data Analysis includes NASA's contribution to the European Space Agency (ESA) Jupiter Icy Moons Explorer (JUICE) mission, Icy Satellites Surface Technology, and Outer Planets Research.

Mission Planning and Other Projects

ICY SATELLITES SURFACE TECHNOLOGY

NASA is developing the technologies needed to explore the icy moons of Jupiter and Saturn, including those in support of a future Ocean Worlds lander mission. These include electronics and computers capable of surviving extremely harsh radiation environments, solar power systems to operate in the cold far from the Sun, actuators and mechanisms to operate on frigid surfaces, and mobility systems to traverse through thick ice crusts to reach and explore hidden oceans. Advances in autonomous spacecraft operations and sample acquisition will help maximize the science return from future missions.

Recent Achievements

Engineers fabricated nano-vacuum channel transistors onto silicon carbon wafers using conventional manufacturing techniques and demonstrated no degradation under high radiation environments. This may increase the duration of future missions to Europa, where Jupiter’s extremely high radiation levels currently degrade electronic systems, even with shielding.

The project competitively selected two proposals to develop autonomous task control that NASA could use on a future sample acquisition mission to an icy satellite. Both efforts will demonstrate their newly developed capabilities on NASA’s autonomy testbeds developed last year under this project.

OTHER MISSIONS AND DATA ANALYSIS

JUPITER ICY MOONS EXPLORER (JUICE)

NASA is collaborating on this ESA-led mission to Ganymede and the Jupiter system. The JUICE mission provides an opportunity for comparative investigation of three of the ocean worlds in the Jupiter system: Europa, Ganymede, and Callisto. Researchers believe Ganymede and Callisto possess liquid water oceans sandwiched between ice layers deep beneath their surfaces. ESA plans to launch the mission in 2022 for arrival at Jupiter in 2030. The NASA contribution consists of three separate pieces of hardware: one full instrument, the Ultra Violet Spectrograph (UVS); two sensors for the Swedish National Space Agency Particle Environment Package suite of instruments (PEP-Hi); and the transmitter and receiver hardware for the Radar for Icy Moons Exploration (RIME) instrument.

Recent Achievements

NASA delivered the thermal structural models for all three NASA JUICE contributions, UVS, PEP-Hi, and RIME in 2020. The team delivered the flight models for the UVS and RIME hardware for integration with the JUICE spacecraft in 2020.

EUROPA LANDER CONCEPT

Europa Lander is continuing pre-formulation (pre-Phase A) technology development studies in 2021 using funding provided in prior years. Given the early nature of this project, NASA cannot provide a year-by-year funding profile and the FY 2022 President's Budget Request includes no funding for this mission. However, based on pre-formulation efforts thus far, NASA expects the cost of a short-lived lander mission with limited sampling capability to approach $4 to $5 billion.

OUTER PLANETS RESEARCH

Outer Planets Research increases the scientific return of current and past NASA outer planets missions and paves the way for future missions (e.g., refining landing sites on Titan, characterizing the ice shell on Europa and Enceladus).

Recent Achievements

New analysis of data acquired by the Cassini mission has revealed for the first time that Saturn's moon Enceladus may have a warm and active interior. While it has been known for more than a decade that Enceladus's south polar region hides an ocean of warm water beneath its crust, it is only recently that evidence has emerged that Enceladus's entire interior may have recently been warm and wet. This finding has broad implications for habitability and complex chemistry throughout the solar system.

Recent research into Titan, based primarily on data from Cassini, has begun to reveal the history behind some of its surface features. Evidence shows that some puzzling features contained methane and ethane lakes in the past but are now dry. These dry lakebeds are complementary to the active oceans and lakes seen today on Titan's surface, full of liquid hydrocarbons such as ethane and methane. Studies into the history of these surface features are telling us about the global circulation of Titan's atmosphere and how it affects Titan's long-term evolution.

Studies of Saturn's rings show that astronomers' long-held view that the rings are ancient may be incorrect. Instead, measurements taken by the Cassini mission indicate that Saturn's rings may be substantially less massive than previously assumed. This implies that the rings may have appeared only

OTHER MISSIONS AND DATA ANALYSIS

recently around Saturn, perhaps just 100 million years ago, rather than four billion years ago. Studies of these rings as low-mass objects may have significant implications for understanding the formation of planetary systems in our own solar system and beyond, because the rings serve as a dynamics laboratory by which scientists can study the effects of gravity in disks, both local and far away.

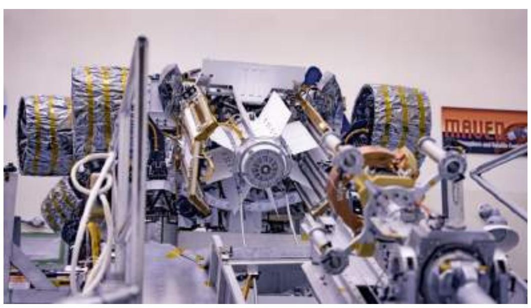
RADIOISOTOPE POWER

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**133.5**	**146.3**	**146.4**	**154.6**	**162.8**	**154.4**	**170.4**
Change from FY 2021			**0.1**				
Percentage change from FY 2021			**0.1%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Mars 2020 Perseverance Rover's Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) hot-fit check at KSC in FY 2020.

Planetary Science missions demand advances in technology to enable successful trips to distant solar system destinations, harsh environments, and to enable missions with highly challenging trajectories and operations. To meet these needs, Planetary Science supports the development of advanced multi-mission capabilities through technology investment in key spacecraft systems, such as radioisotope power. The Radioisotope Power Systems (RPS) Program managed by Glenn Research Center includes technology maturation and system development and works in partnership with the U.S. Department of Energy (DOE) to ensure continuing plutonium-238 production and Pu-238 production operations infrastructure. The program also supports nuclear launch approval activities.

EXPLANATION OF MAJOR CHANGES IN FY 2022

This budget transitions the RPS Next Gen Radioisotope Thermoelectric Generator (RTG) work to the General Purpose Heat Source - Radioisotope Thermoelectric Generator (GPHS-RTG, Cassini-type) production line for future missions. The projected 2028 Next Gen RTG performance was not significantly higher than that of the GPHS-RTG, and NASA determined the cost and schedule risk due to additional technology development was sufficiently high to justify not providing further investment at this time.

ACHIEVEMENTS IN FY 2020

NASA delivered and integrated a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) into the Mars Rover 2020 in advance of the July 30, 2020 launch. The team supported mission integration activities such as the MMRTG hot-fit check to the rover in early 2020 and final on-pad integration and

RADIOISOTOPE POWER

launch activities. The program delivered all milestones ahead of schedule, within budget, and exceeding the specified power needed for the mission.

The RPS program began engineering and National Environmental Policy Act (NEPA) support to the recently selected Dragonfly mission to Titan. Dragonfly has baselined the use of one MMRTG as its spacecraft power source. In addition, the Program has supported technical information exchanges in support of the Trident Mission, one of the four Discovery Announcement of Opportunity (AO) missions under Phase A study, which could use two MMRTGs.

Technology maturation activities continued in both thermoelectric and dynamic energy conversion areas. Potential advances in conversion efficiencies continue at the component level, with mission and system studies identifying possible system applications that would benefit. The program released a Sources Sought Notice, via DOE to solicit interest and identify capable businesses for a potential lunar surface Dynamic Radioisotope Power System (DRPS) solution. This potential solution will serve as a pathfinder for providing long-lived power for scientific exploration that is approximately four times more efficient than the traditional RPS systems that use thermoelectrics for the conversion technology. DRPS is a type of RPS that utilize moving parts to generate a current.

NASA completed assessment and finalized the programmatic environmental assessment for launches involving Radioisotope Heater Units (RHU). Per the interagency agreement with NASA, DOE continues implementation of the Constant Rate Production (CRP) plan for Pu-238, manufacturing new Pu-238, utilizing both the High Flux Isotope Reactor at Oak Ridge National Lab (ORNL), and the Advanced Test Reactor at Idaho National Laboratories (INL); packaging of the fuel into heat sources at Los Alamos National Laboratory (LANL); and placing them in storage at INL awaiting flight usage. CRP continues to perform ongoing facility maintenance and upgrades. DOE installed the new hot press glovebox at LANL and began its preparation for certification.

WORK IN PROGRESS IN FY 2021

Energy conversion technologies will result in delivery of three DRPS technology demonstration convertors and performance data from the industry teams. These efforts will culminate in a DRPS activity Gate 2 review in FY 2021. The program plans to initiate a DRPS design effort, via DOE for a potential lunar surface RPS solution in providing long-lived power for scientific exploration.

The next generation RTG technology effort will down-select to a single contractor and initiate the refurbishment of an existing GPHS-RTG system along with initiating the development of a production line needed to deliver a Next Gen Mod 1. This system will have performance like the prior GPHS-RTG systems used on Cassini and New Horizons.

NASA will continue to develop processes and decision-making steps applicable to RPS usage on NASA missions by developing a RHU-documented safety analysis by DOE. DOE will initialize the development of a documented safety analysis for the General Purpose Heat Source (GPHS) module, the building block for fueling an RPS.

NASA will fund DOE to support the Dragonfly mission for launch in 2027 with an MMRTG. NASA and DOE will continue the support technical discussion in support of the potential Trident mission. To support the Dragonfly and Trident missions, NASA (via DOE) will initiate the acquisition of another unfueled MMRTG.

RADIOISOTOPE POWER

KEY ACHIEVEMENTS PLANNED FOR FY 2022

NASA will continue to support the utilization of RPS on missions, provide a liaison between DOE and the Dragonfly mission on system integration, and engage with potential Discovery and New Frontiers AO mission teams as required. NASA will acquire, via DOE, existing and emerging RPS generators and will provide services to enable the baselined MMRTG for Dragonfly.

Program Elements

RADIOISOTOPE POWER SYSTEM (RPS)

The Radioisotope Power System project will continue to ensure the availability of RPS for the exploration of the solar system in environments where conventional solar or chemical power generation is impractical or impossible. NASA will achieve this goal by working with DOE to provide fueled RPS to missions and to support mission design and integration activities. The project will continue to reduce costs to the missions and increase system performance. RPS will continue energy conversion research and development to advance state-of-the-art performance in heat to electrical energy conversion.

DOE OPERATIONS AND ANALYSIS

NASA funds DOE national laboratory personnel and infrastructure required to maintain the capability to develop and fuel radioisotope power systems for deep space missions. DOE resumed domestic production of Plutonium-238 for the first time since the 1980s. They are now using a Constant Rate Production (CRP) approach. NASA funds the effort and the DOE Oak Ridge National Laboratory leads the effort and irradiates targets at its High Flux Isotope Reactor. The DOE Idaho National Laboratory (INL) supplies Neptunium-237 and irradiates targets at the Advanced Test Reactor, which is required to meet Pu-238 production rates. DOE continues to increase annual production, producing approximately 200-300 grams per year. As the process is refined and automated over the next several years, it is expected to ramp up to a full operational capability of 1.5 kilograms per year. DOE Los Alamos National Laboratory (LANL) manages the existing Pu-238 inventories and manufactures fuel, resulting in continual annual fueled clad manufacturing by LANL and delivery to INL at a CRP rate of 10 to 15 clads per year. INL integrates the fueled clads with generator systems and manages the transportation and launch operations activities in support of NASA missions.

RADIOISOTOPE POWER

Program Management & Commitments

Glenn Research Center manages the Radioisotope Power Systems (RPS) Program.

Program Element	Provider
RPS	Provider: GRC Lead Center: GRC Performing Center(s): GRC, JPL, GSFC, KSC, DOE Cost Share Partner(s): N/A
DOE Operations and Analysis	Provider: DOE Lead Center: GRC Performing Center(s): GRC Cost Share Partner(s): N/A

Acquisition Strategy

DOE provides radioisotope power systems and production operations on a reimbursable basis. Maturity of the technologies determines the acquisition of technologies and new systems. NASA or DOE laboratory competed acquisitions can be used to mature technology before system development begins. NASA-led DOE laboratory acquisitions procure unfueled designs and flight-qualified hardware when initiating a system development.

The program acquires content via existing Agency contracts with JPL and APL. The program will use in-house or competitive procurements as needed.

JAMES WEBB SPACE TELESCOPE

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**423.0**	**414.7**	**175.4**	**172.5**	**172.0**	**172.0**	**172.0**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

James Webb Space Telescope

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	1,800.1	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	1,800.1
Development/Implementation	6,218.3	423.0	357.4	**3.4**	0.0	0.0	0.0	0.0	0.0	7,002.1
Operations/Close-out	0.0	0.0	57.3	**172.0**	172.5	172.0	172.0	114.7	0.0	860.6
2021 MPAR LCC Estimate	**8,018.4**	**423.0**	**414.7**	**175.4**	**172.5**	**172.0**	**172.0**	**114.7**	**0.0**	**9,662.7**
Total Budget	**8,018.4**	**423.0**	**414.7**	**175.4**	**172.5**	**172.0**	**172.0**	**172.0**	**0.0**	**9,720.1**
Change from FY 2021				**-239.3**						
Percentage change from FY 2021				**-57.7%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

The James Webb Space Telescope on the vibration table at the Northrop Grumman Space Park facility where it completed its observatory-level environmental testing.

PROJECT PURPOSE

The James Webb Space Telescope (Webb) is a large, space-based astronomical observatory. The mission is in many ways a successor to the Hubble Space Telescope, extending Hubble's discoveries by looking into the infrared spectrum. Webb will observe the highly red-shifted early universe and study relatively cool objects like protostars and protoplanetary disks, which emit infrared light strongly where dust obscures shorter wavelengths. With more light-collecting area than Hubble and with near-to mid-infrared-optimized instruments, Webb will observe objects farther away and further back in time.

The four main science goals are to:

- Search for the first galaxies or luminous objects formed after the Big Bang;
- Determine how galaxies evolved from their formation until now;
- Observe the formation of stars from the first stages to the formation of planetary systems; and
- Measure the physical and chemical properties of planetary systems and investigate the potential for life in those systems.

While Hubble greatly improved knowledge about distant objects, its infrared coverage is limited. Light from distant galaxies is red-shifted out of the visible part of the spectrum and into the infrared by the expansion of the universe. Webb will explore the poorly understood epoch when the first luminous objects in the universe came into being after the Big Bang.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The project conducted a schedule risk assessment in June 2020, which resulted in an Agency change to the Launch Readiness Date (LRD) from March 2021 to October 2021. COVID-19 impacts, additional work, and appropriate schedule margin requirements made this change necessary. There is no change to the life cycle cost.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

PROJECT PARAMETERS

Webb is an infrared-optimized observatory that will conduct imaging and spectrographic observations in the 0.6- to 28-micrometer wavelength range. Webb will be roughly 100 times more capable than Hubble because its mirror is seven times larger. It will spend about twice as much time observing targets since the Earth will not be in the way. Its detectors cover larger regions of the sky and are always on (i.e., are always running in parallel), and its multi-object spectroscopic capabilities greatly expand the number of spectra per field.

The 6.5-meter primary mirror consists of 18 actively controlled segments. A multilayer sunshield the size of a tennis court passively cools the mirror, telescope optics, and instruments to about 40 Kelvin. Webb will launch in 2021 from Kourou, French Guiana on an Ariane 5 rocket contributed by the European Space Agency (ESA). Webb will operate in deep space about 1 million miles from Earth.

Webb's instruments include the Near-Infrared Camera (NIRCam), Near-Infrared Spectrograph (NIRSpec), Mid-Infrared Instrument (MIRI), and the Fine Guidance Sensor/Near-Infrared Imager and Slitless Spectrograph.

The Near-Infrared Camera takes images with a large field of view and high-resolution, over the wavelength range of 0.6 to 5 micrometers. The Near-Infrared Camera also aligns and focuses the optical telescope. The Near-Infrared Camera detects light from the earliest stars and galaxies in the process of formation, stars in nearby galaxies, young stars in the Milky Way, and solar system Kuiper Belt objects. The Near-Infrared Camera is equipped with coronagraphs, which allow astronomers to view dimmer objects near stars. With the coronagraphs, astronomers hope to determine the characteristics of planets orbiting nearby stars.

A spectrograph disperses light from an object into a spectrum. The atoms and molecules in the object imprint lines on its spectrum that uniquely fingerprint each chemical element present. Analyzing the spectrum of an object provides information on its physical properties, including temperature, mass, chemical composition, and motion.

The Near-Infrared Spectrograph can obtain simultaneous spectra of more than 100 objects in a single exposure, over the wavelength range of 0.6 to 5 micrometers.

The Mid-Infrared Instrument takes wide-field images and narrow-field spectra, over the wavelength range of 5 to 28 micrometers. The Mid-Infrared Instrument operates at about seven degrees Kelvin, which an onboard cooling system makes possible.

The Fine Guidance Sensor is a camera that provides fine pointing control and locks the telescope onto its target. The sensor operates over a wavelength range of 1 to 5 micrometers. The Near-Infrared Imager and Slitless Spectrograph instrument provide unique imaging and spectroscopic modes to investigate the distant universe, as well as exoplanets.

For more information, go to: http://www.jwst.nasa.gov

ACHIEVEMENTS IN FY 2020

NASA made significant progress in the integration and testing of the Webb system. The project also completed significant and technically challenging developments and tests successfully. The project

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

completed Key Decision Point D (KDP-D) program review with entrance into the assembly, integration and test phase of the mission; the project completed Observatory level acoustics testing; and the project completed Observatory level vibration testing.

WORK IN PROGRESS IN FY 2021

In FY 2021, the project will complete post-environmental testing sunshield deploy, stow, and fold activities for launch configuration; select Cycle 1 General Observing awards for the mission; conduct testing of the Webb flight operations system and science processing system; and transport Webb to the launch site in Kourou, French Guiana.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The President's FY 2022 budget request provides the full level of funding required to keep Webb on schedule for a FY 2022 launch. In FY 2022, the project plans to launch the observatory; conduct six months of on orbit commissioning of the observatory; and begin normal operations.

SCHEDULE COMMITMENTS/KEY MILESTONES

NASA plans to launch Webb in October 2021 to begin a five-year prime mission.

Milestone	Confirmation Baseline Date	FY 2022 PB Request
Rebaseline	Feb 2019	Feb 2019
System Integration Review (SIR) Part 1	Aug 2019	Jul 2019
System Integration Review (SIR) Part 2	N/A	Oct 2019
KDP-D	Sep 2019	Nov 2019
KDP-E	Jan 2021	Sep 2021
Launch	Mar 2021	Oct 2021
Begin Phase E	Sep 2021	May 2022
End of Prime Mission	Sep 2026	May 2027

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2019	7,002.6	N/A	2021	7,002.1	0%	LRD	Mar 2021	Oct 2021	7

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimates reflect the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost. NASA originally baselined Webb in 2009, re-baselined Webb in 2012, and conducted a re-plan in 2018 which became a new reporting baseline in Public Law 116-6, Consolidated Appropriations Act, 2019. The original baseline is provided in the Supporting Data section.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**7,002.6**	**7,002.1**	**-0.5**
Aircraft/Spacecraft	3,818.5	3,962.4	+143.9
Payloads	776.2	826.0	+49.8
Systems Integration & Test (I&T)	441.2	503.1	+61.9
Launch Vehicle	10.4	2.0	-8.4
Ground Systems	801.6	922.4	+120.8
Science/Technology	34.3	45.6	+11.3
Other Direct Project Costs	1,120.4	740.7	-379.7

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Project Management & Commitments

NASA Headquarters is responsible for Webb program management and GSFC is responsible for Webb project management.

Element	Description	Provider Details	Change from Baseline
Observatory	Includes Optical Telescope Element (OTE), spacecraft, sunshield, observatory assembly integration and testing, and commissioning. Designed for at least a five-year lifetime. Northrop Grumman Aerospace Systems (NGAS) has the lead for the OTE, sunshield, spacecraft bus, and selected assembly, integration, and testing activities	Provider: NGAS and GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Mission management and system engineering	Includes management of all technical aspects of mission development and system engineering of all components	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
ISIM	Contains the science instruments and Fine Guidance Sensor. Provides structural, thermal, power, command, and data handling resources to the science instruments and Fine Guidance Sensor	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
NIRCam	Operates over the wavelength range of 0.6 to 5 micrometers and is optimized for finding first light sources	Provider: University of Arizona, Lockheed Martin Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
NIRSpec	Operates over the wavelength range of 0.6 to 5 micrometers with three observing modes	Provider: ESA Lead Center: ESA Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
MIRI	Operates over the wavelength range of 5 to 28 micrometers and provides imaging, coronagraphy, and spectroscopy	Provider: ESA, University of Arizona, JPL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): ESA	N/A

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Fine Guidance	Provides scientific target pointing information to the observatory's attitude control sub-system	Provider: Canadian Space Agency (CSA) Lead Center: CSA Performing Center(s): N/A Cost Share Partner(s): CSA	N/A
Launch vehicle and launch operations	Ariane 5	Provider: ESA Lead Center: ESA Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Ground control system and science operations and control center	Includes mission operations and science operations center	Provider: Space Telescope Science Institute (STScI) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The Ariane 5 launch vehicle anomaly investigation and return to flight continues to slip, Then: Webb's 10/31/2021 launch date will be potentially impacted. The project has no launch date constraints, although the development cost cap could be impacted. NASA has not requested additonal budget due to COVID schedule impacts.	The program and project are working closely with ESA and Arianespace on their anomaly disposition, including the retrofit of the fairing, qualification testing, and schedule impacts. There are two Ariane 5 launches prior to Webb.

Acquisition Strategy

The project has awarded all major contracts.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Science and Operations Center	STScI	Baltimore, MD
NIRCam	University of Arizona; Lockheed Martin	Tucson, AZ Palo Alto, CA
Observatory	NGAS Ball Aerospace ITT/Exelis/Harris Alliant Techsystems	Redondo Beach, CA Boulder, CO Rochester, NY Edina, MN
Near-Infrared Detectors	Teledyne Imaging Systems	Camarillo, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Apr 2010	Critical Design Review (CDR)	Determined mission design is mature and recommended a more in-depth review of the integration and testing plan	N/A
Quality	Test Assessment Team	Aug 2010	Evaluate plans for integration and testing	The team recommended several changes to the test plan	N/A
Other	Independent Comprehensive Review Panel	Oct 2010	Determine the causes of cost growth and schedule delay on Webb, and estimate the launch date and budget, including adequate reserves	The report made 22 recommendations, covering several areas of management and performance	N/A
Other	The Aerospace Corporation	Apr 2011	Analysis of alternatives	Determined that Webb design was still the best value to achieve the primary scientific objectives of the mission	N/A

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	SRB	May 2011	Review technical, cost, and schedule plans	The SRB proposed rebaselined project technical, cost, and schedule plans and made recommendations to the Agency	N/A
Performance	NASA Headquarters Office of Evaluation	Jun 2012	Replan assessment review	A review assessed progress against replan	N/A
Performance	SRB	Apr 2016	OTE/Integrated Science SIR	Completed	N/A
Performance	SRB	Aug 2016	OTE/Integrated Science Pre-Environmental Review	Completed	N/A
Other	SRB	Mar 2018	Schedule risk assessment	SRB recommended new launch date	N/A
Other	IRB	Apr 2018	Conduct assessment of mission development for schedule and mission success	The IRB recommended to Agency re-baseline of schedule, cost, and launch date	N/A
Other	SRB	Apr 2019	Interim review schedule risk	Completed; validated Mar 2021 LRD is achievable	N/A
Performance	SRB	Part 1 Jul 2019 Part 2 Oct 2019	Observatory SIR	Completed; confirmed project was ready to proceed to observatory integration	N/A
Performance	SRB	Aug 2021	Operational Readiness Review	TBD	N/A

ASTROPHYSICS

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Astrophysics Research	231.2	249.3	**285.5**	328.0	339.0	344.1	345.3
Cosmic Origins	202.7	203.8	**115.0**	126.3	114.7	115.1	126.9
Physics of the Cosmos	132.8	146.4	**156.0**	160.0	169.1	159.8	167.6
Exoplanet Exploration	554.2	552.4	**543.3**	547.6	525.8	489.2	431.5
Astrophysics Explorer	185.3	204.4	**300.4**	300.0	342.9	404.1	522.9
Total Budget	**1,306.2**	**1,356.2**	**1,400.2**	**1,461.8**	**1,491.5**	**1,512.3**	**1,594.1**

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Astrophysics

ASTROPHYSICS RESEARCH

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Astrophysics Research and Analysis	86.6	91.1	**107.4**	94.9	95.2	95.2	95.2
Balloon Project	44.8	44.8	**45.8**	45.7	46.3	46.3	46.3
Science Activation	45.6	45.6	**55.6**	55.6	55.6	55.6	55.6
Other Missions and Data Analysis	54.3	67.8	**76.7**	131.8	141.9	147.0	148.2
Total Budget	**231.2**	**249.3**	**285.5**	**328.0**	**339.0**	**344.1**	**345.3**
Change from FY 2021			**36.2**				
Percentage change from FY 2021			**14.5%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

NASA launched the Balloon-Borne Chirpsounder demonstration flight on a zero-pressure scientific balloon May 4, 2021, at 1 p.m. EDT from Fort Sumner, New Mexico. The balloon flew ~4 hours before it descended southwest of Albuquerque, New Mexico. Preliminary indications show operations performed nominally.

The Astrophysics Research program develops innovative technologies for future missions to explore and understand the cosmos. The program studies a wide range of astronomical observations from the births of the first stars, black holes, and distant galaxies in the cosmic history, to the nature of planets circling other stars in our Milky Way galaxy. High-altitude balloon and sounding rocket flights test new types of instruments and study the nature of energetic particles.

The program provides basic research awards for scientists to test their theories and to understand how they can best use data from NASA missions to gain new knowledge from the cosmos. Awardees analyze the data from Astrophysics missions to understand astronomical events, such as the explosion of a star, or the fingerprints of early cosmic history in the microwave background. The Science Activation project delivers the Science Missions Directorate's (SMD) unique science content and expertise to learners of all ages through networks of local and national partners.

ASTROPHYSICS RESEARCH

EXPLANATION OF MAJOR CHANGES IN FY 2022

The budget request increases funding for Astrophysics research to enhance NASA's engagement with minority-serving institutions and to address the priorities expressed in the 2021 Astrophysics Decadal Survey recommendations. The budget supports an increase for Science Activation to combat social inequities. The project will achieve this through competitive selections, and augmented collaborations for rural, indigenous, and other underserved areas; citizen science projects; and plans to use lessons-learned from past celestial and other milestone events to engage underserved communities.

ACHIEVEMENTS IN FY 2020

NASA brought its first Astrophysics CubeSat mission, HaloSat, to a successful completion. It was developed jointly by the University of Iowa, NASA Goddard Space Flight Center, and the Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS). NASA first funded HaloSat in FY 2018, launched it in May 2018, and deployed it from the International Space Station in July 2018. Halo Sat re-entered Earth's atmosphere in January 2021. During science operations, HaloSat completed two sky surveys with its X-ray instrument. Four graduate students used the data to complete their Ph.D. and Master's degree thesis projects.

In FY 2020, NASA launched three Astrophysics sounding rocket payloads. The first (October 7, 2019) and third (September 8, 2020) launches were of the Determining Unknown yet Significant Traits (DUST) mission, a mission studying dust grain growth in micro gravity. The second sounding rocket mission, Far-ultraviolet Off Rowland-Circle for Imaging and Spectroscopy (FORTIS), from John Hopkins University, launched on October 28, 2019 and demonstrated multi-object spectroscopy over wide angular fields in the far- ultraviolet radiation (UV).

The Suborbital Imaging Spectrograph for Transition region Irradiance from Nearby Exoplanet (SISTINE) Rocket mission from the University of Colorado launched on August 11, 2019. SISTINE enables studies of the UV environment around low-mass stars and the effects of UV on potential exoplanet atmospheres. NASA launched all payloads from the White Sands Missile Range in New Mexico.

NASA conducted three balloon campaigns in FY 2020, specifically the Fall Fort Sumner, New Mexico, campaign from August - October 2019, the Antarctica campaign in December 2019-January 2020, and the super-pressure balloon campaign from Wanaka, New Zealand. The Antarctica campaign launched two astrophysics missions (SuperTIGER and BLAST-TNG). SuperTIGER (Trans Iron Galactic Element recorder) led by Washington University in St. Louis, MO is studying source material and acceleration processes for the galactic cosmic radiation, by measuring the chemical abundance of elements heavier than iron in the cosmic radiation. Balloon-borne Large Aperture Submillimeter Telescope (BLAST-TNG) from the University of Pennsylvania is investigating the effects of magnetic field lines on star formation. The Fall Fort Sumner, NM campaign included heliophysics, earth atmospheric science, astrophysics, student experiments, and engineering test missions. NASA terminated the super-pressure balloon campaign in Wanaka New Zealand before the launch and the deployed team had to return to the United States due to the onset of COVID-19. NASA also cancelled the Palestine, Texas, and Fall Fort Sumner campaigns due to COVID-19.

NASA funded researchers at Princeton University led a theory investigation showing how pulsars produce their coherent radio emission, using first-principles numerical simulations. The team found that electron–positron pair production near the neutron star launches powerful electromagnetic waves that can propagate through the dense plasma in the pulsar magnetosphere. These waves are as radio emission on

ASTROPHYSICS RESEARCH

Earth. These results lay the foundation for the solution of a 55 years-old problem of the origin of pulsar emission.

NASA funded researchers in an international collaboration led by the Louisiana State University of the Calorimetric Electron Telescope (CALET) high-energy particle astrophysics experiment has completed five years of on-orbit operation as an attached external payload on the International Space Station. In collaboration with partners in Japan and Italy, the CALET team publish groundbreaking direct observations of the highest energy, 4.8 TeV (Trillion Electronvolts), cosmic ray electrons, measurements of energetic protons and gamma rays, carbon and oxygen cosmic ray nuclei, as well as new observations of Relativistic Electron Precipitation (REP) events in 2020.

In 2020, the Super Trans-Iron Galactic Element Recorder (SuperTIGER) instrument successfully flew for the second time on a 39 million cubic foot stratospheric balloon from McMurdo Station, Antarctica. This 32-day flight was the culmination of five years of effort, including three challenging Antarctic seasons, and significantly augmented the ultra-heavy cosmic-ray data set from the record breaking first 55-day flight. These very rare cosmic rays heavier than nickel produced primarily by neutron-capture processes provide important clues for the origins of cosmic rays and where these elements synthesize.

The Science Activation project accomplishments include:

- 50,500 volunteer events since the program began, including 1,500 during the pandemic;
- 350 science centers and museums received hands-on toolkits that were also available digitally in both English and Spanish to all users;
- 423 subject matter experts provided science content across the four disciplines; and
- Over 1.9 million educators accessed online science materials tailored to State-based education standards, organized by grade-level, not including a 700 percent increase in downloads during the pandemic;
- The National Academies of Science, Engineering, and Mathematics (NASEM) assessed the project and released its report in November 2019. The report found the project to be of considerable value and suggested a few ideas for improvement; based on the report's suggestions, the project solicited and conducted both internal and external virtual peer reviews.

WORK IN PROGRESS IN FY 2021

NASA scheduled six Astrophysics sounding rockets for launch in FY 2021. The first two and the last mission will launch from the White Sands Missile Range. The first sounding rocket is the Dual Channel Extreme Ultraviolet Continuum Experiment (DEUCE) mission from University of Colorado Boulder. It launched on November 2, 2020 and is testing if B-Stars are viable candidates for providing the ionizing radiation to the intergalactic medium. The second sounding rocket mission, CIBER-2 (Cosmic Infrared Background Experiment), from Rochester Institute of Technology will measure the cosmic near-infrared extragalactic background light.

NASA-funded researchers at University of Maryland Baltimore County along with astroparticle physicists and graduate students at other universities have developed the nuSpaceSim simulation software package designed as an end-to-end modeling tool for the design of sub-orbital and space-based neutrino detection experiments. nuSpaceSim is a comprehensive suite of physics modeling packages designed to

ASTROPHYSICS RESEARCH

accept an experimental design input and then model the experiment's sensitivity to both neutrino flux as well as astrophysical transient events. nuSpaceSim uses state-of-the art, vectorized and multi-threaded computer code to precisely simulate neutrino interactions in the Earth and then model the generation of extensive air shower (EAS) optical and radio emission signals from Earth. nuSpaceSim is the first neutrino simulation package that combines the neutrino-induced optical and radio signal modeling in a single package to facilitate the experimental design, observation strategy, and interpretation of data for space-based neutrino experiments. The initial public release of nuSpaceSim will be in 2021 to the neutrino research community.

NASA planned four balloon campaigns in 2021; the New Zealand campaign to launch test flight of the super-pressure balloon with a science mission of opportunity, the Spring Fort Sumner, New Mexico campaign, the Palestine, Texas, campaign, and the Fall Fort Sumner, New Mexico campaign. NASA postponed the Antarctica long-duration balloon campaign to FY 2022 due to COVID-19 as well as the New Zealand campaign and the Palestine, Texas campaign. The Columbia Scientific Balloon Facility team is conducting crew chief training. These training exercises (simulated balloon launches) allow the team to practice launching super-pressure like balloons and train the next generation of crew chiefs for launch operations.

NASA released all Halo Sat mission data in public data archives and the mining and publication of the data is still ongoing. Astrophysics has four more CubeSats in development: Colorado Ultraviolet Transit Experiment (CUTE), led by the University of Colorado Boulder, measures UV spectra of planets transitioning in front of stars. BurstCube, led by the NASA Goddard Space Flight Center, detects sudden gamma-ray bursts that occur when neutron stars collide. Supernova Remnants and Proxies for ReIonization Testbed Experiment (SPRITE), led by the University of Colorado Boulder, observes UV spectra of star forming regions in numerous nearby galaxies, to trace the history of star formation. In FY 2020, NASA began funding a new CubeSat called BlackCat, led by The Pennsylvania State University, which will discover transient X-ray sources.

NASA completed nine six-month long studies of possible SmallSat missions to do high priority astrophysics science at a lower cost than a typical Small Explorer Mission. NASA selected one of these (Dorado) for a competitive Phase-A downselect in the recent Explorers Mission of Opportunity solicitation. Based on the success of these studies, NASA initiated a second set of such studies, which will complete early in calendar-year 2021.

Science Activation advances knowledge for learners of all ages. NASA realigned the Science Activation project with stakeholder, community, and National Academies (NAS) feedback. By the end of FY 2021, the Science Activation plans better connections between subject matter experts in both strategic and competed arenas and the community-based networks in all 50 states and territories. New processes will ensure cohesion across the collective set of awards and stronger linkage between objectives and measures of success using agreed upon mid-level objectives. In addition, NASA will highlight and report new citizen science efforts. The revitalized project (phase 2.0) began January 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

NASA will continue a competed Astrophysics Research program with emphasis on detector, instrument, optics, and key supporting technologies for use as payloads in future missions. Theoretical work will provide the foundation to develop science requirements for new missions. Data analysis will multiply the science yield from NASA's astrophysics missions.

ASTROPHYSICS RESEARCH

The Astrophysics Division's Research & Analysis task force on equity, diversity, and inclusion continues to align division-level practices with the NASA core value and SMD science strategy. Such efforts include examining the R&A process for better inclusion and diversity and piloting inclusion plans as an evaluation criterion for R&A programs. As a pilot initiative, the Astrophysics Division will require Astrophysics Theory Program proposals to include an inclusion plan for creating and sustaining a positive and inclusive working environment for those carrying out the proposed investigation, and contributions the proposed investigation will make to the training and development of a diverse and inclusive scientific workforce.

The Balloon project plans to support a super-pressure balloon campaign from New Zealand, and two domestic campaigns with conventional flights from Palestine, Texas, and Fort Sumner, New Mexico (Spring and Fall).

The Sounding Rocket project is planning a campaign in Australia at the Equatorial Launch Australia (ELA) site. Three missions: Dual-channel Extreme Ultraviolet Continuum Spectrograph (DEUCE), Suborbital Imaging Spectrograph for Transition region Irradiance from Nearby Exoplanet (SISTINE), and X-ray Quantum Calorimeter (XQC) will observe astrophysical targets in the Southern Hemisphere. The three sounding rocket launches from Australia will have access to celestial targets in the Southern Hemisphere including the center of the Milky Way. The first Australia campaign payload is the above-mentioned DEUCE mission. NASA recovered the DEUCE payload after the November 2, 2020 launch, and will launch it again in the southern Hemisphere. The SISTINE payload is the second Australia sounding rocket mission. The third mission XQC, from the University of Wisconsin will obtain high spectral resolution X-ray observation of diffuse hot gas. NASA is planning an Australia campaign for June-July of 2022. The sixth sounding rocket mission in FY 2022 is the Rocket for Extended X-ray Spectroscopy (tREXS) from the Pennsylvania State University, which is spectrally resolve the soft X-ray background.

As a new activity beginning in FY 2022, the Science Activation project will expand its expert base and connections into the Nation's communities for learners of all ages, not just students. The project will continue to fill gaps identified in the 2019 National Academies of Sciences, Engineering, and Medicine (NASEM) assessment and meet stakeholder priorities in the areas of rural learners, underserved communities, and bilingual language learners. All efforts have independent evaluation of measures of success.

Science Activation will combat social inequities through competitive selections to broaden participation for learners in new and augmented collaborations for rural, indigenous, and other underserved areas; citizen science projects; and plans to use lessons learned from past celestial and other milestone events to engage these communities.

Program Elements

RESEARCH AND ANALYSIS

This project supports basic research, solicited through NASA's annual Research Opportunities in Space and Earth Sciences (ROSES) announcements. NASA solicits investigations relevant to Astrophysics over the entire range of photon energies, gravitational waves, and particles of cosmic origin. Scientists and

ASTROPHYSICS RESEARCH

technologists from a mix of disciplines review proposals and provide findings that underlie NASA's merit-based selections.

Astrophysics Research and Analysis solicits technology development for detectors and instruments for potential use on future space flight missions, and science and technology investigations using sounding rockets, high-altitude balloons, and similar platforms. A new type of scientific instrument often flies first on a stratospheric balloon mission or on a sounding rocket flight, which takes it briefly outside Earth's atmosphere. Instruments for balloons and sounding rockets are less expensive than orbital missions and experimenters can build them quickly to respond to unexpected opportunities, such as a newly discovered supernova. The experimenter usually retrieves the equipment after the flight so that new instruments can be tested, improved, and flown again. Suborbital flights are important for training the next generation of scientists and engineers to maintain U.S. leadership in Science Technology Engineering and Math. The project also supports small experiments flown on the International Space Station, laboratory astrophysics, and limited ground-based observations.

The Astrophysics Theory program element solicits basic theory investigations needed to interpret data from NASA's space astrophysics missions and develop the scientific basis for future missions. Astrophysics Theory topics include the formation of stars and planets, supernova explosions and gamma-ray bursts, the birth of galaxies, dark matter, dark energy, and the cosmic microwave background.

The Exoplanet Research program element solicits observations to detect and characterize planets around other stars and to understand their origins.

The Nancy Grace Roman Technology Fellowship develops early career researchers, who could lead future flight instruments and missions. Initially, NASA identifies promising early career researchers and supports their investigations. NASA then selects a subset of fellows for additional funding to start a laboratory or develop a research group at the Fellow's institution.

BALLOON PROJECT

The Balloon project offers inexpensive, high-altitude flight opportunities for scientists to conduct research and test new technologies before space flight application. Balloon experiments cover a wide range of disciplines in astrophysics, solar physics, heliospheric physics, and Earth upper-atmosphere chemistry as well as selected planetary science, such as comet observations. Observations from balloons have detected echoes of the Big Bang and probed the earliest galaxies. The Balloon project continues to increase balloon size and enhance capabilities, including an accurate pointing system to allow high-quality astronomical imaging and a super-pressure balloon that maintains the balloon's integrity at a high altitude to allow much longer flights at mid-latitudes that include nighttime viewing of astronomical objects.

SCIENCE ACTIVATION

The Science Activations project delivers SMD's unique content and expertise into the learning environment for learners of all ages. For the next five years, a cooperative network of 29 competitively-selected teams from across the Nation will connect NASA science experts, real content, and experiences with community leaders to do science in ways that activate minds and promote deeper understanding of our world and beyond. Awardees of cooperative agreements work collaboratively with each other, with internal NASA organizations, and with local and national partners to achieve a multiplier effect utilizing NASA and SMD investments. They are focused on building stronger connections with subject matter

ASTROPHYSICS RESEARCH

experts and broadening participation by underserved audiences. All awards include independent evaluators that assess the individual project's measures of success as well as a portfolio-level independent evaluator.

In 2019, NASA requested the National Academies (NASEM) to conduct an overarching assessment of Science Activation, and in November 2019 NASEM validated the portfolio and approach. Included in the assessment were seven recommendations to improve efforts for the next five years. Recommendations included: How to establish an understanding of how Science Activation meets the needs of audiences and fits into the larger national ecosystem; how NASA science assets will connect to meet needs and how those outcomes will be measured; how will the collective network work better together; how the new awardees and partners can improve the portfolio, especially in the areas of broadening participation; how deeper connections can be formed with subject matter experts; how outside independent advisors could be utilized; and how an independent portfolio-level evaluator could add value to the success of the program.

By the end of FY 2021, the Science Activation plans better connections between subject matter experts in both strategic and competed arenas and the community-based networks in all 50 states and territories. Funding will provide opportunities for indigenous learners in the Southwest, Appalachia, upper Northwest, and Alaska. Neurodiverse high school students will have new opportunities as well as low-vision and bilingual language learners in communities across the United States. One example is a grant to engage autistic high school students in California and New York in informal NASA activities, including building and launching a rocket payload using a NASA funded telescope. New processes will ensure cohesion across the collective set of awards and stronger linkage between objectives and measures of success using agreed upon mid-level objectives. In addition, NASA will highlight and report new citizen science efforts for life-long learners. The revitalized project (phase 2.0) began January 2021.

Program Schedule

The program issues solicitations every year. A Senior Review process assesses all missions in the extended operations phase every three years and all data archives every three or four years.

Date	Significant Event
Q1 FY 2021	ROSES-2020 selection within six to nine months of receipt of proposals
Feb 2021	ROSES-2021 NRA solicitation release
Q1 FY 2022	ROSES-2021 selection within six to nine months of receipt of proposals
Feb 2022	ROSES-2022 NRA solicitation release
Mar 2022	Senior Review of Operating Missions
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Feb 2023	ROSES-2023 NRA solicitation release
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Feb 2024	ROSES-2024 NRA solicitation release

ASTROPHYSICS RESEARCH

Date	Significant Event
Mar 2024	Astrophysics Archives Programmatic Review
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Feb 2025	ROSES-2025 NRA solicitation release
March 2025	Senior Review of Operating Missions
Q1 FY 2026	ROSES-2025 selection within six to nine months of receipt of proposals
Feb 2026	ROSES-2026 NRA solicitation release

Program Management & Commitments

Program Element	Provider
Research and Analysis Project	Provider: All NASA Centers Lead Center: Headquarters (HQ) Performing Center(s): All Cost Share Partner(s): None
Balloon Project	Provider: Wallops Flight Facility (WFF) Lead Center: WFF Performing Center(s): WFF Cost Share Partner(s): None
Science Activation	Provider: All NASA Centers Lead Center: Headquarters (HQ) Performing Center(s): All Cost Share Partner(s): OSTEM

Acquisition Strategy

NASA issues solicitations for competed research awards each February through ROSES. Panels of subject-matter expert scientists conduct peer reviews on all proposals. A Senior Review panel reviews all missions in extended operations phase every three years, and all data archives every three or four years.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Operation of the Columbia Scientific Balloon Facility	Northrop Grumman Innovation Systems	Palestine, TX, Fort Sumner, NM, and New Zealand

ASTROPHYSICS RESEARCH

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Senior Review of Operating Missions	2019	Review of Astrophysics operating missions	Recommendations on mission extensions	2022, 2025
Quality	National Academies Independent Assessment of Science Activation Committee	2019	Validation of approach and logic model	Informs next phase of project ending in 2026	One-Time
Quality	Astrophysics Archives Programmatic Review	2020	Review of Astrophysics data archives	Recommended improvements in archives	May 2023
Quality	Astrophysics Advisory Committee	2020	Review to assess program against strategic objectives of Astrophysics science	Rated GREEN for all science strategic objectives	2021
Quality	Astrophysics Advisory Committee	2021	Government Performance and Results Act/Modernization Act	TBD	2022
Quality	Senior Review of Operating Missions	2022	Review of Astrophysics operating missions	TBD	2025
Quality	Astrophysics Archives Programmatic Review	May 2023	Review of Astrophysics data archives	TBD	TBD
Quality	Astrophysics Advisory Committee	2022	Review to assess program against strategic objectives of Astrophysics science	TBD	TBD

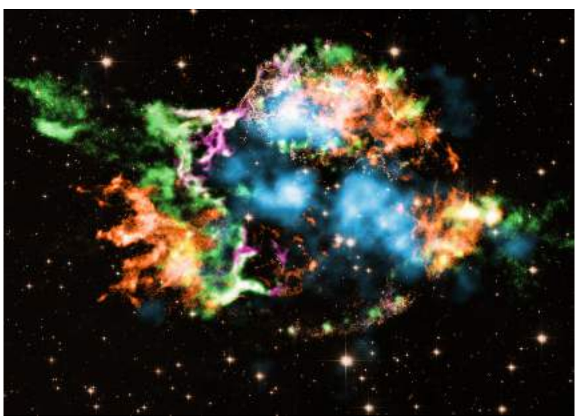
OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Astrophysics Directed R&T	0.0	0.0	**7.9**	8.3	15.6	19.7	19.5
Contract Administration, Audit and Quality Assurance Services	12.7	17.7	**20.0**	20.0	20.0	20.0	20.0
Astrophysics Senior Review	0.0	0.0	**0.0**	51.5	51.7	52.0	52.5
Astrophysics Data Program	20.4	21.6	**22.6**	23.6	23.6	23.6	23.6
Astrophysics Data Curation and Archival	21.2	28.5	**26.3**	28.4	31.0	31.7	32.7
Total Budget	**54.3**	**67.8**	**76.7**	**131.8**	**141.9**	**147.0**	**148.2**
Change from FY 2021			**8.9**				
Percentage change from FY 2021			**13.1%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



The HEASARC is compiling data to make discoveries. Somehow a theoretical implosion converts to an actual explosion and the star blows itself apart. How this change of infall to outflow happens is a matter of uncertainty and debate. Earlier theoretical models completely failed to produce a stellar explosion through relatively straightforward physics. More modern models suggest that subatomic particles called neutrinos play a key role in the explosion. Neutrinos, so-called "ghost particles" are difficult to detect since they hardly ever interact with matter under normal conditions.

Astrophysics Research Other Missions and Data Analysis funds Astrophysics senior review; data program; data curation and archival; support for contract administration; contract audits and contract quality assurance for the Science Mission Directorate; and the Astrophysics directed research and technology project.

Mission Planning and Other Projects

DIRECTED RESEARCH AND TECHNOLOGY

This project funds the civil service staff that will work on emerging Astrophysics projects, instruments, and research.

OTHER MISSIONS AND DATA ANALYSIS

CONTRACT ADMINISTRATION, AUDIT, AND QUALITY ASSURANCE SERVICES

This project provides critical safety and mission product inspections as well as contract audit services from the Defense Contract Management Agency and Defense Contract Audit Agency, respectively. It also provides for contract assurance audits, assessments, and surveillance by the NASA Contract Assurance Services Program.

ASTROPHYSICS SENIOR REVIEW

Every three years, the Astrophysics division conducts a Senior Review to perform evaluations of missions that have successfully completed, or are about to complete, their prime mission operation phase. The Senior Review findings help NASA prioritize which missions will receive funding for extended operations. The 2019 Senior Review found that NASA's fleet of operating astrophysics missions constitute a "portfolio of extraordinary power" and recommended that NASA continue their operations. The next Senior Review will take place in spring 2022.

ASTROPHYSICS DATA ANALYSIS PROGRAM (ADAP)

ADAP solicits research that emphasizes the analysis of NASA space astrophysics data archived in the public domain at one of NASA's Astrophysics Data Centers. NASA's archival astronomical data holdings continue to grow with the ongoing successful operation of a portfolio of missions. The missions range from modest Explorer-class like the Nuclear Spectroscopic Telescope Array (NuSTAR) and the Transiting Exoplanet Survey (TESS) to the great observatories Hubble and Chandra. Investigations funded under the ADAP ensure that data holdings continue to be the subject of vigorous scientific research, thereby maximizing the scientific return on NASA mission investments.

The ADAP portfolio includes focused investigations that involve the analysis of archival data from a single mission, as well as broader investigations that combine data from multiple missions and span a wide wavelength range. Such multi-mission, multi-wavelength studies are a unique and exciting aspect of the program. The combinations of data collected by different missions operating in different regions of the spectrum often yield scientific insights that are unobtainable through analysis of the individual data sets alone.

Recent Achievements

During FY 2020, the ADAP supported more than 160 science investigators at academic institutions, NASA centers, and other Federal laboratories across the country. The scope of the investigations is as vast as the universe itself. It includes studies of every aspect of the Milky Way Galaxy including the physics and chemistry of the Interstellar Medium, the formation and evolution of stars and exoplanetary systems, the detection and characterization of exoplanets, and the structure of stars and the processes by which they age and die. It also includes the physics of supernovae explosions and the exotic neutron stars as well as the black holes they produce.

Beyond our galaxy, ADAP-supported researchers are studying the fundamental nature of galaxies and the mechanism by which the very first proto-galaxies formed after the Big Bang grew and evolved into the diverse population of galaxies we observe today. They are also studying active galaxies, the hearts of which contain supermassive black holes that produce enormous amounts of energy and drive furious bursts of star formation. There are ADAP investigations that peer further back into the history of our

OTHER MISSIONS AND DATA ANALYSIS

universe, back to a time before the first stars and the first galaxies, and search for clues into the nature of the Big Bang and insight into the fate of our universe.

ASTROPHYSICS DATA CURATION AND ARCHIVAL RESEARCH (ADCAR)

The Astrophysics Data Centers constitute an ensemble of archives receiving processed data from individual missions and making them accessible to the scientific community. After the completion of a mission, the relevant, active, multi-mission archive takes over all data archiving activities. ADCAR covers the activities of the Astrophysics Data Centers and the NASA Astronomical Virtual Observatories (NAVO).

Recent Achievements

The Astrophysics Archives continued to provide their extensive services and community support through telework, despite COVID-19.

In FY 2020, the Astrophysics Data System (ADS) bibliographic database launched personalized reading recommendations based on a subscriber's research interest. The user may now use institutional affiliations as selection criteria, providing a reliable way to identify researchers and evaluate institutional research output. The ADS data holdings have increased to 14.9 million records and 130 million citations, an increase of 6 percent and 10 percent year-over-year, respectively.

In FY 2020, the High Energy Astrophysics Science Archive Center (HEASARC) worked with multiple mission teams on future data releases and archive plans. Additionally, the HEASARC released data from multiple sounding rocket and balloon flights and from the CubeSat Halosat. The HEASARC made numerous releases of new software capabilities, web services and calibration updates, and responded to 230 million data requests (file downloads) and about 10 million catalog queries.

In FY 2020, the Infrared Science Archive (IRSA) responded to 23 million queries; Nearly 1,800 refereed astrophysics journal articles featured IRSA data. IRSA now holds the public and proprietary data for the Stratospheric Observatory for Infrared Astronomy (SOFIA). In addition to the 2020 Near-Earth Object Wide-field Infrared Survey (NEOWISE) Data Release and Planck Public Release 3, IRSA made regular data releases for Spitzer, SOFIA, and NASA's InfraRed Telescope Facility.

The NASA/Infrared Processing & Analysis Center Extragalactic Database (NED) responded to more than 107 million web server queries, and added data for 64,000 new objects, making 1.3 million new object links to articles. NED now contains over 1.1 billion distinct objects and nearly 14 billion photometric measurements. NED released enhancements to the user interface, and increased interoperability with ADS.

In FY 2020, virtual observatory (VO) protocol requests to the NASA archives increased by about 30 percent to about 58 million. The 2020 Senior Review found that "NAVO and VO protocols are key to interoperability" across the NASA archives. NAVO leads in developing the PyVO Python library to enable full integration of archive access within standard frameworks used in astronomical data analysis. NAVO is planning enhancements of VO protocols to address the coming era of big data.

COSMIC ORIGINS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Hubble Space Telescope	90.8	93.3	**98.3**	98.3	98.3	98.3	98.3
Other Missions and Data Analysis	111.9	110.5	**16.7**	28.0	16.4	16.8	28.6
Total Budget	**202.7**	**203.8**	**115.0**	**126.3**	**114.7**	**115.1**	**126.9**
Change from FY 2021			**-88.8**				
Percentage change from FY 2021			**-43.6%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

This Hubble image of the central bar in the nearby galaxy NGC 1365 captures hundreds of baby stars that are forming from the coalescing gas and dust (seen as the dark dust lanes). These data are part of a joint survey with the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile. The survey will help scientists understand how the diversity of galaxy environments observed in the nearby universe, including NGC 1365 and other galaxies such as NGC 2835 and NGC 2775, influence the formation of stars and star clusters. (SSC/Caltech) et al., October 9, 2019.

"How did we get here?" This simple but fundamental question drives the broad science objectives of NASA's Cosmic Origins program. Our search for answers raises underlying questions and topic areas, such as, how and when did the first stars and galaxies form? When did the universe first create the elements critical for life? How did galaxies evolve from the very first systems to the types we observe "in the here and now," such as the Milky Way in which we live? How do stars and planetary systems form and change over time?

Observatories collect data at different wavelengths to fully address these questions. Currently operating facilities in the Cosmic Origins program are the Hubble Space Telescope and the Stratospheric Observatory for Infrared Astronomy (SOFIA).

For more information, go to: http://cor.gsfc.nasa.gov/

COSMIC ORIGINS

EXPLANATION OF MAJOR CHANGES IN FY 2022

This budget proposes the termination of the SOFIA mission. SOFIA’s annual operations budget is the second-most expensive operating mission in the Astrophysics Division (after the Hubble Space Telescope), yet the science productivity of the mission is not on par with other large science missions. Dramatic improvement in SOFIA's scientific productivity is not expected. The nature of the program, which relies on observations using an expensive platform with expensive consumables, results in low cost efficiency compared to most observatories. Additionally, the James Webb Space Telescope, planned to launch in 2021, will provide data at mid-infrared wavelengths, partially mitigating the absence of SOFIA.

HUBBLE SPACE TELESCOPE OPERATIONS

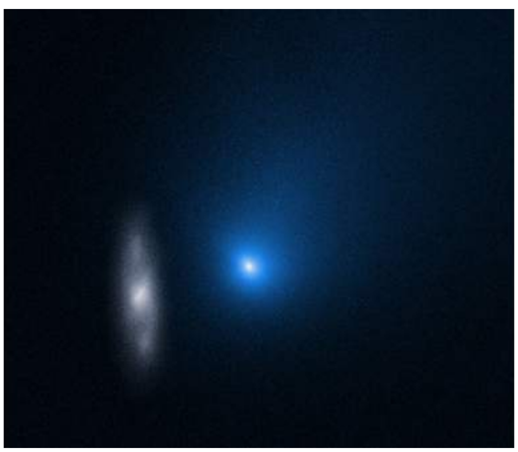
Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**90.8**	**93.3**	**98.3**	**98.3**	**98.3**	**98.3**	**98.3**
Change from FY 2021			**5.0**				
Percentage change from FY 2021			**5.4%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Comet 2I/Borisov is only the second known object from outside our solar system to pay us a visit, the first being Oumuamua in 2017. Hubble took this image on November 16, 2019, when the comet was near to its closest approach to the sun. Directly to the left is a distant galaxy.

One of NASA’s most successful and long-lasting science missions, the Hubble Space Telescope, has beamed over 1 million images back to Earth, helping resolve many of the great mysteries of astronomy. The telescope helped scientists determine the age of the universe, the identity of quasars, and the existence of dark energy. Hubble launched in 1990 and is currently in an extended operations phase. The fifth servicing mission in 2009, the last visit by a Space Shuttle crew, added new batteries, gyroscopes, and instruments to extend Hubble’s life even further into the future.

April 24, 2020 marked the start of Hubble’s 30th year in orbit. The observatory is currently in its most scientifically productive period.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

The 2019 Senior Review of Operating Missions recommended continuing Hubble operations as long as the observatory remains highly capable scientifically and recommended extending mission operations for FY 2020 and beyond. This budget supports that recommendation. The National Air and Space Museum

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

recognized the Hubble team for 30 years of achievements by awarding them the National Air and Space Museum Collins Trophy.

Hubble currently has three functional gyros and no backups. These three gyros should allow science operations to continue well into the mid-2020s, allowing overlap with Webb science operations. Hubble does have plans and flight software that will allow for both two and one-gyro modes of operations. The science observations in the two and one-gyro modes of operations will be a few percent less efficient.

Motivated by a consistent underrepresentation of female Principal Investigators in selected proposals, Hubble initiated a dual-anonymous peer review starting in 2018 with Cycle 26 and has now completed three rounds of this program. Statistics show a near tripling of the number of PIs who are leading their first Hubble investigation, but statistics are not yet definitive on the effect on selected female PIs.

NASA announced the Cycle 28 selections in June 2020.

Researchers used Hubble to search for an intermediate-mass black hole in the nearby globular cluster NGC 6397. The mass of a black hole can vary from less than twice the mass of our Sun to over a billion times our Sun's mass. Midway between are intermediate-mass black holes weighing roughly hundreds to tens of thousands of solar masses. The detection of intermediate-mass black holes has been elusive. Astronomers predict they exist in the centers of globular star clusters, however, the results from Hubble were surprising, as researchers concluded, based on the amplitudes and shapes of the stellar orbits, that there is not an intermediate-mass black hole, but a swarm of smaller black holes, a mini-cluster in the core of the globular.

Astronomers using Hubble identified a comet near a group of asteroids, known as Trojans. This is the first time Astronomers have found a comet-like object near the Trojan asteroid population. Hubble observations reveal the comet is transitioning from a frigid asteroid-like body to an active comet, sprouting a long tail, outgassing jets of material, and enshrouding itself in a coma of dust and gas. The comet came from the frigid Kuiper Belt and was likely captured by Jupiter's powerful gravity after it encountered the giant planet. Jupiter's gravity will eventually redirect the comet back onto its trip toward the Sun.

WORK IN PROGRESS IN FY 2021

In FY 2021 and beyond, NASA will support mission operations, systems engineering, software maintenance, ground systems support, and guest-observer science grants. Work continues on mission life-extension initiatives, such as optimizing the use of Hubble’s gyroscopes and extending the lifetime of Hubble's instruments. NASA will select Cycle 29 for observations in mid FY 2021 and will release Cycle 30 call for proposals late in FY 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The Space Telescope Science Institute (STScI), which manages Hubble’s science program, will select Cycle 30 science observations. Similar to other recent competitions for Hubble observing time, NASA

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

expects requested observational orbits to outnumber the available orbits by six to one, indicating that Hubble remains one of the world's preeminent astronomical observatories.

Project Schedule

Date	Significant Event
Jun 2020	Announcement of Cycle 28 selections
Jan 2021	Release of Cycle 29 Call for Proposals
Apr 2021	Deadline for Cycle 29 Proposal Submissions
Jul 2021	Approximate date for Announcement of Cycle 29 selections
Jan 2022	Release of Cycle 30 Call for Proposals
Apr 2022	Deadline for Cycle 30 Proposal Submissions
Jul 2022	Approximate date for Announcement of Cycle 30 selections

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
Observatory Operation	Provides safe and efficient control and utilization of Hubble, maintenance and operation of its facilities and equipment, as well as creation, maintenance, and utilization of Hubble operations processes and procedures	Provider: Lockheed Martin Lead Center: Goddard Space Flight Center (GSFC) Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Science Management	Evaluates proposals for telescope time and manages the science program	Provider: STScI/Association of Universities for Research in Astronomy (AURA) Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): European Space Agency (ESA)	N/A

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

Acquisition Strategy

NASA competes all new Hubble research opportunities.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Observatory Operation	Lockheed Martin	Littleton, CO
Science Management	STScI/AURA	Baltimore, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Senior Review	2019	Evaluate efficiency and productivity of Hubble operations	Maximize Hubble science return and reliability within available resources	2022, 2025, 2028

OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Astrophysics Strategic Mission Prog Mgmt	0.4	5.2	**7.4**	7.3	7.3	7.8	7.8
Cosmic Origins Strategic Research and Technology (SR&T)	18.3	18.3	**7.8**	18.4	6.7	6.7	18.4
Stratospheric Observatory for Infrared Astronomy (SOFIA)	85.2	85.2	**0.0**	0.0	0.0	0.0	0.0
Cosmic Origins Future Missions	0.0	1.9	**1.5**	2.4	2.4	2.4	2.4
SIRTF/Spitzer	8.0	0.0	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**111.9**	**110.5**	**16.7**	**28.0**	**16.4**	**16.8**	**28.6**
Change from FY 2021			**-93.8**				
Percentage change from FY 2021			**-84.9%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

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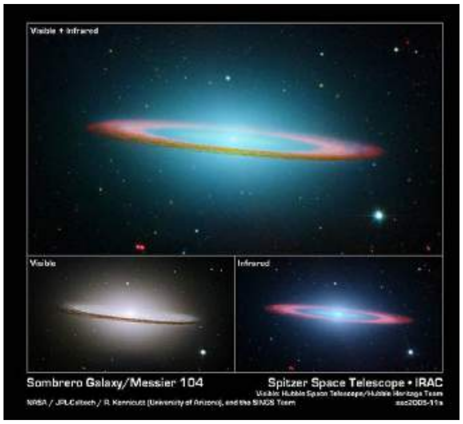

NASA launched its Spitzer Space Telescope into orbit around the Sun on Aug. 25, 2003. Since then, the observatory has lifted the veil on the wonders of the cosmos. Spitzer's primary mission lasted five-and-a-half years and ended when it ran out of the liquid helium coolant necessary to operate two of its three instruments. Its passive-cooling design has allowed part of its third instrument to continue operating for more than 10 additional years. Mission operations ended on January 30, 2020.

Cosmic Origins Other Missions and Data Analysis funds the Spitzer Space Telescope, program management, supporting research and technology, and early studies of potential future Cosmic Origins missions.

Mission Planning and Other Projects

ASTROPHYSICS STRATEGIC MISSION PROGRAM MANAGEMENT

Astrophysics Strategic Mission Program Management (ASMPM) provides programmatic, technical, business management, and program science leadership for all strategic Astrophysics missions. This support continues throughout the definition, design, development, launch, and operations phases, and facilitates science investigations derived from those missions. It also provides the funding for Astrophysics HQ civil servants.

COSMIC ORIGINS STRATEGIC RESEARCH AND TECHNOLOGY

Cosmic Origins (COR) Strategic Research and Technology (SR&T) supports program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology solicitation. In addition, funding supports the study of future NASA space observatories.

The scientific community is preparing for the recommendations of the Astrophysics Decadal Survey. NASA expects the Decadal Survey release in the spring of 2021. The Cosmic Origins program supports strategic planning on how to implement the recommendations of the Decadal Survey based on the four large-mission concept studies and the ten completed probe studies.

This budget request supports an industry solicitation for an on-going segmented-aperture Mirror Technology Development program element. NASA completed the first one-year study in 2019, which included an end-to-end integrated telescope/coronagraph system-level engineering design, modeling studies, and associated testbed demonstrations. A follow-up industry solicitation to address and retire technology gaps, identified by the large mission concepts, resulted in contract awards to two industry teams. This technology maturation work is underway.

Recent Achievements

During 2020, NASA and academic technologists published a study of Astrophysics technology development achievements over the past decade. Despite the Covid-19 pandemic, the COR program office held its Strategic Astrophysics Technology Principal Investigator annual presentation week with all principal investigators (PIs) presenting remotely. The technologists held multiple technology-readiness

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level assessments in support of timely NASA delivery of technologies to European Space Agency/NASA partnered missions. Finally, the technologists supported preparation efforts in anticipation of the upcoming release of the 2021 Astronomy and Astrophysics Decadal Survey report, to enable the Astrophysics Projects Division (APD) to respond rapidly to the Decadal Survey recommendations.

COSMIC ORIGINS FUTURE MISSIONS

Cosmic Origins Future Missions funding supports studies of future mission concepts.

Recent Achievements

The COR scientific community is engaged in identifying meritorious and compelling science drivers that could lead to diverse mission concept studies and technology development that will inform the 2020 Astronomy and Astrophysics Decadal Survey.

COR engaged the astronomical community, raised awareness, and addressed diversity, equity, and inclusion in NASA astrophysics through four presentations, two conference exhibit booths, and six conference splinter sessions. These engagements included first-time participation in the annual meeting of the National Society of Black Physicists and 80 percent increased participation (compared to FY 2020) in the annual meeting of the American Astronomical Society.

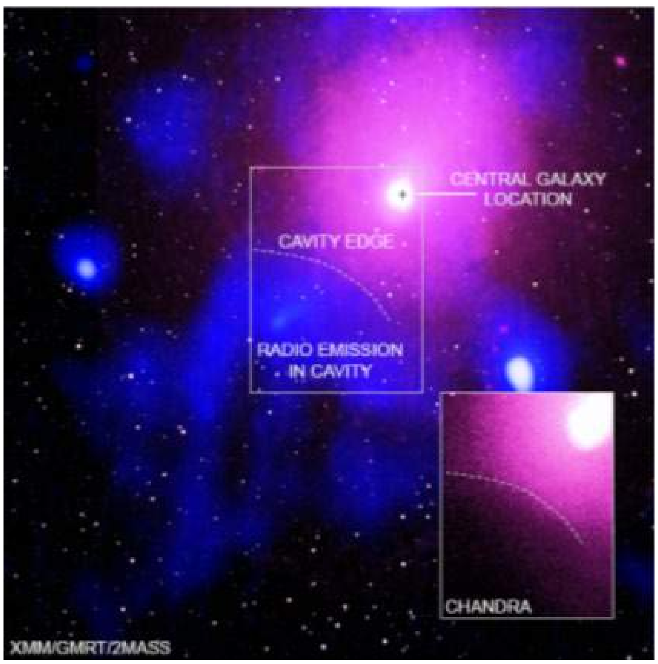
PHYSICS OF THE COSMOS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Other Missions and Data Analysis	132.8	146.4	**156.0**	160.0	169.1	159.8	167.6
Total Budget	**132.8**	**146.4**	**156.0**	**160.0**	**169.1**	**159.8**	**167.6**
Change from FY 2021			**9.6**				
Percentage change from FY 2021			**6.6%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



These spectacular composite images of the Ophiuchus cluster contain evidence for the biggest explosion seen in the Universe. This discovery combines data from NASA's Chandra X-ray Observatory, the ESA/NASA XMM-Newton Observatory, the Murchison Widefield Array, and the Giant Metrewave Telescope. In the center of the Ophiuchus cluster is a large galaxy containing a supermassive black hole. Researchers have traced the source of this gigantic eruption to jets that blasted away from the black hole and carved out a large cavity in the hot gas.

The universe enables scientists to study the most profound questions at the intersection of physics and astronomy. How do matter, energy, space, and time behave under extreme gravity? What is the nature of dark energy and dark matter? How did the universe grow from the Big Bang to its present size? The Physics of the Cosmos (PCOS) program incorporates cosmology, high-energy astrophysics, and fundamental physics projects that address central questions about the nature of complex astrophysical phenomena, such as black holes, neutron stars, dark matter and dark energy, cosmic microwave background, and gravitational waves.

The operating missions within the PCOS program continue to provide answers to these fundamental questions and more.

PCOS includes a vigorous program to develop the technologies necessary for the next generation of space missions to address the science questions of this program.

For more information, go to: https://science.nasa.gov/about-us/smd-programs/physics-of-the-cosmos

PHYSICS OF THE COSMOS

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

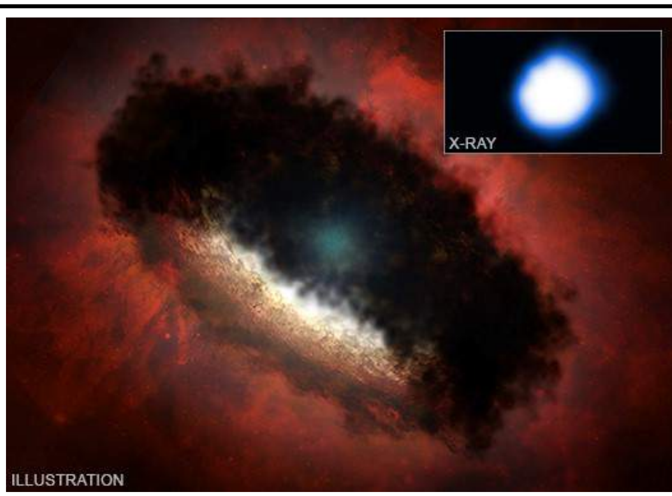
OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Physics of the Cosmos SR&T	45.9	45.7	**58.7**	79.2	87.3	78.8	87.1
Euclid	7.1	11.0	**8.9**	9.9	10.3	9.5	9.0
PCOS/COR Technology Office Management	5.2	6.2	**6.3**	5.7	6.4	6.4	6.4
Physics of the Cosmos Future Missions	0.0	1.6	**1.5**	2.4	2.4	2.4	2.4
Fermi Gamma-ray Space Telescope	11.9	15.9	**13.9**	0.0	0.0	0.0	0.0
Chandra X-Ray Observatory	60.2	62.0	**62.8**	62.8	62.8	62.8	62.8
X-ray Multi-Mirror Mission (XMM)	2.5	4.0	**4.0**	0.0	0.0	0.0	0.0
Total Budget	**132.8**	**146.4**	**156.0**	**160.0**	**169.1**	**159.8**	**167.6**
Change from FY 2021			**9.6**				
Percentage change from FY 2021			**6.6%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Astronomers have reported the first detection of X-rays from the earliest phase of evolution of a star like our Sun. This discovery, made using NASA's Chandra X-ray Observatory, helps to unlock questions about how the Sun and the Solar System formed and evolved.

Other Missions and Data Analysis supports Physics of the Cosmos (PCOS) Supporting Research and Technology, the PCOS/COR Technology Management Office, PCOS Future Missions, Euclid, Fermi, Chandra, and X-ray Multi-Mirror Mission (XMM).

Mission Planning and Other Projects

PCOS SUPPORTING RESEARCH AND TECHNOLOGY

PCOS Supporting Research and Technology leads strategic technology development efforts to prepare for the next generation of PCOS space missions,

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including program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology (SAT) program element.

NASA and the European Space Agency (ESA) are continuing to define the partnership for NASA's contribution to ESA's Athena mission, an X-ray observatory dedicated to high-resolution spectroscopy, and ESA's Laser Interferometer Space Antenna (LISA) mission, a space-based gravitational wave observatory. This project supports the technology development and pre-formulation activities necessary to contribute to the ESA missions.

Recent Achievements

NASA is proceeding towards formalizing Athena as a project in early 2022. The technologies made significant progress in the development of X-Ray Integral Field Unit detectors including successful completion for technology readiness-levels four and five. The X-Ray Cryogenic Facility (XRCF) at Marshall Space Flight Center is developing the required interface definitions for calibrating the Athena telescope mirror. The team identified XRCF upgrades to provide ground support equipment to move the mirror module during testing. NASA completed development of the engineering development unit for the vibration isolations system, which they are planning to ship to ESA in April 2021. LISA technologies are on track and the technologists completed the respective technology-readiness reviews for the laser system and the charge management device. The engineering model of the laser is being prepared for shipment to ESA.

EUCLID

NASA is collaborating on Euclid, an ESA mission, selected as part of ESA’s Cosmic Visions program in June 2012 and scheduled for launch in 2022. Euclid seeks to investigate the accelerated expansion of the universe, the so-called “dark energy,” using a Visible Instrument and a Near Infrared Spectrometer and Photometer instrument, as well as ground-based data. The Euclid Consortium, comprised of over 1,200 scientists and engineers from over 50 institutes in Europe, the United States, and Canada, is responsible for development of the two instruments and the science data centers. NASA contributes flight detector subsystems for the Near Infrared Spectrometer and Photometer instrument and a NASA Euclid Science Center that forms part of the Euclid Science Ground System. In exchange, NASA receives membership in the Euclid Science Team and Consortium and competed science opportunities for U.S. investigators.

Recent Achievements

NASA completed instrument-level testing and shipped the Near Infrared Spectrometer, including the NASA delivered hardware (detectors, cables, and sensor chip electronics) to ESA in July 2020. The NASA science team members continued to provide key, critical roles in preparing for the Euclid science survey data, providing a robust method to calibrate Euclid's photometric redshift survey, and identifying optimum observation strategies. These efforts will lead to system performance that exceeds the baseline plan for the spectroscopic survey.

PCOS/COR TECHNOLOGY OFFICE MANAGEMENT

The PCOS/COR Technology Office Management project provides programmatic, technical, and business management, as well as program science leadership.

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Recent Achievements

The technology office is leading the management of NASA's contribution to the ESA-led Athena mission, an X-ray observatory dedicated to high-resolution spectroscopy. NASA is providing the microcalorimeter and software contributions to the Wide Field Imager.

The technology office is also leading the management of NASA's contribution to ESA on the LISA mission, a low-frequency gravitational wave observatory, and it is contributing elements of the payload. NASA established a LISA study office to manage the LISA technology development.

PCOS FUTURE MISSIONS

PCOS Future Missions funding supports concept studies of future missions.

Recent Achievements

The PCOS program is continuing its work with the scientific community for design studies and technology development to inform the 2020 Astronomy and Astrophysics Decadal Survey.

Operating Missions

FERMI

The Fermi Gamma-ray Space Telescope explores extreme environments in the universe, from black holes on all scales to ultra-dense neutron stars spinning thousands of times per second, to expand knowledge of their high-energy properties. Fermi observations are answering long-standing questions across a broad range of topics, including solar flares, the origin of cosmic rays, and the nature of dark matter. NASA’s Fermi mission launched in June 2008, developed in collaboration with the U.S. Department of Energy, along with important contributions from academic institutions and partners in France, Germany, Italy, Japan, Sweden, and the United States. Fermi entered extended mission operations in August 2013. The 2019 Senior Review of Operating Missions recommended continuing Fermi operations through FY 2022.

Recent Achievements

The Fermi-Large Area Telescope collaboration has published its fourth source catalog, named 4FGL. Based on eight years of data, it contains 5,064 celestial objects emitting gamma rays at energies around 1 GeV, adding more than 2,000 high-energy sources to the previous collection (published in 2015). More than one fourth of the objects are of unknown nature, calling for numerous follow-up studies. Although its volume is modest compared to the billions of sources listed in optical catalogs, the 4FGL catalog is by far the deepest in gamma-ray astronomy and serves as a reference to the entire domain.

CHANDRA

Launched in 1999, Chandra is transforming our view of the universe with its high-quality X-ray images, providing unique insights into violent events and extreme conditions such as explosions of stars, collisions of galaxies, and matter around black holes. Chandra enables observations of clusters of galaxies

OTHER MISSIONS AND DATA ANALYSIS

that provide direct evidence of the existence of dark matter and greatly strengthens the case for the existence of dark energy. Observations of the remains of exploded stars, or supernovas, have advanced our understanding of the behavior of matter and energy under extreme conditions. Chandra has also discovered and studied thousands of supermassive black holes in the centers of distant galaxies. The 2019 Senior Review of Operating Missions recommended continuing Chandra operations as long as the observatory remains highly capable scientifically. The 2022 Senior Review of Operating Missions will review Chandra extended mission operations for FY 2023 and beyond.

Recent Achievements

Researchers using NASA's Chandra X-ray Observatory and Fermi Gamma-Ray Space Telescope, in concert with data from the Very Long Baseline Array, revealed the dramatic influence of the black hole on its surroundings in the active galaxy TXS 0128+554.

Astronomers found the biggest explosion seen in the universe. This record-breaking eruption came from a black hole in a distant galaxy cluster. Astronomers made this discovery using X-ray data from NASA's Chandra X-ray Observatory and ESA's XMM-Newton, and radio data from the Murchison Widefield Array (MWA) in Australia and the Giant Metrewave Radio Telescope in India. They detected the unrivaled outburst in the Ophiuchus galaxy cluster, which is about 390 million light years from Earth. Galaxy clusters are the largest structures in the Universe held together by gravity, containing thousands of individual galaxies, dark matter, and hot gas.

Astronomers using X-ray data from these orbiting observatories studied hundreds of galaxy clusters, and how their apparent properties differ across the sky. A new study using data from NASA’s Chandra X-ray Observatory and ESA’s XMM-Newton is challenging that basic notion. Astronomers generally agree that after the Big Bang, the cosmos has continuously expanded, and that the expansion should be uniform in all directions. The new Chandra results challenge that assumption and show differences in how fast the universe is expanding in different directions.

Astronomers using Chandra observed a black hole hurling hot material into space at close to the speed of light. The black hole and its companion star make up a system called Monitor of All-sky X-ray Image (MAXI) J1820+070, located in our galaxy about 10,000 light years from Earth. The black hole has a mass about eight times that of the Sun, identifying it as a stellar-mass black hole formed by the destruction of a massive star.

X-RAY MULTI-MIRROR MISSION (XMM)

XMM is an ESA-led mission with substantial NASA contributions. The telescope launched in December 1999 and provides unique data for studies of the fundamental processes of black holes and neutron stars. XMM studies the evolution of chemical elements in galaxy clusters and the distribution of dark matter in galaxy clusters and elliptical galaxies. The 2019 Senior Review of Operating Missions recommended continuing operations through FY 2022. The 2022 Senior Review of Operating Missions will consider a proposal for extended mission operations beyond FY 2022.

Recent Achievements

Astronomers using ESA’s XMM-Newton and NASA’s Chandra X-ray space observatories, along with radio telescopes on ground, have spotted the aftermath of the most powerful explosion ever seen in the Universe. The huge outburst occurred in the Ophiuchus galaxy cluster, a large cosmic conglomerate with thousands of galaxies, hot gas, and dark matter held together by gravity. Scientists link the eruption to

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powerful jets released by the supermassive black hole that sits at the core of the cluster's central galaxy and actively feeds on the surrounding gas, occasionally blasting off large amounts of matter and energy.

The XMM-Newton X-ray observatory spied hot gas sloshing around within a galaxy cluster, a never-before-seen behavior that may be driven by turbulent merger events. The study found direct signs of plasma flowing, splashing and sloshing around within the Perseus galaxy cluster, one of the most massive known objects in the universe, and the brightest galaxy cluster in the sky in X-rays. While researchers predicted this kind of motion theoretically, they had never seen it before in the cosmos.

A study using XMM-Newton, NASA's Chandra, and Japan Aerospace Exploration Agency's (JAXA) Suzaku telescopes data has provided a glimpse of what is going on in the centers of "active galaxies." The study showed three distinct regions where matter absorbs the X-rays and confirmed that gas and dust in the host galaxy itself plays a critical role. This finding helps scientists better understand how the matter around the vicinity of the supermassive black hole is distributed.

EXOPLANET EXPLORATION

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Nancy Roman Space Telescope	510.7	505.2	**501.6**	501.8	485.1	448.5	385.7
Other Missions and Data Analysis	43.5	47.2	**41.7**	45.8	40.7	40.7	45.8
Total Budget	**554.2**	**552.4**	**543.3**	**547.6**	**525.8**	**489.2**	**431.5**
Change from FY 2021			**-9.1**				
Percentage change from FY 2021			**-1.6%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Artist's concept of Kepler-1649c orbiting around its red dwarf star. This newly discovered exoplanet is in its star's habitable zone and is the closest to Earth in size and temperature found yet in Kepler's data. Credit: NASA/Ames Research Center/Daniel Rutter.

Humankind is gaining insight into timeless questions: Are we alone? Is Earth unique, or are planets like ours common? One of the most exciting new fields of research within the NASA Astrophysics portfolio is the search for planets, particularly Earth-like planets, around other stars.

Since the discovery of the first exoplanets in the 1990s, astronomers have confirmed over 4,200 planets orbiting most types of stars in our galaxy. At first, most of the planets discovered were so-called "Hot Jupiters"— gas giants similar in size to the planet Jupiter but orbiting much closer to their parent stars. However, analysis of the complete Kepler data set shows that smaller planets, with sizes in the Earth-to-Neptune range, are more common, but without counterpart in our solar system. Rocky planets in the habitable zone of their parent stars also appear to be common. The Transiting Exoplanet Survey Satellite (TESS) mission is now discovering many more small planets orbiting bright stars.

NASA's Exoplanet Exploration Program is advancing along a path of discovery leading to a point where scientists can directly study the atmospheres and surface features of habitable, rocky planets like Earth around other stars in the solar neighborhood. In the future, NASA aims to develop systems that will allow scientists to take the pivotal step from identifying an exoplanet as Earth-sized to determining whether it is truly Earth-like, and possibly even detecting if it bears the fingerprints of life. Such an ambitious goal includes significant technological challenges. An important component of the Exoplanet Exploration effort is a robust technology development program with the goal of enabling a future direct detection and characterization mission.

EXOPLANET EXPLORATION

For more information, go to: https://exoplanets.nasa.gov/

EXPLANATION OF MAJOR CHANGES IN FY 2022

This budget funds the Nancy Grace Roman Space Telescope (formerly Wide Field Infrared Survey Telescope [WFIRST]), the top priority large mission of the 2010 "New Worlds, New Horizons, Astronomy and Astrophysics" decadal survey.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	652.8	6.2	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	659.0
Development/Implementation	0.0	504.6	505.2	**501.6**	501.8	485.1	448.5	348.0	0.0	3,294.7
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	37.7	362.3	400.0
2021 MPAR LCC Estimate	**652.8**	**510.7**	**505.2**	**501.6**	**501.8**	**485.1**	**448.5**	**385.7**	**362.3**	**4,353.7**
Total Budget	**652.8**	**510.7**	**505.2**	**501.6**	**501.8**	**485.1**	**448.5**	**385.7**	**362.3**	**4,353.7**
Change from FY 2021				**-3.6**						
Percentage change from FY 2021				**-0.7%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The Nancy Grace Roman Space Telescope is a NASA observatory designed to tackle essential questions in the areas of dark energy, exoplanets, and infrared astrophysics.

PROJECT PURPOSE

The Nancy Grace Roman Space Telescope (Roman Space Telescope or Roman, for short) will investigate long-standing astronomical mysteries, such as the force behind the universe’s accelerating expansion, and search for distant planets beyond our solar system. Roman will unravel the secrets of dark energy and dark matter, search for and image exoplanets, and explore many topics in infrared astrophysics. This newest NASA observatory addresses the top priority large mission of the 2010 Decadal Survey in Astronomy and Astrophysics.

Roman carries two instruments. The Wide Field Instrument will accomplish the mission's primary science over large areas of the sky. The Coronagraph Instrument Technology

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Demonstration matures components and systems for imaging and spectroscopy of individual nearby exoplanets. NASA has timed Roman's launch in the mid-2020s to overlap Roman mission's operations with those of the James Webb Space Telescope and provide synergistic science capabilities. Roman ushers in a new era of big data for astrophysics, producing an archive of approximately 10 terabytes of data per day of operations. Teams at NASA's Goddard Space Flight Center, the Space Telescope Science Institute, and the Infrared Processing and Analysis Center will conduct operations.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The FY 2022 budget request includes funds for the Nancy Grace Roman Space Telescope.

NASA's estimates for cost and schedule for Nancy Grace Roman Space Telescope have increased due to COVID-19 impacts. NASA continues to assess these impacts, and cost changes are being evaluated. NASA will complete its assessment of COVID-19 impacts on mission cost and schedule and complete the project re-plan in the summer of 2021.

PROJECT PARAMETERS

The Nancy Grace Roman Space Telescope is a NASA observatory designed to investigate essential questions in the areas of dark energy, exoplanets, and infrared astrophysics. To address these questions, the telescope has a large, 7.9-foot (2.4-meter) diameter primary mirror, since a larger surface area gathers more light and produces images that are sharper. Roman's mirror is the same size as the Hubble Space Telescope's primary mirror, and it is less than one-fourth the weight, only 410 pounds (186 kilograms), thanks to major improvements in technology. To make Roman's sensitive measurements possible, the telescope observes from a vantage point orbiting about 930,000 miles (1.5 million kilometers) away from Earth in the direction opposite the Sun. Near this location, called the second Sun-Earth Lagrange point or L2, the observatory requires little propellant to maintain a steady orbit with very little disturbance, thanks to the balance of gravitational forces.

The Roman Wide Field Instrument is a 300-megapixel infrared camera and spectrometer built to perform the primary science with a field of view that is 200 times greater than the Hubble Space Telescope's infrared instrument, allowing it to capture more of the sky with less observing time. The camera features eight filters for different wavelengths of infrared light suited to studying varied astronomical objects, plus two spectroscopic filters to measure distances and other characteristics of galaxies and supernovae across the universe.

In addition to the Wide Field Instrument, Roman will advance exoplanet observations by carrying the first active coronagraph into space. The Coronagraph Instrument, built as a technology demonstration, combines multiple technologies and operation modes to block or null the light from bright nearby stars and allow high-contrast imaging of faint exoplanets orbiting those stars. This capability is critical for next-generation telescopes capable of analyzing the atmospheres of Earth-like planets around other stars. The design and development of the Coronagraph Instrument has already increased the maturity of critical technologies for these potential future missions, including deformable mirrors, detectors, and instrument control algorithms.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

The Nancy Grace Roman Space Telescope is planning for a primary mission lifetime of 5 years, with enough propellant for a 5-plus-year extended mission.

For more information, go to: https://roman.gsfc.nasa.gov/

ACHIEVEMENTS IN FY 2020

NASA renamed the mission the Nancy Grace Roman Space Telescope (formerly the Wide-Field Infrared Survey Telescope or WFIRST) in honor of the NASA's first Chief of Astronomy who was also NASA's first female executive. Dr. Nancy Grace Roman paved the way for space telescopes focused on the broader universe and NASA considers her the mother of NASA's Hubble Space Telescope.

Despite COVID-19 restrictions to in-house activities at NASA and major Roman contractor sites, along with significant disruptions in domestic and international supply chains, Roman made significant progress. Some notable milestones achieved in FY 2020 include:

The Roman project completed its Preliminary Design Review in October 2019. In February 2020, Roman successfully passed Key Decision Point-C and NASA approved the mission to enter Phase C, the final design and fabrication phase of the project.

Roman passed the Ground System Preliminary Design Review part 2 in July 2020 and the Instrument Carrier Critical Design Review in September 2020.

WORK IN PROGRESS IN FY 2021

COVID-19 restrictions began shortly after the start of Project Implementation at Key Decision Point-C. Facility shutdowns due to COVID-19 and the loss of efficiency created by restrictions to ensure employee safety and reduce risk of the spread of the pandemic have made project re-planning necessary to coordinate remaining efforts along a realistic timeline toward launch. NASA will complete Joint Confidence Level analysis in July 2021. NASA expects completion of re-plan efforts, along with Roman Standing Review Board independent analysis in support of the Mission Critical Design Review in September 2021.

NASA is making progress in all areas of the project despite COVID-19 restrictions. Engineering design and drawing deliveries are progressing, as are hardware fabrication and engineering development unit/engineering test unit builds. The project has delivered, tested, and certified all eighteen sensor chip assemblies for the Wide Field Instrument, the most critical components of the camera, along with four of the six flight spare sensor chip assemblies. The project completed fabrication and initiated testing of engineering test units for other critical components, such as the Wide Field Instrument mosaic plate assembly that holds the sensor chip assemblies and the spacecraft solar array sun shield and deployable aperture cover. The primary, secondary, and tertiary mirrors for the Optical Telescope Assembly have completed or made significant progress in fabrication, assembly, and testing.

NASA held successful Critical Design Reviews (CDRs) for the Optical Telescope Assembly in December 2020, the Wide Field Instrument in January 2021, and the Coronagraph Instrument Technology Demonstration in April 2021. These CDRs, along with planned CDRs for ground systems and spacecraft,

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

will enable a successful Mission CDR in September 2021, ending FY 2021 with a solid plan to complete development and achieve launch and on-orbit operations.

In FY 2021, the Coronagraph Instrument team passed the Deformable Mirrors technology readiness level 6 demonstration review, completing all technology demonstration requirements ahead of schedule. Engineering development units and flight parts are being fabricated for all coronagraph instrument subsystems. The Coronagraph Instrument team completed all the subsystem peer reviews and CDRs leading up to the successful Coronagraph Instrument CDR held in April 2021. Centre National d'Études Spatiales/Laboratoire d'Astrophysique de Marseille delivered the flight off-axis parabola mirrors. The European Space Agency is on track to deliver the electron multiplying charge coupled device flight detectors before the Roman Mission CDR. Despite pandemic restrictions and impacts at JPL, on foreign contributors, and within the supply chain, the Coronagraph Instrument team has maintained solid developmental progress on the overall schedule. The team is on track to deliver the instrument for integration ahead of the Roman mission need date.

The Roman project will conduct the Mission CDR in September 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

Fabrication, assembly, and test of engineering and flight hardware will continue throughout FY 2022. The Optical Telescope Assembly forward optical assembly struts will be complete, enabling testing with the imaging optical assembly prior to integration with the Instrument Carrier. Designs of composite structures for the Instrument Carrier and for the launch loads and vibration isolation system will be complete and fabrication will be in work. NASA will make final selection of the flight sensor chip assemblies and begin installation into the mosaic plate assembly. Launch vehicle selection will occur in FY 2022.

For the Coronagraph Instrument Technology Demonstration, the fabrication and assembly of the mechanical and optical engineering development units are completed and integrated with completed flight electronics into the functional test bed. All flight certified optical and mechanical units are completed and integrated onto the optical module and tested with the engineering development units' electronics. NASA will integrate flight avionics, camera, and the mechanical/thermal systems onto pallets. NASA will receive and integrate all foreign partner contributions. The project will hold the System Integration Review (SIR) in the third quarter of FY 2022, allowing for the assembly and integration of the entire Coronagraph Instrument.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
KDP-C	Feb 2020	Feb 2020
CDR	Jul 2021	Sep 2021
SIR	Jul 2023	Oct 2024 (TBD pending Re-plan)

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2022 PB Request
Pre-Ship Review	May 2025	TBD pending Re-plan
Launch	Oct 2026	TBD pending Re-plan
Begin Phase E	Jan 2027	TBD pending Re-plan
End Prime Mission	Jan 2031	TBD pending Re-plan

Development Cost and Schedule

This report is the first report of development costs for this mission.

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2021	2,898	>70%	2021	TBD*	TBD	LRD	Oct 2026	TBD*	TBD

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

**The project is assessing COVID-19 impacts on its schedule and estimated development costs and will complete a re-plan in the summer of 2021.*

Development Cost Details

This report is the first report of base year development costs for this mission. The project is assessing COVID-19 impacts on its schedule and estimated development costs and will complete a re-plan in the summer of 2021.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**2,898.1**	**TBD**	**N/A**
Aircraft/Spacecraft	278.1	TBD	N/A

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Payloads	661.6	TBD	N/A
Systems I&T	183.2	TBD	N/A
Launch Vehicle	238.6	TBD	N/A
Ground Systems	217.6	TBD	N/A
Science/Technology	79.4	TBD	N/A
Other Direct Project Costs	1,239.6	TBD	N/A

Project Management & Commitments

NASA Headquarters is responsible for Roman program management and GSFC is responsible for Roman project management.

Element	Description	Provider Details	Change from Baseline
Project Management and Systems Engineering	Management of all technical and programmatic aspects of mission development and system engineering of each element and the integrated system	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Mission Science Management	Management of all project science activities from formulation through development and operations	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC and partners Cost Share Partner(s): N/A	N/A
Wide Field Instrument	Overall instrument management; in-house development of the Focal Plane System, Grism, Prism, and all subsystems other than the Ball-managed Wide Field Instrument Opto-Mechanical Assembly (WOMA)	Provider: NASA, Ball Aerospace Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Instrument Carrier	Structural Support for the Optical Telescope Assembly, Wide Field Instrument, and Coronagraph Instrument	Provider: NASA, Northrup Grumman Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Spacecraft	Main bus for Roman; providing power, electrical, thermal, and propulsion systems	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Coronagraph Instrument	Management of all technical and programmatic aspects of instrument development and system engineering of the technology demonstration for space-based exoplanet characterization	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Star Tracker, Flight Battery, Use of Ground Station, and ESA Project Scientist	Optical device that measures the positions of stars using photocells or a camera; rechargeable power source; use of a ground station in Western Australia for Roman over the three-month commissioning phase and five-year prime mission; and one full-time equivalent ESA employee as the ESA Project Scientist to participate in Roman science operations at the Space Telescope Science Institute (STScI)	Provider: ESA Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Electron-Multiplying Charge-Coupled Device Detectors	Devices for digital imaging under low-light conditions	Provider: ESA Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Super-polished optics and Off Axis Parabolas	Optical elements to collimate and direct light within the Coronagraph Instrument	Provider: CNES/LAM Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): CNES	N/A

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Precision Alignment Mechanisms	Mechanisms to direct light within the Coronagraph Instrument with 1-2 arcsecond pointing accuracy	Provider: Max Planck Institute for Astronomy (MPIA) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): MPIA	N/A
Polarization Optics	Optical elements to select the polarization state of light within the Coronagraph Instrument	Provider: Japan Aerospace Exploration Agency (JAXA) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): JAXA	N/A
Use of Ground Station	Daily use of a ground station in Japan and data transport to the Science Operations Center (SOC)	Provider: JAXA Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Launch Vehicle	Launch services for Roman on required trajectory for L2 operational orbit	Provider: TBD Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mission Operations	Management of on-orbit operations	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC and partners Cost Share Partner(s): N/A	N/A
Ground control system and science operations and control center	Science Operations Center responsible for processing, analysis, and archiving of data from the observatory	Provider: Space Telescope Science Institute (STScI) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Ground control system and science operations and control center	Science Center responsible for processing, analysis, and archiving of coronagraph data for infrared astronomy	Provider: Infrared Processing and Analysis Center (IPAC) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The Roman Space Telescope does not keep time-varying thermal distortion within one exposure (180 seconds) sufficiently low, Then: There is a possibility that the wavefront error stability requirement of 1nm, a level impossible to verify by test, will be exceeded on-orbit.	Roman will perform observatory Structural, Thermal, Optical Performance Integrated Modeling and Analysis to determine wavefront error stability and perform off-nominal thermal distortion analyses to account for uncertainties in the parameters of the as-built system, in order to ensure acceptable probability of success in meeting thermal distortion requirements. Use of the L3Harris Open Frame Unit testbed to provide early demonstration of mK level thermal control stability will further mitigate the risk.
If: The Roman Space Telescope does not keep mechanical vibrations, induced by reaction wheels and high-gain antenna actuation, within one exposure (180 seconds) sufficiently low, Then: There is a possibility that the wavefront error stability requirement of 1nm, a level impossible to verify by test, will be exceeded on-orbit.	Roman will perform observatory Jitter Integrated Modeling incorporating realistic reaction wheel and payload vibration isolator models to determine wavefront error stability and perform tests on a flight-like PM structure to verify performance predictions.

Acquisition Strategy

NASA will competitively select the launch vehicle through the NASA Launch Services program. The project has awarded all other major contracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Optical Telescope Assembly	L3Harris	Rochester, NY
Wide Field Instrument Opto-Mechanical Assembly (WOMA)	Ball Aerospace	Boulder, CO
	Space Dynamics Laboratory	Logan, UT
Sensor Chip Assemblies	Teledyne	Camarillo, CA
	Hawaii Aerospace	Honolulu, HI
Science Operations Center Support	AURA/Space Telescope Science Institute	Baltimore, MD

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Element	Vendor	Location (of work performance)
Science Center Support	IPAC/Caltech	Pasadena, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Feb 2018	SRR/MDR: Evaluate whether Roman requirements are properly formulated to meet mission objectives and to assess the credibility of Roman's estimated budget and schedule	Proposed mission/system architecture is credible and responsive to mission requirements and constraints including resources	Oct 2019
Performance	SRB	Oct 2019	PDR: Evaluate the completeness / consistency of the Roman preliminary design in meeting all requirements with appropriate margins, acceptable risk, and within cost and schedule constraints; and to determine readiness to proceed with the detailed design phase	Roman's planning, technical, cost and schedule baselines developed during Formulation are complete	Sep 2021
Performance	SRB	Sep 2021	CDR: Demonstrate maturity of the Roman design is appropriate to meet requirements and support proceeding with full-scale fabrication and assembly	TBD	Oct 2024

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2024	SIR: Determine Roman readiness to proceed to system integration and test phase	TBD	Feb 2026
Performance	SRB	Feb 2026	PSR: Evaluate the readiness of the project to perform the mission and ship to the launch site	TBD	TBD
Performance	SRB	TBD	LRR: Evaluate the readiness of the project to operate and perform the mission	TBD	N/A

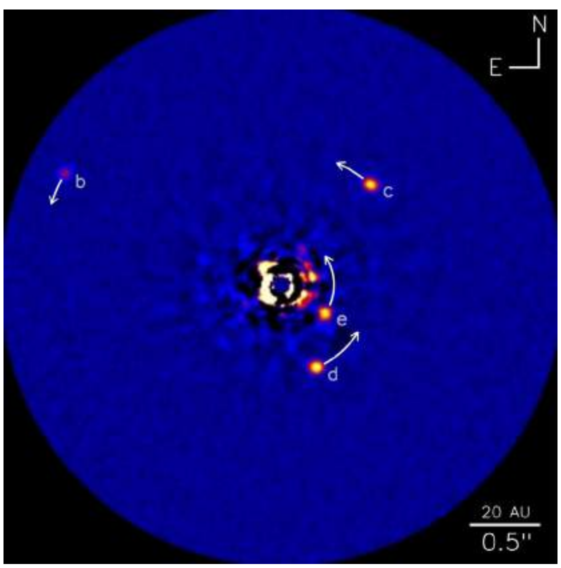
OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Exoplanet Exploration Strategic Research and Technology	28.6	30.8	**24.8**	28.1	22.2	22.3	27.4
Exoplanet Exploration Technoloy Off Mgmt	6.3	7.5	**7.8**	7.4	8.2	8.1	8.1
Exoplanet Exploration Future Missions	0.7	1.6	**1.7**	2.8	2.8	10.3	10.2
Keck Operations	6.6	7.3	**7.5**	7.4	7.4	0.0	0.0
Kepler	1.3	0.0	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**43.5**	**47.2**	**41.7**	**45.8**	**40.7**	**40.7**	**45.8**
Change from FY 2021			**-5.5**				
Percentage change from FY 2021			**-11.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Over seven years of data obtained from the Near Infra-Red Camera 2 instrument on the Keck-II telescope have revealed the orbital motions of the four planets in the HR 8799 planetary system. (see: https://exoplanets.nasa.gov/news/1404/a-four-planet-system-in-orbit-directly-imaged-and-remarkable/)

Mission Planning and Other Projects

Exoplanet Exploration Other Missions and Data Analysis includes funding for Exoplanet Exploration Supporting Research and Technology, Exoplanet Exploration Technology Office Management, Keck Operations, and funding for future mission selections.

EXOPLANET EXPLORATION STRATEGIC RESEARCH AND TECHNOLOGY

Exoplanet Exploration Strategic Research and Technology supports program-specific strategic research and technology development activities to enable future NASA space missions to discover and understand distant worlds.

NASA currently supports 14 competitively selected exoplanet technology development projects

OTHER MISSIONS AND DATA ANALYSIS

involving researchers across the Nation. The selected projects focus on advancing technologies to separate the feeble reflected light of an exoplanet from the overwhelming glare of its parent star. Those technologies will one day enable a mission capable of the goal of NASA's Exoplanet Exploration Program in imaging and measuring the spectra of habitable, Earth-like exoplanets orbiting Sun-like stars in our solar neighborhood.

NASA also supports a range of exoplanet science investigations through its investments in the Keck Observatory in Hawaii and the Wisconsin-Indiana-Yale-National Optical Astronomy Observatory (WIYN) Telescope in Arizona. Those science investigations include ground-based, follow-up observing programs that support the Agency's Transiting Exoplanet Survey Satellite (TESS) mission as well as programs that support the operational planning and design of future missions.

Recent Achievements

Coronagraphs and starshades are enabling technologies for the direct imaging and spectroscopy of exoplanets around stars. They block the glare of bright starlight and thus make possible the detection of its surrounding planets. NASA could use these technologies in possible future missions to directly image these distant worlds and search for evidence of biosignature gases in their atmospheres. NASA is assessing new coronagraph techniques for their application to future large space telescopes, including those with segmented mirrors, via modeling and laboratory demonstrations. In addition, the NASA Starshade team, with membership from government, academia, and industry, has defined and is executing a detailed plan for ground-based demonstration, successfully completing eight of fifteen milestones on the path to maturing five critical technology elements by the mid 2020's. In the past year, the Starshade team demonstrated its second critical technology, suppression of solar glint from the starshade edges.

The NASA Exoplanet Archive is the world-leading archive of information on exoplanets and their host stars. The archive holds data on more than 4,200 confirmed planets and has been used in over 1,000 refereed scientific publications. The Exoplanet Archive directly supports the TESS mission through the coordination of a planetary candidate follow-up program with scientists confirming 74 planets from the 2,321 candidates identified so far by TESS.

NASA-National Science Foundation Exoplanet Observational Research (NN-EXPLORE) delivered the new precision radial velocity instrument, NEID, to the WIYN telescope in Arizona in CY 2019, with commissioning of the new instrument now scheduled for completion in early CY 2021. The partnership provides observing time for U.S. astronomers on telescopes with radial velocity (RV) spectrographs in the southern hemisphere for follow-up observations of TESS exoplanet candidates to determine their masses. NN-EXPLORE is developing NASA's response, in conjunction with the NSF, to a key recommendation of the National Academies' Exoplanet Science Strategy (2018) report: a new initiative to advance the state of the art in radial velocity measurements, toward the goal of measuring the masses of temperate terrestrial planets orbiting Sun-like stars.

The Exoplanet Science Research and Technology project supports high-resolution imaging with speckle instruments (speckle instruments help recover high-resolution features in images limited by atmospheric blurring) for follow up exoplanet validation and characterization on three observatories operated by NSF's NOIRLab: WIYN in Arizona, Gemini North in Hawaii, and Gemini South in Chile.

OTHER MISSIONS AND DATA ANALYSIS

EXOPLANET EXPLORATION TECHNOLOGY OFFICE MANAGEMENT

Exoplanet Exploration Technology Office Management provides scientific and technical leadership and business management for the program's portfolio of projects. It coordinates, supports, and tracks the progress of the program's numerous technology development tasks, manages shared testbed infrastructure for the use of the community of exoplanet technologists, actively engages science community stakeholders, and provides effective public and professional communication of exoplanet science discovery and enabling technologies.

Recent Achievements

Scientists continue to add to the count of known exoplanets, with the TESS mission providing the latest wave of discoveries. Scientists have confirmed more than 4,200 exoplanets to date. Current estimates suggest one in four stars host rocky planets with the right conditions for liquid water to flow freely on their surfaces. Researchers frame this probability with the fact that there are over 100 billion stars in our galaxy alone. In support of the goal of finding and studying these temperate planets, the office has managed inputs to the 2020 Decadal Survey of Astronomy and Astrophysics and will support the implementation of the Decadal Survey

EXOPLANET EXPLORATION FUTURE MISSIONS

Exoplanet Exploration Future Missions funding supports the execution of the exoplanet mission science and technology definition teams, and ultimately the formulation, development, and implementation of a future Exoplanet Exploration flight mission.

Recent Achievements

Community-based science and technology teams completed mission concepts and technology development plans in support of the 2020 Astrophysics Decadal Survey. To prepare for the next decade, NASA is studying the scientific merits of exoplanet missions in both the probe (medium) and large classes. The project provided independent review for the concept studies including the establishment of the standards definition and evaluation team. The team provided a consistent and independent measure of the exoplanet science yields for the large mission concepts, and independent assessment of technological maturity of the large mission concepts.

Operating Missions

KECK OPERATIONS

Keck Operations is the NASA portion of the Keck Observatory partnership. NASA is a partner for one-sixth of the observing nights on the two 10-meter telescopes of the W.M. Keck Observatory (WMKO), the largest optical telescope pair in the world. NASA uses its share of observing time in support of its Astrophysics and Planetary Science programs. The project allocates observing time for NASA astrophysics science goals, as well as for solar system objects and direct space mission support. Supported missions in recent years include Kepler, TESS, EUCLID, and the Roman Space Telescope for astrophysics as well as Juno, New Horizons, and Cassini for planetary science. All observing time

OTHER MISSIONS AND DATA ANALYSIS

proposal requests are competitive with peer-review and selection managed by the NASA Exoplanet Science Institute. The Keck Observatory Archive (KOA), managed by the NASA Exoplanet Science Institute, ingests and curates existing and new data from the Keck Observatory.

Recent Achievements

The large number of proposals submitted continues to demonstrate strong demand for NASA observing nights. During the 2021A observing semester that runs from February through July 2021, NASA reserved 13 nights for on-going, high-priority key strategic mission support programs. Scientists at institutions around the United States submitted 90 proposals requesting 124.6 nights for the remaining 33.5 nights, yielding an overall oversubscription rate of 3.7 for both Keck telescopes. The over-subscription varies between three and five times as many requests for time on the telescopes than is available from semester to semester depending on the telescope, instrument, and season. The astronomical community actively uses the KOA with approximately 20 percent of WMKO publications citing the archive as the source of their data. NASA attributes the annual growth to the availability of more than 10 instruments in KOA covering 25 years of the "Keck Sky." NASA has recently approved a Data Services Initiative to enhance operational efficiency and easy access to fully processed data from Keck instruments.

ASTROPHYSICS EXPLORER

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
SPHEREx	66.6	68.5	**89.9**	96.7	75.0	24.0	6.0
Other Missions and Data Analysis	118.7	135.8	**210.4**	203.3	267.9	380.1	516.9
Total Budget	**185.3**	**204.4**	**300.4**	**300.0**	**342.9**	**404.1**	**522.9**
Change from FY 2021			**96.0**				
Percentage change from FY 2021			**47.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Using data from facilities including NASA’s Neil Gehrels Swift Observatory and Transiting Exoplanet Survey Satellite (TESS), scientists have studied 20 instances, and counting, of regular outbursts of an event called ASASSN-14ko. In this illustration, the gas pulled from the star collides with the black hole’s debris disk and causes a flare. Credit: NASA's GSFC/Chris Smith (USRA/GESTAR).

The Astrophysics Explorer program provides frequent flight opportunities for world-class astrophysics investigations using innovative and streamlined management approaches for spacecraft development and operations. The program is highly responsive to new knowledge, new technology, and updated scientific priorities by launching smaller missions formulated and executed in a relatively short development cycle. NASA selects new missions based on an open competition of concepts solicited from the scientific community. The program emphasizes the accomplishments of missions under the control of the scientific research community within constrained mission life-cycle costs.

The most recent Astrophysics Medium-Class Explorers (MIDEX) missions cost up to $451 million in total, including launch services. Small Explorers (SMEX) may cost up to $215 million including launch services. Pioneer missions cost up to $20 million, excluding the launch. The most recent Explorer missions of opportunity (MO) have a total NASA cost of under $100 million, including the launch, and may be of several types. Possible types are new science missions using existing spacecraft and small complete missions. NASA intends to solicit proposals for MOs in conjunction with each Announcement of Opportunity (AO) issued for MIDEX and SMEX investigations.

ASTROPHYSICS EXPLORER

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Explorers Futures budget enables NASA to respond to recommendations from the next Astrophysics decadal survey, such as a probe class mission.

ACHIEVEMENTS IN FY 2020

Imaging X-ray Polarimetry Explorer (IXPE) entered the fabrication and testing phase of all its major components. However, a two-month COVID-19-driven shut-down of IXPE payload fabrication activities at MSFC resulted in a two-month delay in the completion of the IXPE payload fabrication.

The Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx) continued Phase B preliminary design and technology development.

NASA selected SMEX and Explorer MO proposals for competitive Phase A mission concept studies.

WORK IN PROGRESS IN FY 2021

All major components of IXPE continue to be constructed and tested. The project successfully completed the systems integration review in September 2020, followed by KDP-D in November 2020. The project is currently performing observatory integration and testing of the payload and spacecraft.

SPHEREx successfully completed the Preliminary Design Review (PDR) in October 2020, followed by the KDP-C in December 2020, and will complete the Critical Design Review (CDR) in the first quarter of FY 2022. The project is in its final design and fabrication phase.

The SMEX and MO Phase A mission concept studies continue in FY 2021, with study received in March 2021. NASA expects to select one SMEX mission and one MO in late FY 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The X-ray Imaging and Spectroscopy Mission (XRISM) will undergo spacecraft-level integration and test led by JAXA, with assistance from NASA project members. NASA will select, through peer review, investigators from the U.S. scientific community to participate in the analysis of data from the performance verification phase of XRISM operations after post-launch commissioning.

Contribution to Ariel Spectroscopy of Exoplanets (CASE) will continue formulation as it prepares for its preliminary design review currently planned for early FY 2022.

NASA plans to launch IXPE in January 2022.

Program Schedule

Date	Significant Event
Aug 2021	AO for MIDEX and MO to propose

ASTROPHYSICS EXPLORER

Date	Significant Event
Nov 2021	Downselect one SMEX and one MO mission for implementation
Nov 2022	Select MIDEX and Explorer MO proposals for competitive Phase A mission concept studies
Mar 2024	AO announcement for SMEX and MO opportunity to propose
Aug 2024	Downselect one MIDEX and Explorer MO mission for implementation
Mar 2025	Select SMEX and Explorer MO proposals for competitive Phase A mission concept studies
2026	AO announcement for MIDEX and MO opportunity to propose

Program Management & Planned Cadence

The Astrophysics and Heliophysics Explorer Programs are both coordinated sets of uncoupled missions, where each mission is independent and has unique science. The Programs share a common program office at GSFC and a common management structure. The Explorer program manager resides at GSFC, reporting functionally to the Center Director and programmatically through the Astrophysics and Heliophysics Division Directors to the Associate Administrator for SMD.

This budget brings the Astrophysics Explorer Program into alignment with the Decadal Survey's recommendation of a two to three-year mission cadence.

Acquisition Strategy

NASA selects all Explorer missions through competitive AOs.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	2019	Assess performance of program	Successful	2024

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REONIZATION, AND ICES EXPLORER

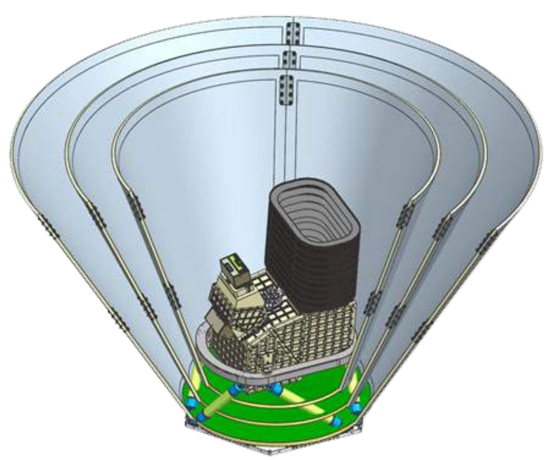
Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	24.7	39.5	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	64.2
Development/Implementation	0.0	27.1	68.5	**89.9**	96.7	74.6	11.0	0.0	0.0	367.8
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.4	13.0	6.0	0.1	19.5
2021 MPAR LCC Estimate	**24.7**	**66.6**	**68.5**	**89.9**	**96.7**	**75.0**	**24.0**	**6.0**	**0.1**	**451.4**
Total Budget	**24.7**	**66.6**	**68.5**	**89.9**	**96.7**	**75.0**	**24.0**	**6.0**	**0.1**	**451.4**
Change from FY 2021				**21.4**						
Percentage change from FY 2021				**31.2%**						

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



The SPHEREx spacecraft (photon shields cut away) showing the bus with the payload optical and thermal subsystems. The optics and detector cool passively by radiating heat to space with a 3-stage V-groove passive cooler. Photon shields protect the cooler and optics from radiation from the Sun and Earth.

PROJECT PURPOSE

The Spectro-Photometer for the History of the Universe, Epoch of Re-ionization, and Ices Explorer Mission (SPHEREx) will serve as a powerful tool for understanding how our universe evolved and how common the ingredients for life are in our galaxy’s planetary systems. SPHEREx will be NASA's first all-sky spectral astronomy survey mission and will investigate the quantum physics of the Big Bang origin of the Universe. The mission will chart the origin and history of galaxy formation, from light produced by the first galaxies that ended the cosmic dark ages, to the present day. Astronomers will use the mission to gather data on hundreds of millions of galaxies and stars.

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

SPHEREx will survey water and organic molecules in interstellar ices.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

PROJECT PARAMETERS

SPHEREx is a medium Explorer-class astrophysics mission planned to launch in 2025. It is a three-axis stabilized spacecraft that will be launched into sun-synchronous Earth orbit with an altitude of approximately 700 kilometers for a baseline two-year science mission. The SPHEREx Project Office resides at the Jet Propulsion Laboratory (JPL), and the SPHEREx Principal Investigator resides at the California Institute of Technology (Caltech). JPL and Caltech will develop the SPHEREx payload consisting of the thermal subsystem, optical subsystem, and instrument control electronics. Ball Aerospace will provide the spacecraft bus and telescope, as well as the overall SPHEREx Observatory integration and testing. The Korea Astronomy and Space Science Institute (KASI) will contribute the non-flight cryogenic test chamber. SPHEREx will launch on a SpaceX Falcon 9.

ACHIEVEMENTS IN FY 2020

SPHEREx continued its Phase B activities to establish baseline requirements and define all system interfaces. The project successfully completed the telescope design review in September 2020.

WORK IN PROGRESS IN FY 2021

The SPHEREx Preliminary Design Review (PDR) took place in October 2020, followed by a KDP-C confirmation review in December 2020, and entered its final design and fabrication phase (Phase C). NASA awarded the launch vehicle contract to SpaceX in February 2021. Caltech design work on the instrument control electronics and the optical subsystem for the payload is ongoing, in addition to JPL design work of the payload thermal subsystem, and KASI work on the instrument test chamber. Ball Aerospace will continue with procurements and design work for the spacecraft bus.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

The project will hold the mission Critical Design Review (CDR) in the first quarter of FY 2022. The project will begin fabrication and assembly of the SPHEREx payload and spacecraft bus subsystems in FY 2022.

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2022 PB Request
Key Decision Point (KDP)-C	Dec 2020	Dec 2020
Critical Design Review (CDR)	Sep 2021	Q1 FY 2022
System Integration Review	Mar 2023	Mar 2023
KDP-D	May 2023	May 2023
Launch Readiness Date (LRD)	Apr 2025	Apr 2025
Phase E start	May 2025	May 2025

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2021	367.8	>70%	2021	367.8	0%	Launch Readiness Date (LRD)	April 2025	April 2025	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Development Cost Details

This is the first report of development costs for this mission.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**367.8**	**367.8**	**0.0**
Aircraft/Spacecraft	54.9	54.9	0.0
Payloads	45.8	45.8	0.0
Systems I&T	11.9	11.9	0.0
Launch Vehicle	112.4	112.4	0.0
Ground Systems	12.0	12.0	0.0
Science/Technology	21.0	21.0	0.0
Other Direct Project Costs	109.8	109.8	0.0

Project Management & Commitments

The principal investigator for SPHEREx is from Caltech. JPL manages the overall SPHEREx mission and will provide systems engineering, mission assurance, payload thermal and mechanical mission system and the operations science team.

Element	Description	Provider Details	Change from Baseline
Payload Thermal Subsystem	The thermal subsystem consists of the photon shields, focal plan radiator, telescope support structure, and V-groove radiators	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): None	N/A
Payload Optical Subsystem	The optical subsystem consists of the baffle and focal plane assemblies	Provider: Caltech Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Payload Electronics Subsystem	The electronics subsystem consists of the payload flight software and instrument control electronics	Provider: Caltech Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Spacecraft	Spacecraft Bus	Provider: Ball Aerospace Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Telescope	20cm wide-field off-axis all-aluminum telescope	Provider: Ball Aerospace Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Focal Plane Assemblies	The two focal plane assemblies are separated by a dichroic to deliver full short and long wavelength coverage	Provider: JPL Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Detectors	Each of six detector arrays has its own linear variable filters.	Provider: Teledyne Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Test Chamber	The non-flight cryogenic test chamber will support two test modes; optical mode with an optical window, and dark mode with a cryogenic integrating sphere.	Provider: KASI Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Launch Vehicle	Launch vehicle and related launch services	Provider: SpaceX Lead Center: KSC/VAFB Performing Center(s): None Cost Share Partner(s): None	N/A

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The Instrument Control Electronics (ICE) delivery is delayed, Then: The overall payload subsystem development schedule will be impacted.	SPHEREx Project will identify schedule options to accommodate potential ICE delays.
If: The telescope delivery is delayed, Then: The overall payload subsystem development schedule will be impacted.	SPHEREx Project will identify schedule options to accommodate potential telescope delays.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Observatory integration, spacecraft bus	Ball Aerospace	Boulder, Colorado
Payload detectors	Teledyne	California
Payload telescope	Ball Aerospace	Boulder, Colorado
Launch Vehicle	SpaceX	Hawthorne, California
PI, CO-Is, Mission Payload	Caltech	Pasadena, California

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2020	PDR	Successful	Sep 2021
Performance	SRB	Sep 2021	Mission CDR	TBD	Mar 2023
Performance	SRB	Mar 2023	SIR	TBD	Feb 2024
Performance	SRB	Feb 2024	ORR	TBD	N/A

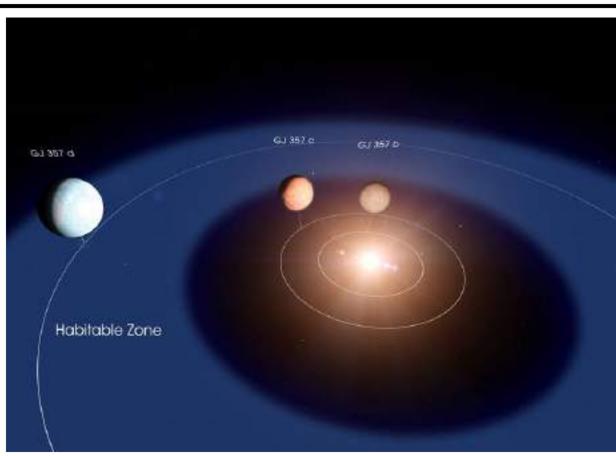
OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Contribution to ARIEL Spectroscopy of Ex	1.0	--	**15.1**	8.3	4.5	2.6	7.3
Astrophysics Explorer Future Missions	7.5	--	**75.5**	149.7	234.2	355.4	487.4
Astrophysics Explorer Program Management	5.0	--	**20.3**	16.9	11.4	7.7	11.1
Neutron Star Interior Composition Explor	4.8	--	**4.4**	0.0	0.0	0.0	0.0
Neil Gehrels Swift Observatory	5.4	--	**5.8**	0.0	0.0	0.0	0.0
Nuclear Spectroscopic Telescope Array	7.8	--	**8.6**	0.0	0.0	0.0	0.0
Transiting Exoplanet Survey Satellite	7.4	--	**14.1**	0.0	0.0	0.0	0.0
Galactic/Extragalactic ULDB Spectroscopi	3.4	--	**5.2**	1.0	0.0	0.0	0.0
Imaging X-Ray Polarimetry Explorer	61.5	--	**12.1**	5.7	1.9	0.0	0.0
X-Ray Imaging and Spectroscopy Mission	15.0	--	**49.2**	21.8	15.9	14.4	11.1
Total Budget	**118.7**	**135.8**	**210.4**	**203.3**	**267.9**	**380.1**	**516.9**
Change from FY 2021			**74.6**				
Percentage change from FY 2021			**54.9%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



The NASA Explorers TESS mission discovered three exoplanets orbiting a red dwarf star that is 31 light years away (illustrated above).

Mission Planning and Other Projects

Astrophysics Explorers Other Missions and Data Analysis includes funding for small missions in formulation and development (CASE, SPHEREx, GUSTO, IXPE, XRISM), operating missions (TESS, NICER, NuSTAR, Neil Gehrels Swift Observatory), and funding for future mission selections and program management functions.

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CONTRIBUTION TO ARIEL (ATMOSPHERIC REMOTE-SENSING INFRARED EXOPLANET LARGE-SURVEY MISSION) SPECTROSCOPY OF EXOPLANETS (CASE)

ARIEL is a joint ESA/NASA mission planned for launch in 2028 that will observe hundreds of warm transiting gas giants, Neptune sized planets, and super-Earths. The mission responds to high-priority science from the last Decadal Survey of Astronomy and Astrophysics by addressing the question: "What are the characteristics of planetary systems orbiting other stars and do they harbor life?”

ARIEL’s main science goals include measuring the composition and structure of planetary atmospheres, determining the vertical and horizontal temperature structure, and identifying chemical processes at work (thermochemistry, photochemistry, transport quenching). A mission designed and optimized for transiting exoplanet spectroscopy will address a key gap in NASA’s exoplanet exploration mission portfolio. CASE will fill that gap and ensure the full participation of the U.S. community in ESA’s ARIEL mission. The CASE project hardware contribution to ARIEL is a pair of heritage sensor chip assemblies, cold front-end electronics, and cryogenic flex cables together with packaging and thermal management capability. CASE is currently in its preliminary design and technology completion Phase B and working with the ARIEL consortium partners on interface requirements for the NASA contribution.

Recent Achievements

After extensive and successful testing at the Detector Characterization Lab under the ARIEL temperature regime, JPL decided to use Euclid residual detectors. JPL and ARIEL are currently working to formalize this agreement.

ASTROPHYSICS EXPLORERS FUTURE MISSIONS

Astrophysics Explorers Future Missions funding supports future astrophysics Explorers missions, missions of opportunity, and Pioneer class missions through concept studies and selections. Astrophysics Explorers Future Missions funding will support initiation of an Astrophysics Probe mission as early as 2022, pending Decadal Survey recommendations.

ASTROPHYSICS EXPLORERS PROGRAM MANAGEMENT

Astrophysics Explorers program management provides programmatic, technical and business management of ongoing missions in formulation and development.

GALACTIC/EXTRAGALACTIC ULTRALONG-DURATION BALLOON SPECTROSCOPIC TERAHERTZ OBSERVATORY (GUSTO)

In March 2017, NASA's Astrophysics Explorers Program selected the GUSTO balloon payload as a Mission of Opportunity. GUSTO will launch on a high-altitude stratospheric super-pressure balloon from McMurdo, Antarctica, in December 2022 for approximately 75 days. GUSTO’s telescope, with its Terahertz heterodyne array receivers, will provide the spectral and spatial resolution needed to study the interstellar medium. The GUSTO mission will provide the first complete study of all phases of the stellar life cycle, from the formation of molecular clouds, through star birth and evolution, to the formation of

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gas clouds and the restart of the cycle. During flight, the GUSTO payload will conduct its scientific observation while tracking the prevailing stratospheric winds at the float altitude of 33.5 kilometers.

Recent Achievements

Integration and testing of payload and gondola, as well as complete observatory, continues. The project successfully conducted the cool-down of the flight cryostat during February 2021. Work on the observatory transporter has progressed toward critical design review in March 2021. The Applied Physics Laboratory assembled the gondola and it awaits the arrival of the payload during the summer of 2021. The GUSTO team scheduled the telescope payload integration into the gondola to form the observatory in the fall of 2021.

THE IMAGING X-RAY POLARIMETRY EXPLORER (IXPE)

NASA selected IXPE, a Small Explorer-class (SMEX) mission, to continue into Phase B formulation in January 2017. Due to the hundred-fold improvement in the sensitivity of X-ray polarimeters during the past two decades, IXPE will enable astrophysicists to open an important, new field of investigation into some of the most extremely unusual objects found in the universe. IXPE will examine polarized X-ray emissions from both galactic and extragalactic X-ray sources, such as active galactic nuclei, quasars, pulsars, pulsar wind nebulae, magnetars, accreting X-ray binaries, supernova remnants, and the Galactic Center. These observations will allow the investigation of general relativistic and quantum effects in the extreme environment associated with these sources and will significantly improve our understanding of fundamental physics. IXPE will launch into a low Earth orbit at a low inclination angle for a two-year mission beginning in January 2022.

Recent Achievements

IXPE entered the fabrication and testing phase of all its major components. Despite a two-month COVID-19-driven shut-down of IXPE payload fabrication activities at MSFC, resulting in a two-month delay in the completion on the IXPE payload fabrication, the systems integration review was successfully completed in September 2020, followed by a KDP-confirmation review in November 2020. IXPE is currently in Observatory integration and testing.

THE X-RAY IMAGING AND SPECTROSCOPY MISSION (XRISM)

The X-ray Imaging and Spectroscopy Mission (XRISM), previously named XARM, is a joint NASA and JAXA mission that will recover the soft X-ray spectroscopic capability lost with the Hitomi mission that ended in March 2016. JAXA is planning to launch XRISM in early 2022. The key scientific objective of XRISM is to pioneer a new horizon of the Universe with unprecedented high-resolution X-ray spectroscopy. XRISM will provide breakthrough science in a number of areas, including structure and formation of the Universe, the evolution of clusters of galaxies, and the transport and circulation of energy in the cosmos. NASA is developing the Resolve Soft X-ray Spectrometer and many of its subsystems and the X-ray mirror assemblies for the observatory. NASA is also responsible for the Science Data Center, which is developing the analysis software for all instruments, the data processing pipeline, as well as support of Guest Observers (GO) and the XRISM GO Program.

Recent Achievements

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NASA's contribution to the XRISM mission passed KDP-D in November 2020. Integration in Japan of the NASA Calorimeter Spectrometer Insert (CSI) and flight aperture assembly with the JAXA dewar showed the CSI meets its top-level performance requirements. Subsequent testing of the integrated system revealed a small helium leak in the JAXA dewar that is still under investigation by NASA and JAXA personnel amidst heavy travel constraints during the COVID-19 pandemic. Because of delays in integration and testing, NASA postponed delivery of the flight electronics boxes planned for 2020, although testing and pre-ship review have been successfully completed in the United States.

Operating Missions

NEUTRON STAR INTERIOR COMPOSITION EXPLORER (NICER)

The NICER instrument launched on June 3, 2017, to an external logistics carrier on the International Space Station (ISS) for an 18-month prime mission. Its main goal is spectroscopic X-ray observations of neutron stars with high-time resolution, to measure their masses and radii precisely and thus to test models of how matter behaves at extreme densities: a neutron star squeezes up to twice the mass of the Sun into a city-size volume, so the density and pressure are higher than in atomic nuclei. NICER measures fluctuating X-rays from other sources, such as disks of hot gas pouring onto a black hole or neutron star from a stellar companion, or the gas around very massive black holes at the centers of galaxies. The 2019 Senior Review of Operating Missions approved extended mission operations through FY 2022 to include additional cycles of the NICER Guest Observer program element. NICER demonstrated achievement of its prime-mission science goals in a June 2018 review, with public release of key science results in December 2019.

Recent Achievements

In December 2019, NICER produced the first precise and robust measurements of both a neutron star’s size and its mass and revealed that million-degree “hot spots” on its surface are much stranger than previously thought. Sweeping in and out of view as the star spins, emission from these spots appears as extremely regular pulsations, the origin of the name “pulsar.” A neutron star is so dense its gravity warps the fabric of space and time nearby, so that light from a pulsar is “bent,” with some of it redirected into our view even when emitted from the star’s far side. NICER took advantage of this effect for the first time, yielding key measurements of a pulsar’s mass (1.4 times our Sun) and radius (8 miles) to help answer an enduring question in astrophysics: What form does matter take in the ultra-dense cores of neutron stars? The accompanying result for the surface hot-spot shapes, sizes, and locations, a guidepost to the star’s magnetic configuration, defied textbook expectations, revealing that extended heated regions appear only in one hemisphere on the star. NICER will publish follow-on measurements for additional pulsars in 2021.

NICER captured an unprecedented look at the disappearance and rebirth of the accretion flow around a supermassive black hole at the center of an active galactic nucleus (AGN). Triggered by a visible-light flare in December 2017, NICER embarked on a 2.5-year monitoring campaign, witnessing first an X-ray flare, then a precipitous decline over 40 days to virtually no X-ray emission (more than 1,000 times fainter than at the start), and finally a rebound over 400 days to being the brightest AGN in the sky (at 20 times the initial brightness). The leading explanation for these rapid and never-before-seen changes is that

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they were triggered by the destruction of a star that wandered too close to the central black hole, disrupting the black hole's regular "feeding" on nearby gas. Conventional wisdom was that changes in AGN X-ray emission should occur on timescales of a century or more; this NICER result and others like it are making a seminal contribution to our understanding of "changing look" AGNs and the mechanisms powering the most massive and luminous black holes in the universe.

NICER's operational flexibility on the ISS has enabled it to play the role of X-ray sensor for dozens of multi-wavelength campaigns targeting a large variety of cosmic phenomena through observations coordinated with telescopes around the world and in space.

NEIL GEHRELS SWIFT OBSERVATORY

The Neil Gehrels Swift Observatory is a multi-wavelength space-based observatory that is uniquely equipped to make rapid-response observations to fast-breaking events. The observatory measures the position, brightness, and physical properties of gamma-ray bursts, and is revolutionary in allowing scientists to solve the mystery of their origin in the birth-cries of stellar-mass black holes. The observatory continues to target gamma-ray burst science, while also using its capabilities to increase our understanding of the entire transient universe, ranging in distance from the solar system to high-redshift quasars, and in time from the present to the epoch of reionization. Neil Gehrels Swift Observatory is a MIDEX class mission that launched in 2004 and is currently in extended mission operations. The 2019 Senior Review of Operating Missions recommended continuing operations through FY 2022.

Recent Achievements

From November to December 2019, the Swift Ultraviolet/Optical Telescope (UVOT) made the first observations of water-loss from an interstellar comet, 2I/Borisov, as it approached and rounded the Sun, giving us new information on the properties of comets formed in other planetary systems. In February 2020, scientists used a large sample of UVOT observations to show that the chemical composition of galaxies is related to the UV flux of the "Type Ia" supernovae they host, helping us to understand better the type of supernovae used to measure the expansion history of the universe. On March 12, 2020, the Burst Alert Telescope on Swift discovered a highly magnetized neutron star, known as Swift J1818.0-1607, which appears to be the youngest known example of a special class of objects called magnetars, the most magnetic objects in the universe.

NUCLEAR SPECTROSCOPIC TELESCOPE ARRAY (NuSTAR)

Launched in June 2012, NuSTAR completed its prime mission in July 2014 and is now in extended mission operations. NuSTAR enables scientists to locate supermassive black holes in other galaxies, study extreme accretion onto neutron stars, locate and examine the remnants of collapsed stars in our Galaxy and the nearby universe, and observe any new supernovae in the local group of galaxies. NuSTAR's key science products are sensitive X-ray maps of the celestial sky at a higher energy-band than any other focusing X-ray satellite. NuSTAR offers opportunities for a broad range of science investigations, ranging from probing cosmic ray origins and studying the extreme physics around collapsed stars to mapping microflares on the surface of the Sun. NuSTAR performs key follow-up observations of sources found by NASA's Chandra, Spitzer, and Wide-field Infrared Survey Explorer (WISE) satellites. The NuSTAR mission implemented a Guest Observer program in 2015. Scientists are now implementing the observations selected under Cycle 6 of the Guest Observer program. Some

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NuSTAR observations are coordinated with other missions, including Swift, Chandra, INTEGRAL, XMM-Newton, and NICER. Such coordinated observations take advantage of NuSTAR's unique access to high-energy X-rays with synergistic lower-energy X-ray capabilities of these other missions, such as NICER's exquisite X-ray timing, Chandra's high spatial resolution imaging, and Swift's agility for rapidly slewing across the sky to monitor variable sources. NASA approved the 2019 Senior Review of Operating Missions recommendation to continue NuSTAR extended operations through FY 2022.

Recent Achievements

NuSTAR continues, to provide insights into the high-energy Universe and some of the most powerful and mysterious objects in it. During its eight years of successful operations, the number of NuSTAR science publications have increased every year, shedding light on objects ranging from quasars billions of light years away, to energetic sources within our own galaxy, to objects in our Solar System, such as the Sun and Jupiter. Over 800 papers reported on NuSTAR observations between 2013 and 2020 in the refereed scientific literature.

Some of the highlights over the past year have involved variable sources. Time-domain studies have always been central to high-energy astrophysics. With typical X-ray sources measuring light-seconds to light-hours across, and associated with some of the most powerful, energetic events in the universe, variability is a fundamental aspect of most high-energy sources and provides a key diagnostic tool for physical understanding. Indeed, the brightest X-ray source in the sky will often be a new transient that lasts from seconds to months.

Recent exciting NuSTAR results on transient sources include witnessing the formation of a compact object (i.e., a neutron star or black hole) in real time from the supernova explosion of a star in a nearby galaxy. Considering the slightly more distant universe, NuSTAR watched the disappearance and resurgence several months later of the hot, X-ray emitting "corona" of a nearby active galaxy. In this galaxy, 1ES 1927+654, the debris tail of a star falling into a black hole millions of times more massive disrupted the black hole's accretion stream, ultimately choking off the corona for several weeks. NuSTAR has also watched an exciting class of "ultraluminous X-ray sources" vary, appear, and disappear in the outskirts of nearby galaxies. Astronomers know at least some such sources to be neutron stars, and this variability behavior may be teaching us about the role of strong magnetic fields in these extreme sources with sizes comparable to Washington, D.C. and masses comparable to the Sun.

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

The Transiting Exoplanet Survey Satellite (TESS) mission launched on April 18, 2018. TESS is performing an all-sky survey to search for planets transiting nearby stars. By finding planets smaller than Neptune that transit stars bright enough to enable follow-up, TESS discoveries are prime targets to learn about the composition and atmospheric properties of planets beyond the solar system. TESS monitors the sky with four wide-field visible-light cameras to detect periodic drops in brightness caused by planets passing in front of their stars. TESS also obtains full-frame images of the entire field-of-view (24 x 96 degrees) at a cadence of 10 minutes and for a subset of preselected targets, collects data at a higher time-resolution of one image every 20 seconds.

TESS is designed to survey over 85 percent of the sky (an area of sky 400 times larger than covered by Kepler) to search for planets around nearby stars (within approximately 200 parsecs). TESS stars are typically 30-100 times brighter than those surveyed by the Kepler satellite. Planets detected around these

OTHER MISSIONS AND DATA ANALYSIS

stars are far easier to characterize with follow-up observations, resulting in refined measurements of planet masses, sizes, densities, and atmospheric properties.

Recent Achievements

TESS has identified over 2,330 candidate planets, with 79 confirmed as bona fide planets. Planet searches and ground-based observations are ongoing to find, confirm, and characterize more planets. TESS is well on its way to achieving its main goal of finding over 50 planets with masses measured through ground-based follow-up. Several are already included on the James Webb Space Telescope list of targets for guaranteed time observations, highlighting their value to the science community. Of particular note is the discovery of TESS's first Earth-size planet within the habitable zone of its star, the first planet found orbiting a white dwarf, and a planet orbiting the nearest and brightest young star, which allows us to study planet formation around a star that is itself still forming.

TESS ended its prime operations in July 2020 and is now in extended operations. With TESS now in extended operations, the mission successfully commissioned new data modes that enable TESS to study very short duration events in unprecedented detail, such as stellar flares and pulsations. NASA will continue to operate TESS to expand the survey to new fields, smaller planets, and wider orbits. While still performing exoplanet science, the breadth of the mission is expanding and now includes science that is closer to home, investigations of Near-Earth Asteroid investigations and comets in our Solar System, as well as studies of distant galaxies through observations of active galaxies and gamma-ray bursts.

HELIOPHYSICS

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Heliophysics Research	251.7	280.8	**210.6**	213.2	212.0	219.5	221.5
Living with a Star	146.0	148.2	**115.3**	146.1	170.2	235.8	278.9
Solar Terrestrial Probes	126.8	132.2	**253.3**	252.6	228.8	197.6	120.4
Heliophysics Explorer Program	184.1	170.7	**189.2**	151.6	157.9	162.9	226.3
Heliophysics Technology	15.9	19.2	**28.3**	39.8	47.7	17.8	11.4
Total Budget	**724.5**	**751.0**	**796.7**	**803.3**	**816.6**	**833.6**	**858.5**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Heliophysics

HELIOPHYSICS RESEARCH

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Heliophysics Research and Analysis	66.6	77.0	**52.0**	52.6	52.6	54.6	56.6
Sounding Rockets	69.7	73.6	**60.1**	60.1	60.1	65.1	65.1
Research Range	31.0	32.0	**26.4**	26.8	26.9	26.9	26.9
Other Missions and Data Analysis	84.4	98.2	**72.0**	73.7	72.4	72.9	72.9
Total Budget	**251.7**	**280.8**	**210.6**	**213.2**	**212.0**	**219.5**	**221.5**
Change from FY 2021			**-70.2**				
Percentage change from FY 2021			**-25.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Shown here is one of two rockets for the VISIONS-2 mission. Credit: Allison Stancil-Ervin.

The Sun, a typical medium star midway through its life, governs the solar system. The Sun wields its influence through its gravity, radiation, solar wind, and magnetic fields, all of which spread out through the heliosphere, interacting with other planets, the Earth, and its space environments to produce space weather, which can affect human technological infrastructure and activities. Heliophysics seeks to understand the Sun, heliosphere, and planetary space environments as a single connected system to answer these fundamental questions:

- How and why does the Sun vary?
- How do Earth and the heliosphere respond to the Sun's changes?
- How do the Sun and the solar system interact with the interstellar medium?
- How do these processes affect human activities?

The Heliophysics Research program supports a wide variety of activities in support of these questions including:

- Investigations of the Sun, including processes taking place throughout the solar interior and atmosphere and the evolution and cyclic activity of the Sun.

HELIOPHYSICS RESEARCH

- Investigations of the origin and behavior of the solar wind, energetic particles, and magnetic fields in the heliosphere and their interaction with Earth and other planets, as well as with the interstellar medium.
- Investigations of the physics of magnetospheres, including fundamental interactions of plasmas and particles with fields and waves, and coupling to the solar wind and ionospheres.
- Investigations of the physics of the terrestrial mesosphere, thermosphere, ionosphere, including the coupling of these phenomena to the lower atmosphere and magnetosphere.

For more information, go to: https://science.nasa.gov/heliophysics/programs/research

EXPLANATION OF MAJOR CHANGES IN FY 2022

Funding associated with technology development activities, including CubeSats and Heliophysics Technology and Instrument Development for Science (HTIDeS), have been moved to the new Heliophysics Technology Program.

ACHIEVEMENTS IN FY 2020

In FY 2020, the Heliophysics Research program implemented an increase in overall selections rates; increased award funding; and new and innovative elements around technology, high-risk high-reward, and interdisciplinary science. The program continued to enhance the scientific return of heliophysics research by innovatively connecting observations from one or more missions with satellite or ground observations from other divisions and/or other agencies (within or outside of the United States). In FY 2020 NASA released two targeted guest investigator solicitations for Global-scale Observations of the Limb and Disk (GOLD), Ionospheric Connection Explorer (ICON), and Parker Solar Probe (PSP), as well as an Early Career Investigators program element, and a U.S. Participating Investigators program element for non-NASA missions.

NASA launched seven sounding rocket missions with campaigns in remote areas. The Sounding Rockets project began the year at White Sands Missile Range with the launch of DUST (Determining Unknown yet Significant Traits) in October 2019. In late November and early December 2019, the Investigation of Cusp Irregularities-5 (ICI-5) and the Cusp Heating Investigation (CHI) launched from Svalbard to investigate the source of disturbances in the ionosphere. NASA launched PolarNOx from Poker Flat Research Range in January 2020 to investigate the abundance of nitric oxide in the mesosphere, created by the aurora in the polar night, which can transport to the stratosphere and destroy ozone. The Sounding Rockets project returned to operations during COVID-19 with the successful launch of the DUST-2 mission from the White Sands Missile Range in September 2020.

In addition, one CubeSat launched in December 2019, Scintillation Observations and Response of The Ionosphere to Electrodynamics (SORTIE). SORTIE's goal is to discover the sources of wave-like plasma perturbations in the F-region ionosphere, and the role of mechanical forcing in the formation of wave-like plasma perturbations.

The GOLD mission enabled significant progress in understanding the effects of solar and atmospheric variability on Earth’s thermosphere and ionosphere. Researchers using GOLD data suggested a physical pathway for planetary wave coupling in the atmosphere-ionosphere system via planetary wave-modulated tides causing multi-day oscillations in electron density. GOLD observed a reduction in the ratio of atomic oxygen to molecular nitrogen during the break-up of the polar vortex in the stratosphere in early 2019, revealing a connection between the weather of the polar stratosphere and the weather of the thermosphere.

New research using data from the Van Allen Probes mission, which has made unprecedented measurements of the dynamics of Earth's radiation belts, has revealed that human activity can cause charged particles to be ejected from the radiation belts. Radio waves from high-powered, ground-based transmitters used to communicate with submarines also propagate into space. They scatter low-energy electrons in a localized region a distance of one Earth radius above Earth's surface. The effect of the waves is clearly visible, and important in quantitatively assessing the impacts of different loss processes.

The Magnetospheric Multiscale (MMS) mission, which consists of four satellites orbiting in a tighter formation than any previous satellite mission, was used in conjunction with the Japanese Arase satellite to show that oxygen ions flowing out of both the nightside aurora and the dayside cusp reach the near-Earth plasma sheet during the main phase of geomagnetic storms. They become the source for ions that cause strong disturbances in Earth's magnetic field during the storms. Also, MMS observations near the bow shock between the Sun and Earth were used to verify a prediction that the most energetic particles gain their energy via a distortion of magnetic structures and subsequent scattering of particles.

The PSP mission, which has gotten closer to the Sun than any previous human-made object, is expected to see the plasma making up the solar wind co-rotate with the Sun once it is close enough to the Sun. Though PSP has not yet traversed within the predicted distance of co-rotation, it observed strong sporadic flows in the co-rotating direction, and numerous regions where the magnetic field changes directions ("switchbacks") and jets of plasma. This suggests that the transition to co-rotating flow dominated by the interplanetary magnetic field is more turbulent than expected, and that PSP is getting near the transition point.

Understanding the nature of solar flare trigger mechanisms is key to improving space weather prediction capabilities. Hinode and Solar Dynamics Observatory (SDO) observations, in combination with modeling, provide strong evidence for the onset mechanism of flares. The intrusion of flux at the Sun's surface leads to instabilities in the overlaying coronal magnetic fields, which results in a rapid release of energy through magnetic reconnection. A unique and creative technique to infer far-side solar structures was developed utilizing acoustic wave information derived from the SDO and STEREO missions as well as ground-based observations. Until now our ability to detect the formation of structures on the far-side of the Sun has been limited. This new technique enables far-side mapping of the Sun without deploying satellites to that area. This will facilitate early detection of potential extreme events that impact Earth.

Through observations from the Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission, along with support from Geostationary Operational Environmental Satellite(s) (GOES) and other observations from the NASA Heliophysics fleet, new insights into how and where energy is released during intense geomagnetic storms were obtained. Magnetic reconnection converts magnetic to particle energy and drives space currents, which can disrupt electrical power line transmission. It was found that magnetic reconnection events occur closer to Earth, and the conditions conducive to reconnection are more common, than previously thought. The knowledge gained will enable improved modeling of storm-time energy release and its effects on space currents and ground disturbances.

HELIOPHYSICS RESEARCH

WORK IN PROGRESS IN FY 2021

NASA will continue to fund projects competitively selected for Research Opportunities in Space and Earth Science (ROSES) 2020 and 2021. Notable new research solicitations include: Geospace Dynamics Constellation (GDC) Interdisciplinary Scientists; Heliophysics Mission Concept studies to support planning activities for the new Decadal Survey; Interdisciplinary Science for Eclipse in preparation of the 2024 Solar Eclipse; and Heliophysics Living With a Star Tools and Methods.

NASA will continue maintaining the Diversify, Realize, Integrate, Venture, Educate (DRIVE) initiative as part of the integrated research program and will continue planning for Phase 2 selections of the DRIVE Science Centers.

The current sounding rockets manifest features 18 NASA missions and five reimbursable missions in FY 2021 from various locations. Due to safety concerns with COVID-19, the project will predominately launch from U.S. ranges in FY 2021: Wallops Island in Virginia, White Sands in New Mexico, and Poker Flat in Alaska. However, the Sounding Rockets project will attempt their inaugural campaign in Australia with the launch of several investigations of celestial targets of interest in the Southern sky. The Wallops Flight Facility's (WFF) Research Range will support the first Rocket Lab launch from U.S. soil. Planned launches include delivery of payloads for the U.S. Space Force and NASA.

NASA will continue to support the formulation and development of six CubeSats. Science will continue to collaborate with the Human Exploration and Operations Mission Directorate to enable the CubeSat mission to Understand Solar Particles over Earth's Poles (CUSPP) on the first flight using the Space Launch System, Exploration Mission-1 (EM-1), along with the Cusp Plasma Imaging Detector (CuPID) CubeSat (Artemis I/Artemis Rideshare). Other CubeSat launches will include Daily Atmospheric Ionospheric Limb Imager, Low-Latitude Ionosphere/Thermosphere Enhancements in Density, Miniature X-ray Solar Spectrometer, and the Scintillation Prediction Observations Research Task.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

In FY 2022, NASA will select new awards solicited in ROSES 2021. While most of the solicitations represent the periodic solicitations of ongoing Research & Analysis elements, there are some efforts that are sufficiently different from previous years that merit attention.

The Geospace Dynamics Constellation (GDC) Interdisciplinary Scientists (IDSs) program, solicited through ROSES 2021, seeks individuals to expand the GDC mission science team, assembled under the Living With a Star program. These activities will build upon the GDC Science and Technology Definition Team (STDT) Final Report and GDC pre-formulation efforts. These IDSs will join the GDC science team for Phases A-D and will participate in GDC development activities necessary to move the team towards a successful Key Decision Point-B and beyond.

The Heliophysics Mission Concept Studies (HMCS) element will fund six-month-long mission concept studies that are part of community preparation for the next Solar and Space Physics Decadal Survey. These studies will be conducted by the proposal team, using mission design capabilities included in the proposal, and will result in a final mission concept report delivered to NASA. Additionally, NASA will support awardees submitting and briefing the mission concept to the Decadal Survey Committee.

The Interdisciplinary Science for Eclipse (ISE) element will support the development of new research or enhancement of existing research, applied to the 2021 total solar eclipse visible from the Southern Hemisphere on December 4th, 2021. This total solar eclipse will be visible from Antarctica and the

Southern Ocean. This eclipse will be logistically challenging, as the path of totality will only make landfall in Antarctica. Totality will last about two minutes. This eclipse will be unusual as the path of the total eclipse will move from east to west across Antarctica, while most eclipse paths move from west to east. NASA is seeking proposals that would utilize the unique opportunity presented by the solar eclipse to study any relevant heliophysics research topic, such as a topic focused on the Sun or on the Ionosphere-Thermosphere-Mesophere system.

NASA will make Phase 2 selections for the DRIVE Science Centers.

The current sounding rockets mission manifest features 15 missions in FY 2022 from various locations in the United States, Norway, and Kwajalein Atoll.

Program Elements

RESEARCH RANGE

The Research Range project provides operations support, maintenance, and engineering for the WFF launch range in support of suborbital, orbital, and aircraft missions conducted on behalf of NASA and the Department of Defense. New work includes support for NASA technology missions, autonomous aerial vehicle flights, and commercial launch and flight projects.

The range instrumentation includes meteorological, telemetry, radar, command, launch and range control centers, and optical systems. Research Range mobile assets provide range services at other ranges and remote locations around the world.

SOUNDING ROCKETS

The Sounding Rockets project supports the NASA strategic vision and goals for Earth Science, Heliophysics, Planetary Science, and Astrophysics. The missions flown annually by the project provide researchers with unparalleled opportunities to build, test, and fly new instrument and sensor design concepts while simultaneously conducting world-class scientific research. Coupled with a hands-on approach to instrument design, integration, and flight, the short mission life cycle (payloads can sometimes be developed as quickly as three months) helps ensure that the next generation of space scientists receives the training and experience necessary to move on to NASA's larger, more complex space science missions.

With the capability to fly higher than many low-Earth orbiting satellites and the ability to launch on demand, sounding rockets often offer the only means to study specific scientific phenomena of interest to many researchers. Unlike instruments on board most orbital spacecraft or in ground-based observatories, sounding rockets can place instruments directly into regions where and when the science is occurring to enable direct, in-situ measurements. The mobile nature of the project enables researchers to conduct missions from strategic vantage points worldwide. To study solar and astrophysics phenomena, telescopes and spectrometers fly on sounding rockets to collect unique science data and test prototype instruments for future satellite missions.

HELIOPHYSICS RESEARCH

HELIOPHYSICS RESEARCH AND ANALYSIS

This Heliophysics Research and Analysis project supports basic research, solicited through NASA's annual Research Opportunities in Space and Earth Science (ROSES) announcements. It supports investigations in all the research areas of Heliophysics: Sun, heliosphere, magnetosphere, ionosphere, and upper atmosphere, and investigations that span the regimes and address a systems approach – emphasizing the understanding of fundamental processes and interconnections across the traditional science disciplines, on a broad range of spatial and temporal scales. The project also supports investigations focused on processes that create space weather events, and investigations to enable a capability for predicting future space weather events.

Heliophysics supporting research and theory, modeling, and simulation are the foundations of the Heliophysics Research and Analysis project. They lead the way to new understanding of previous investigations and drive science concepts for future missions. They are essential in fully exploiting Heliophysics mission research data collected between the outer edge of the Earth's atmosphere and the interaction of the Sun and solar wind with the local galactic environment currently explored by Voyager. The DRIVE science center's project element supports large principal-investigator proposed team efforts, which require a critical mass of interdisciplinary expertise, to make significant progress in understanding complex physical processes with broad importance. They employ a variety of fundamental research techniques (e.g., theory, numerical simulation, and modeling), analysis, and interpretation of space data.

A new theory, modeling, and simulation element uses data science and data assimilation techniques to extract maximum information relevant to frontier science questions from the petabytes of data collected by the Heliophysics fleet.

NASA split the Heliophysics Flight Opportunities for Research and Technology (H-FORT) project element within the R&A project into three elements: Low Cost Access to Space (LCAS); Flight Opportunities Studies (FOS), which is now part of the Heliophysics Technology program; and Flight Opportunities: SmallSats and Rideshares. These investigations use spaceflight of experimental instrumentation to achieve scientific goals and proof-test new technology that may ultimately find application in larger or strategic Heliophysics space missions. These investigations may use a range of flight opportunities, including suborbital rockets, suborbital reusable launch vehicles, ISS payloads, CubeSats, and balloon flights.

Program Schedule

NASA implements the Heliophysics Research program via a competitive selection process. NASA releases research solicitations each year through the Research Opportunities in Space and Earth Science (ROSES) NASA Research Announcements (NRA).

Date	Significant Event
Q1 FY 2022	ROSES-2021 selection within six to nine months of receipt of proposals
Q2 FY 2022	ROSES-2022 solicitation
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation

HELIOPHYSICS RESEARCH

Date	Significant Event
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation

Program Management & Commitments

Program Element	Provider
Research and Analysis	Provider: Headquarters (HQ) Lead Center: HQ Performing Centers: GSFC, MSFC, JPL, LaRC, JSC Cost Share Partners: None
Sounding Rockets	Provider: GSFC Lead Center: HQ Performing Center: GSFC Cost Share Partners: None
Research Range	Provider: GSFC Lead Center: HQ Performing Center: GSFC/WFF Cost Share Partners: None

Acquisition Strategy

NASA issues solicitations for competed research awards each February in the ROSES NRAs. To the widest extent possible, NASA fully and openly competes all new acquisitions. Proposals are peer-reviewed and selected from the annual ROSES announcement. Universities, government research laboratories, and industry partners throughout the United States participate in research projects.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Sounding Rocket Operations	Orbital ATK	Dulles, VA

HELIOPHYSICS RESEARCH

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Mission Senior Review Panel	Aug 2020	A comparative evaluation of Heliophysics operating missions	The report, released in Nov 2020, assessed missions individually and as part of a system observatory	Apr 2023
Relevance	Heliophysics Advisory Committee	2020	To review progress towards Heliophysics objectives in the NASA Strategic Plan	All areas were rated green as documented in the FY 2019 Agency Financial Report	2021
Relevance	Heliophysics Advisory Committee	2021	To review progress towards Heliophysics objectives in the NASA Strategic Plan	To be determined	2022

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FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Science Planning and Research Support	6.7	6.7	**6.7**	6.7	6.7	6.7	6.7
CubeSat	18.5	20.0	**9.0**	9.0	9.0	9.0	9.0
Solar Data Center	3.0	3.7	**1.2**	1.2	1.2	1.2	1.2
Data & Modeling Services	3.0	5.3	**2.5**	3.0	3.0	3.0	3.0
Space Physics Data Archive	2.5	2.3	**2.3**	2.3	2.3	2.3	2.3
Guest Investigator Program	23.0	32.1	**23.0**	24.5	23.0	23.0	23.0
Community Coordinated Modeling Center	4.5	4.6	**4.9**	5.1	5.4	5.6	5.6
Space Science Mission Ops Services	11.9	11.9	**11.9**	11.9	11.9	11.9	11.9
Voyager	6.4	6.5	**5.5**	5.0	5.0	5.2	5.2
Solar and Heliospheric Observatory (SOHO)	2.3	2.3	**2.4**	2.2	2.2	2.2	2.2
Wind	2.2	2.2	**2.2**	2.3	2.3	2.3	2.3
Geotail	0.4	0.5	**0.4**	0.5	0.5	0.5	0.5
Total Budget	**84.4**	**98.2**	**72.0**	**73.7**	**72.4**	**72.9**	**72.9**
Change from FY 2021			**-26.2**				
Percentage change from FY 2021			**-26.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

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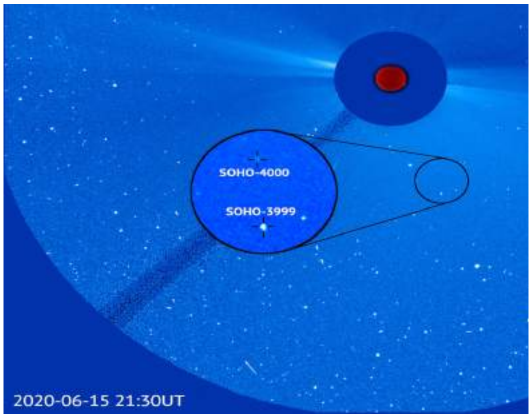

The 4,000th comet discovered by NASA's SOHO observatory and ESA (European Space Agency) is seen in an image from the spacecraft alongside SOHO's 3,999th comet discovery. The two comets are relatively close at approximately 1 million miles apart, suggesting that they could have been connected as recently as a few years ago.

NASA accumulates, archives, and distributes data collected by the Heliophysics System Observatory, a fleet of operating spacecraft. Combining the measurements from all these observing platforms enables interdisciplinary, connected systems science across the vast spatial scales of our solar system. This collective asset enables the data, expertise, and research results to contribute directly to fundamental research on solar and space plasma physics and to the national goal of real-time space weather prediction. NASA teams support day-to-day mission operations for NASA spacecraft and data analysis to advance the state of space science and space weather modeling. NASA conducts science community-based projects to evaluate research models containing space weather information that is of value to industry and government agencies. Heliophysics data centers archive and distribute the science data from operating missions in the Living With a Star (LWS), Solar Terrestrial Probes (STP) Research, and Explorer programs.

Mission Planning and Other Projects

SCIENCE PLANNING AND RESEARCH SUPPORT

This project supports NASA scientists' participation in proposal peer review panels, decadal surveys, and National Academies' studies.

CUBESAT

The Heliophysics CubeSat project continues to work on the cross-discipline investigations already underway. In response to the capabilities demonstrated by CubeSat investigations in the initial pathfinder stage, the CubeSat project expanded in 2019 to take advantage of new science achievable via investigations in the $2 million to $10 million range. The Heliophysics CubeSat project has three projects on orbit with an additional 16 waiting for flight and eight planned for launch in 2021. The project expects to add an additional two to three new projects in FY 2021 and again in FY 2022. The larger investigations will enable the development of remote sensing investigations with more sophisticated CubeSats as well as small constellations of in-situ CubeSat investigations.

SOLAR DATA CENTER

The Solar Data Center provides mission and instrument expertise to enable high-quality analysis of solar physics mission data. It provides leadership for community-based, distributed development efforts to

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facilitate identification and access of solar physics data, including ground-based coordinated observations via the Virtual Solar Observatory, a research tool that allows scientists to search for solar and heliospheric physics data. The Center also provides a repository for software used to analyze these data.

DATA AND MODELING SERVICES

This project supports missions in extended operations and missions planned for decommision, to prepare their data holdings for long-term archival curation. This project also provides for the creation of higher-level data products, which are of significant use to the science community and not funded during the prime mission. Higher-level data products are data that combine results of multiple missions and/or instruments. Elements of this project are competed through the annual ROSES competitive announcement.

SPACE PHYSICS DATA ARCHIVE

The Space Physics Data Archive ensures long-term data preservation and online access to non-solar heliophysics science data. It operates key infrastructure components for the Heliophysics Data Environment, including inventory and web service interfaces to systems and data. It also provides unique enabling science data services.

The Heliophysics data archives are growing at an exponential rate. All science disciplines have seen a surge of data holdings over the last decade to the extent that conventional storage and retrieval becomes impractical. This era of Big Data requires the effective curation, and preservation of critical data products. NASA will move beyond a traditional repository and toward a functional, collaborative data library. Over the next several years, NASA will transform the Heliophysics archives in the Heliophysics Data Library.

Recent Achievements

In response to the shifting science community landscape, technological advancement, and projections of future data quantities, NASA Heliophysics developed a preliminary strategic plan to increase agility, adaptability, and sustainability with data collection, management, and storage efforts. With innovation in mind, NASA is moving forward with cloud storage and partnerships to evolve data accessibility and data capabilities by bringing the data storage and the computing power together. This will enable unprecedented access to and analysis of critical, unexamined data in the Archives by a wide range of stakeholders. This modernization effort will maximize the utility of the data of the Heliophysics System Observatory, sustain the archives, and ensure access for the public to this data.

GUEST INVESTIGATOR PROGRAM

The Guest Investigator program maximizes the output of currently operating Heliophysics missions by supporting studies consistent with the science goals of these missions and those expressed in the 2013 decadal survey and 2020-2024 Science Mission Directorate Science Plan: A Vision for Scientific Excellence. These competitive research investigations use data from multiple spacecraft, as appropriate. Investigations addressing global system science are strongly encouraged, as Heliophysics is, by its nature, the investigation of a large-scale, complex, connected system.

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Recent Achievements

Scientists funded through the Guest Investigator program recently found that a secret behind the workings of sunquakes, seismic activity on the Sun during solar flares, might be hidden beneath the solar surface. These earthquake-like events release acoustic energy in the form of waves that ripple along the Sun's surface, like waves on a lake, in the minutes following a solar flare, an outburst of light, energy, and material seen in the Sun's outer atmosphere. NASA's Solar Dynamics Observatory observed a sunquake with unusually sharp ripples emanating from a moderately strong solar flare. Scientists were able to track the waves that caused these ripples back to their source, using a technique called helioseismic holography. The results, published in the journal Astrophysical Journal Letters, found the acoustic source was around 700 miles below the surface of the Sun, not above the surface as previously was thought. The scientists believe that these waves were driven by a submerged source, which was in turn somehow triggered by the solar flare in the atmosphere above. The new findings might help explain a long-standing mystery about sunquakes: why some of their characteristics look remarkably different from the flares that trigger them.

COMMUNITY COORDINATED MODELING CENTER

The Community Coordinated Modeling Center is a multi-agency partnership to enable and perform the research and development for next-generation heliophysics and space weather models. The project provides the United States and international research community access to simulations to enable "runs on demand," using models to study space weather events in near-real time. This allows the comparison of observational data and model parameters during or shortly after solar activity, thereby improving accuracy of the models.

SPACE SCIENCE MISSION OPERATIONS SERVICES

Space Science Mission Operations (SSMO) Services manages the on-orbit operations of Goddard Space Flight Center (GSFC) Space Science missions. Services include consistent processes and infrastructure for missions operated at various institutions. SSMO currently manages the following missions: Advanced Composition Explorer (ACE), Aeronomy of Ice in the Mesosphere (AIM), Geotail, Interstellar Boundary Explorer (IBEX), Ionospheric Connection Explorer (ICON), Interface Region Imaging Spectrograph (IRIS), Magnetospheric Multiscale Mission (MMS), Parker Solar Probe, Solar Dynamics Observatory (SDO), Solar and Heliospheric Observatory (SOHO), STEREO, THEMIS, TIMED, and Wind. SSMO Services also sustains an operational infrastructure for current and future missions.

Operating Missions

VOYAGER

The Voyager Interstellar Mission is exploring the interaction of the heliosphere and the local interstellar medium. Voyager 1, launched in 1977, is making the first in-situ observations of the region outside the heliosphere from about 151 astronomical units (AU), or 151 times Earth's distance from the Sun, and is traveling at a speed of 3.6 AU per year (38,000 miles per hour). Voyager 2 is about 125 AU from the Sun and traveling at a speed of about 3.2 AU per year. Voyager 2 crossed the heliopause on November 5,

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2018. Voyager 2 is the second human-made object to cross the heliosphere, the protective bubble of particles and magnetic fields created by the Sun. Its twin, Voyager 1, crossed the heliopause on August 25, 2012, and continues to sail outward through the local interstellar medium. Both spacecraft have sufficient power to operate all instruments until the early 2020s; after this time, the project will turn off the instrument heaters and then the instruments one at a time to extend the useful life of the spacecraft to about 2030. NASA has approved Voyager to continue as an extended mission, and Voyager will be invited to the 2023 Heliophysics Senior Review.

Recent Achievements

The Voyagers are observing the declining phase of the solar cycle and are viewing the effects of interplanetary coronal mass ejections, merged interaction regions, and corotating interaction regions on the very local interstellar medium. In addition, Voyager 1 discovered that solar wind pressure pulses propagate through the heliopause and into the interstellar medium and drive shocks that generate plasma waves. Voyager 1 also made the first measurements of the interstellar energy spectra of galactic cosmic ray electrons and nucleons down to a few Mega electron-volt (MeV) and a few MeV/nuc, respectively. MeV, or electronvolt, is the amount of kinetic energy gained by a single electron accelerating from rest through an electric potential difference of one volt in vacuum. Researchers can now use these observations to support studies of solar modulation and set upper limits on the radiation doses that astronauts could experience near one AU. The Voyager data are also critical for understanding Interstellar Boundary Explorer and Cassini (and soon the Interstellar Mapping and Acceleration Probe) energetic neutral atom observations.

SOLAR AND HELIOSPHERIC OBSERVATORY (SOHO)

SOHO, launched in 1995, is a joint-mission of the European Space Agency (ESA) and NASA, and it has been a dependable solar watchdog, providing the only Earth-Sun line coronagraph images of solar storms. Coronal mass ejections (CME) drive most of the space weather effects in the inner heliosphere. SOHO continues to provide essential early alert space weather observations used as inputs to models that further our understanding of the Sun's effect on the Earth. During its extended mission phase, SOHO was declared a national space weather asset and will participate in a programmatic review (outside of the Senior Review) in 2023.

Recent Achievements

On June 15, 2020, a citizen scientist spotted a never-before-seen comet in data from the Solar and Heliospheric Observatory, or SOHO, the 4,000th comet detected using SOHO. SOHO-4000 is relatively small, with a diameter in the range of 15-30 feet, and was extremely faint and close to the Sun when discovered. SOHO is the only observatory that has spotted the comet, as it's impossible to see from Earth with a telescope.

In coordination with Parker Solar Probe's fifth flyby of the Sun, the SOHO team ran a special observation campaign in early June, increasing the frequency with which the Large Angle and Spectrometric Coronagraph (LASCO) instrument onboard SOHO takes images of the Sun's corona, as well as doubling the exposure time for each image. The project designed these changes in LASCO's imaging to help the instrument pick up faint structures that would later pass over Parker Solar Probe.

A recent study combined data from the Energetic and Relativistic Nuclei and Electron experiment (ERNE) and the LASCO on SOHO with observations from the STEREO (Solar TErrestrial RElations

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Observatory) and Wind missions to develop and exploit a new catalogue of coronal shock waves to study the potential role of these waves in accelerating solar energetic particles (SEPs).

SEPs pose a danger to human exploration of the solar system. It is therefore important to understand how to accelerate SEPs to high energies and if a coronal mass ejection may produce SEPs. This study tests a theory of how SEPs are energized.

WIND

Wind, launched in 1994, studies the solar wind and its impact on the near-Earth environment. It provides comprehensive measurements of thermal to solar energetic particles, quasi-static fields to high-frequency radio waves, and gamma rays. In particular, the Wind instrument suite provides comprehensive and unique high-time resolution in-situ solar wind measurements that enable the investigation of wave-particle interactions. Wind provides critical measurements of the solar wind and space weather events. Correlating those critical measurements with measurements from the Parker Solar Probe and Solar Orbiter Collaboration (SOC) missions will improve our understanding of these events as they move out from the Sun. These multi-spacecraft measurements constrain models of space weather events and improve their predictive capabilities. Wind is also the only near-Earth spacecraft equipped with radio waves instrumentation. The Radio and Plasma Wave (WAVES) experiment measures electric and magnetic fields to reveal wave phenomena in the solar wind. WAVES is also the only instrument on Wind that can unambiguously measure the total electron density in the solar wind. No other L1 spacecraft has this capacity, which allows Wind to more accurately calibrate all of its thermal particle instruments. As a result of the 2020 Heliophysics Senior Review, Wind was approved to continue as HSO-Infrastructure. Wind will participate in a programmatic review (outside of the Senior Review) in 2023.

Recent Achievements

Wind's longevity (launched at the end of cycle 22 in 1994 and expected to continue well into solar cycle 25 which began in December 2019) has made it a prime source of data for solar cycle studies, including the unusual behavior of cycle 24. Recent Wind studies discovered fundamentally new science. For instance, scientists discovered a zone of preferential ion heating near the Sun by using a detected particle's charge state (number of electrons in orbit about the nucleus) as a tag for where the particles were heated. Wind observed and aided in the first long-duration (approximately 10 years) statistical analysis of the temperatures, plasma betas, and temperature ratios for the electron, proton, and alpha-particle populations in the solar wind near Earth. This analysis is the first and only statistically significant analysis of the solar wind temperature parameters near Earth, which are relevant for long-term statistical models, parameter range limits for empirical models, constraints for inaccessible astrophysical plasmas, and a reliable baseline for Parker Solar Probe and Solar Orbiter.

GEOTAIL

Geotail, launched in 1992, enables scientists to assess data on the interaction of the solar wind and magnetosphere. Its instruments continue to function, sending back crucial information about how auroras form, how energy from the Sun funnels through near-Earth space, and the ways in which magnetic field lines move and rebound, creating explosive bursts that rearrange the very shape of our magnetic environment. The Geotail mission is a collaborative project undertaken by the Japanese Institute of Space and Astronautical Science and NASA. As a result of the 2020 Heliophysics Senior Review, Geotail was

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approved to continue as HSO-Infrastructure. Geotail will participate in a programmatic review (outside of the Senior Review) in 2023.

Recent Achievements

New research using data from Geotail and Cassini revealed new details on suprathermal atomic and molecular ions in the magnetospheres of Earth, Jupiter, and Saturn. Some of the air we breathe, a gas of approximately 78 percent Nitrogen and approximately 21 percent Oxygen molecules, expands into the high-altitude atmosphere, the thermosphere, and becomes ionized by sunlight and charged particles from space to become the ionosphere. Molecules can break up into their component atoms or combine with other ions to form other molecules. Some ionospheric ions flow out into space, mostly during geomagnetic disturbances, and are further energized. Magnetospheres, plasma bubbles filled with these energized particles, form around planets with magnetic fields, like the Earth, whose magnetic field stands off the steady stream of ions and electrons from the Sun called the solar wind. Particles inside the bubbles can be planet or satellite origin, and outside the bubble, they are mostly Sun origin. However, some inside get out and some outside get in. Improved ion measurements from space give us information to help unravel both the outflowing particles' interactions on the way out and when and how ions escape or penetrate magnetospheres. The findings provide a deeper understanding of Earth's magnetosphere by seeing how magnetospheric processes (including ion composition) vary across the planets in our solar system responding to changes in plasma sources, size, rotation rate, and solar wind structures in their vicinity.

LIVING WITH A STAR

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Other Missions and Data Analysis	146.0	148.2	115.3	146.1	170.2	235.8	278.9
Total Budget	**146.0**	**148.2**	**115.3**	**146.1**	**170.2**	**235.8**	**278.9**
Change from FY 2021			-32.9				
Percentage change from FY 2021			-22.2%				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Artist's concept of the HERMES payload. HERMES will enable NASA to advance the science of space weather forecasting.

The Living With a Star (LWS) program targets specific aspects of the Sun-Earth system that affect life and society. LWS provides a predictive understanding of the Sun-Earth system, linkages among the interconnected systems, and space weather conditions at Earth and the interplanetary medium. Measurements and research from LWS missions may contribute to advances in operational space weather forecasting that help prevent damage to spacecraft, communications and navigation systems, and power grids. LWS products improve our understanding of ionizing radiation, which has human health implications on the ISS and high-altitude aircraft flight, as well as operations of future space exploration with and without human presence. LWS products improve the characterization of solar radiation for global climate change, surface warming, and ozone depletion and recovery.

For more information, go to: http://science.nasa.gov/about-us/smd-programs/living-with-a-star/

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Budget supports formulation of a new spaceflight mission, Geospace Dynamics Constellation (GDC), to conduct a coordinated, global study of the Earth's upper atmosphere. The budget also supports formulation of the Heliophysics Environmental and Radiation Measurement Experiment (HERMES) to investigate the causes of space-weather variability as driven by the Sun and modulated by the magnetosphere. HERMES will be a payload on the lunar Gateway and will contribute to a fundamental goal of LWS to advance the science of space weather forecasting to help prevent damage to spacecraft, communications and navigation systems, and power grids, and to support astronaut safety.

OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Geospace Dynamics Constellation	6.0	15.0	**23.3**	65.5	77.5	137.3	172.7
Heliophysics Environmental & Radiation M	16.0	13.3	**6.5**	2.3	1.4	0.9	0.9
Solar Orbiter Collaboration	4.2	8.1	**8.2**	5.6	5.7	8.2	13.3
LWS Space Environment Testbeds	0.5	0.3	**0.0**	0.0	0.0	0.0	0.0
LWS Science	20.3	30.3	**30.3**	19.3	30.3	30.3	30.3
LWS Program Management and Future Missions	23.9	35.8	**17.7**	17.2	18.3	18.4	14.1
Van Allen Probes (RBSP)	10.8	0.0	**0.0**	0.0	0.0	0.0	0.0
Solar Dynamics Observatory (SDO)	12.0	13.4	**12.0**	12.3	12.3	12.3	12.3
Parker Solar Probe	20.6	7.0	**7.4**	11.1	11.3	14.6	21.6
Space Weather Science and Applications	31.8	25.0	**9.9**	12.7	13.5	13.7	13.7
Total Budget	**146.0**	**148.2**	**115.3**	**146.1**	**170.2**	**235.8**	**278.9**
Change from FY 2021			**-32.9**				
Percentage change from FY 2021			**-22.2%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Solar Orbiter is a joint European Space Agency (ESA) and NASA mission that provides high-resolution views of the previously unexplored poles of the Sun.

Living With a Star Other Missions and Data Analysis budget includes operating LWS missions, a science research program, program management, a space weather science application initiative, and funding for missions to launch in the next decade.

For more information, go to: https://science.nasa.gov/heliophysics/programs/living-with-a-star/

https://science.nasa.gov/heliophysics/space-weather

OTHER MISSIONS AND DATA ANALYSIS

Mission Planning and Other Projects

SPACE WEATHER SCIENCE AND APPLICATIONS

The Space Weather Science and Applications project works to support the effective transition of heliophysics science results, tools, technology, and techniques to applications that enhance the user communities' ability to address impacts caused by the dynamic space environment. This includes support of flight payload development. This activity supports interagency space weather efforts and is consistent with the recommendations of the National Academy 2013 Decadal Survey for Solar and Space Physics. The project is also consistent with the recommendations of the Office of Science and Technology Policy (OSTP) 2019 National Space Weather Strategy and Action Plan and the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act signed into law in 2020. NASA plans to competitively fund concepts and payloads, leverage existing Agency capabilities, collaborate with other agencies, and partner with user communities.

Recent Achievements

LWS awarded more than 60 grants over the last four years that target science priorities identified by our operational agency partners. The NOAA and DoD are assessing the results of the first of these research efforts, to determine which should be introduced into space weather operations. Beginning with the next Research-to-Operations-to-Research solicitation, an optional transition phase will be implemented that focuses the effort on effective transitioning to operations. NASA has made investments in high-end computing at Ames Research Center and the Community Coordinated Modeling Center at the Goddard Space Flight Center to implement an interagency framework with NOAA. NASA is developing a solicitation plan for a Space Weather Center of Excellence as described in the PROSWIFT Act.

In FY 2020 NASA selected the Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) space weather payload to fly on the Gateway in support of the Artemis Program. HERMES will be composed of four scientific instruments that will measure the solar wind and magnetic field environment to enhance our ability to forecast events originating from the Sun that could affect astronauts on and around the Moon, and will serve as a pathfinder for how similar capability will be achieved on a future crewed mission to Mars. A separate LWS project has been established for HERMES; more information is provided in the project section below.

NASA will also fund efforts to support astronaut safety operations at the Johnson Space Center Space Radiation Analysis Group. In preparation for deep space human exploration, NASA will provide funding for the Radiation Assessment Detector (RAD) on the Mars Science Laboratory Curiosity rover in its extended mission for ground truth data for space weather models out to Mars. NASA will partner with European Space Agency (ESA) on their Lagrange space weather mission via a solicitation for focused instruments of opportunity. NASA is developing a mission concept with a potential NASA-provided space weather payload on the Canadian Space Agency Arctic Observation Mission. NASA is also planning an instrument solicitation for a payload pipeline to take advantage of short turnaround rideshare and hosted opportunities.

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LWS SCIENCE

NASA solicits proposals leading to a physics-based understanding of the integral system linking the Sun to the Earth both directly and via the heliosphere, magnetosphere, and ionosphere. LWS Science objectives can be achieved by data analysis, theory and modeling, and the development of tools and methods (e.g., software). The goal of the project is to develop the scientific understanding needed for the United States to address those aspects of heliophysics that may affect life and society. The targeted research element solicits large-scale problems that cross discipline and technique boundaries.

In addition, LWS Science includes funding to train the next generation of heliophysics experts, conduct a heliophysics graduate-level summer school, develop graduate course content, and support a limited number of space weather postdoctoral positions at universities and government laboratories.

Recent Achievements

NASA recently made awards in four of the LWS focused science topics research areas: 1) the variable radiation environment in the dynamical solar and heliospheric system, 2) fast reconnection onset, 3) magnetospheric and ionospheric processes responsible for rapid geomagnetic changes, and 4) causes and consequences of hemispherical asymmetries in the magnetosphere - ionosphere - thermosphere system.

In FY 2020 scientists working on mid-latitude and equatorial dynamics of the ionosphere - thermosphere system have used magnetic field data from approximately 180 magnetometers in ground magnetometer networks to derive the establishment of global ionospheric disturbance current systems in response to the solar wind pressure impulses. Scientists have systematically analyzed the ionospheric disturbance current systems caused by multiple solar wind and magnetospheric processes. They have proposed a new mechanism to explain the generation of the westward plasma drifts in the nighttime equatorial ionosphere during magnetic storms and have made progress in understanding the propagation of energy and momentum deposited by the solar wind in high-latitude regions of the magnetosphere to equatorial regions.

The team working on understanding the response of magnetospheric plasma populations to solar wind structures has made progress on several topics. The LWS team compiled a short list of interests and analysis, and modeling of these events is underway. Scientists also made progress on characterizing magnetospheric wave activity and plasma dynamics using a combination of data analysis and modeling, and on understanding the variability of magnetosphere – ionosphere coupling in terms of the ionospheric response to precipitating particles into the upper atmosphere. This team published 26 paper in peer-reviewed journals and gave 30 conference presentations in the past year.

Another team focused on the understanding of large-scale internal dynamics, magnetic flux creation and emergence by linking solar interior global flows and localized active regions' flows with short-term and long-term solar magnetic variabilities, with the ultimate objective of forecasting/simulating reliable solar inputs to heliospheric and terrestrial models. This team published six papers and gave several conference presentations in the past year.

LWS PROGRAM MANAGEMENT AND FUTURE MISSIONS

The Program Management and Future Missions budget supports critical flight project management functions executed by the LWS program office at NASA Goddard Space Flight Center (GSFC) and provides the resources required to manage the planning, formulation, and implementation of all LWS

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missions. In addition, this project supports strategic planning for addressing the LWS recommendations of the Heliophysics Decadal Survey and the pre-formulation activities for missions that are conceptual.

Recent Achievements

NASA established the Science Mission Directorate (SMD) Rideshare Office within the Heliophysics Division. This office will implement a SMD-wide rideshare strategy for Evolved Expendable Secondary Payload Adapter-class (ESPA-class) payload opportunities. The office is responsible for coordinating rideshare opportunities and collaborating across SMD, other NASA science directorates, other government agencies, and the greater rideshare community to foster a culture of cross-collaboration and maximize science return through shared launch opportunities and resources.

GEOSPACE DYNAMICS CONSTELLATION

Geospace Dynamics Constellation (GDC), the next Living With a Star mission recommended by the decadal survey, will be the first mission to conduct a coordinated, global study of the heart of Earth's space environment. The upper atmosphere is a dynamic region of overlapping neutral atmosphere and ionosphere, where processes are driven by mass and energy inputs from both below (Earth's lower/middle atmosphere) and above (Earth's magnetosphere and the Sun). These inputs from above and the dynamics active within the upper atmosphere include space weather processes that impact the human presence and technological assets in space.

The relative spacing between the individual spacecraft of the GDC constellation will evolve over the course of the mission, fully sampling the spatial and temporal scales necessary to provide complete scientific understanding of this region and various space weather phenomena.

The Decadal Survey's recommended scientific investigation and design reference mission was refined and updated by a community-based Science and Technology Definition Team (STDT). After the STDT report was delivered, NASA initiated pre-formulation and directed project management to Goddard Space Flight Center.

Recent Achievements

On September 8, 2020, GDC successfully completed the Key Decision Point A review, moving the project into the formulation phase. On March 6, 2021, NASA released a draft mission of opportunity solicitation for science investigation teams that will deliver flight units for integration onto the GDC spacecraft (with an expected final release in spring 2021). On March 8, 2021, NASA released a solicitation for Interdisciplinary Scientists that will join the GDC project for Phases A-D independent of the science investigation teams.

HELIOPHYSICS ENVIRONMENTAL AND RADIATION MEASUREMENT EXPERIMENT SUITE (HERMES)

HERMES will be a space weather payload on the Gateway (an outpost in lunar orbit) as part of NASA's Artemis Program. The payload will be comprised of a suite of high-maturity instruments that will enable meaningful science in the lunar environment, directly support crew safety at the Moon, and be a pathfinder for future missions to Mars.

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HERMES will launch with the first two elements of the Gateway currently planned. HERMES will enable the investigation of fundamental science questions like the acceleration mechanisms of solar energetic particles, variability of solar wind structures and Galactic Cosmic Rays, and magnetotail dynamics. Data collected by HERMES will also provide critical safety information for astronaut operations in the lunar environment. HERMES will support operational forecasting and nowcasting, or prediction of current events, of solar energetic particles that pose a risk to astronauts during extravehicular activities on the Gateway or the lunar surface.

In coordination with the two-spacecraft mission THEMIS/ARTEMIS already in lunar orbit, HERMES observations will initiate a heliophysics lunar constellation to conduct science investigations not possible before now. A second payload installed on the Gateway (European Radiation Sensors Array, provided by the European Space Agency) will amplify the work of HERMES by providing additional data characterizing high-energy particles that are dangerous to crew safety.

Recent Achievements

NASA initiated the HERMES mission, managed by the Goddard Space Flight Center, in March 2020. HERMES is currently in its preliminary design phase, with a confirmation review scheduled for fall 2021.

Operating Missions

SOLAR ORBITER COLLABORATION

The NASA and European Space Agency (ESA) Solar Orbiter Collaboration (SOC) mission will provide measurements that will give NASA better insight on the evolution of sunspots, active regions, coronal holes, and other solar features and phenomena. The instruments will explore the near-Sun environment to improve our understanding of the origins of the solar wind streams and the heliospheric magnetic field; the sources, acceleration mechanisms, and transport processes of solar energetic particles; and the evolution of coronal mass ejections (CMEs) in the inner heliosphere. To achieve these objectives, SOC will make in-situ measurements of the solar wind plasma, fields, waves, and energetic particles. SOC will also make imaging/spectroscopic observations. SOC will provide close-up views of the Sun's polar-regions and far side. SOC will adjust its orbit to the direction of the Sun's rotation to allow the spacecraft to observe one specific area for much longer than is currently possible.

ESA provided the spacecraft and manages operations; the ESA member states provided the majority of the instruments. NASA provided the launch vehicle and two science investigations/instruments: the Solar Orbiter Heliospheric Imager (SoloHI) and the Heavy Ion Sensor (HIS). In return for its contributions, NASA will have access to the entire science mission data set.

Recent Achievements

Solar Orbiter launched successfully on February 9, 2020 and entered the operations phase in May 2020. The in-situ instruments are fully operational. The remote sensing instruments, including SoloHI, are currently operating at a low telemetry rate due to orbital constraints, and they will begin nominal operations in November 2021. The first images from Solar Orbiter, released in July 2020, revealed omnipresent miniature solar flares, dubbed "campfires," near the surface of our closest star. SoloHI observed its first CME in February 2021. According to the scientists behind the mission, seeing

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phenomena that were not observable in detail before hints at the enormous potential of Solar Orbiter. NASA released the first batch of data from Solar Orbiter to the public in September 2020.

For more information, go to: https://www.nasa.gov/solar-orbiter

LWS SPACE ENVIRONMENT TESTBEDS

The Space Environment Testbeds (SET) launched on June 25, 2019 as a rideshare payload on the U.S. Air Force Research Laboratory's Demonstration and Space Experiments spacecraft. The SET project seeks to improve the accommodation and/or mitigation of the effects of solar variability on spacecraft by studying how to protect satellites in space. It addresses the identification and understanding of the mechanisms of space environment interactions, modeling of these interactions, and development and validation of ground test protocols to qualify technologies for space. The mission characterizes the harsh space environment near Earth and how it affects spacecraft and their instruments. Engineers can use this information to improve spacecraft design, engineering, and operations in order to protect spacecraft from harmful radiation driven by the Sun. As the complexity of the technologies increases, models derived from the physics-based understanding of the effects are required. The SET mission responds to these needs.

SET is providing new measurements of space weather and trapped particle environments, their effects on electronic devices and systems in medium Earth orbit. SET also supports science research on the Van Allen belts. It provides information to improve the design, operation, and ground test protocol for spacecraft intended to operate in this region, an attractive one for telecommunications, Global Positioning System (GPS) navigation, and DoD applications.

Recent Achievements

SET currently operates in medium-Earth orbit and will operate through FY 2022. All experiments are operating as expected and returning data successfully.

PARKER SOLAR PROBE

Parker Solar Probe, launched in 2018, is unlocking the mysteries of the Sun's atmosphere. Parker Solar Probe will fly through the solar corona 24 times, gradually lowering its orbit closer to the Sun using Venus' gravity during seven flybys over its seven-year mission. After the seventh Venus flyby, the spacecraft will fly though the Sun's atmosphere as close as 3.8 million miles to our star's surface - well within the orbit of Mercury and more than seven times closer than any spacecraft has come before (Earth's average distance to the Sun is 93 million miles).

Flying into the outermost part of the Sun's atmosphere, the corona, for the first time, Parker Solar Probe employs a combination of in-situ measurements and imaging to revolutionize our understanding of the corona and expand our knowledge of the origin and evolution of the solar wind. Parker Solar Probe will also make critical contributions to our ability to forecast changes in Earth's space environment that affect life and technology on Earth.

Recent Achievements

In 2020, Parker Solar Probe successfully completed solar encounters numbers four, five, and six. Its sixth perihelion (closest approach to the Sun) achieved a record-breaking distance within 8.4 million miles of the Sun's surface, less than 1/10th the distance of Earth from the Sun, and a record-breaking a top speed

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of almost 290,000 miles per hour. Eighteen additional solar approaches are planned, with the last three bringing the probe to as close as approximately four percent of the Earth's distance from the Sun in 2024.

Before Parker Solar Probe broke distance records from the Sun, there were theoretical predictions, but no clear observational signs of a dust-free zone directly near the Sun itself. The first observations of Parker Solar Probe revealed, for the first time, evidence of this long-suspected dust-free zone. The brightness of the F-corona, which is a background brightness of the near-Sun space caused by scattering of the Sun's light on near-Sun dust particles, does not increase towards the Sun as much as observations made further away from the Sun suggest. This turn-around is observed in images of the Wide-field Imager of the Solar Probe made at small solar distances occurs at approximately 17 solar radii above the surface, and is a clear indication of a dust-free zone even further in.

SOLAR DYNAMICS OBSERVATORY (SDO)

Launched on February 11, 2010, SDO seeks to understand the Sun's influence on Earth and near-Earth space by simultaneously studying the solar atmosphere on small scales of space and time and in many wavelengths. The observatory enables scientists to determine how the Sun's magnetic field is generated and structured and how stored magnetic energy is converted and released in the form of solar wind, energetic particles, and variations in the solar irradiance. SDO collects data to help explain the creation of solar activity, which drives space weather. Measurements of the interior of the Sun, the Sun's magnetic field, the hot plasma of the solar corona, and the irradiance that creates Earth's ionosphere are the primary data products.

Recent Achievements

SDO team members recently published a freely available electronic textbook on machine-learning (ML) for heliophysics using data from SDO. The team has been a leader in developing ML tools and datasets for those tools. SDO data was processed to form three major "AI-ready" data sets. These data sets are available to the global community and are optimized for ingestion by ML tools and platforms, such as Amazon Cloud. The translation of science data to "AI-ready" requires several deliberate steps, with the intention of making it usable by non-experts. The team anticipates this curated dataset will facilitate ML research in heliophysics and other physical sciences, increasing the scientific return of SDO.

SDO entered its extended mission phase in May 2015. NASA has approved SDO to continue as an extended mission in the most recent 2020 Heliophysics Senior Review, and SDO will be invited to the 2023 Heliophysics Senior Review.

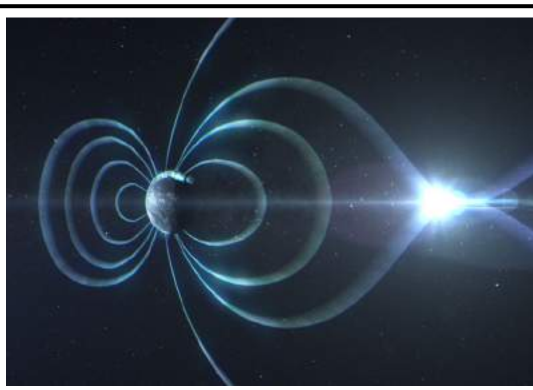
SOLAR TERRESTRIAL PROBES

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Interstellar Mapping and Acceleration Probe (IMAP)	52.0	66.2	**169.6**	151.6	112.2	67.4	15.2
Other Missions and Data Analysis	74.7	66.0	**83.8**	101.0	116.6	130.3	105.2
Total Budget	**126.8**	**132.2**	**253.3**	**252.6**	**228.8**	**197.6**	**120.4**
Change from FY 2021			**121.1**				
Percentage change from FY 2021			**91.6%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Artist depiction of magnetic reconnection at Earth during a solar storm. The MMS mission has revealed that there are multiple such large-scale reconnection lines at the magnetopause.

The Solar Terrestrial Probes (STP) program focuses on understanding the fundamental physical processes of the space environment from the Sun to the Earth, to other planets, and beyond to the interstellar medium. STP provides insight into the basic processes of plasmas (fluids of charged particles) inherent in all astrophysical systems. STP missions focus on processes such as the variability of the Sun, responses of the planets to those variations, and the interaction of the Sun and the solar system. NASA defines specific goals for STP missions and selects investigations for each mission competitively. These missions allow the science community an opportunity to address important research focus areas and make significant progress in understanding fundamental physics.

For more information, go to: https://science.nasa.gov/heliophysics/programs/solar-terrestrial-probes

EXPLANATION OF MAJOR CHANGES IN FY 2022

NASA selected two SmallSat missions from the STP Missions of Opportunity (MO) announcement to share a ride to space in 2025 with Interstellar Mapping and Acceleration Probe (IMAP). The Global Lyman-alpha Imagers of the Dynamic Exosphere (GLIDE) mission will help researchers understand the upper reaches of Earth's atmosphere, the exosphere, where it touches space. The Solar Cruiser technology demonstration mission will investigate the use of solar photons for propulsion in space. Funding for Solar Cruiser has been transferred to the Heliophysics Technology Program.

SOLAR TERRESTRIAL PROBES

ACHIEVEMENTS IN FY 2020

The two science MOs (SIHLA and GLIDE) and the two technology demonstration MOs (SETH and Solar Cruiser) selected in 2019 delivered their concept studies to NASA for evaluation. NASA awarded the contract for the Interstellar Mapping and Acceleration Probe (IMAP) launch vehicle to SpaceX.

WORK IN PROGRESS IN FY 2021

NASA selected the STP technology demonstration MO (Solar Cruiser) and the science MO (GLIDE) to continue formulation. These selected MOs will launch with the IMAP mission to about one million miles (1.5 million kilometers) away from Earth towards the Sun at the first Lagrange point (L1).

IMAP will conduct its confirmation review and enter its final design and fabrication phase.

The procurement process for DYNAMIC began in FY 2021 with the public announcement of the intent to release a DYNAMIC AO, to be followed by release of a draft AO in the second half of the fiscal year. DYNAMIC will enter Phase A in FY 2022 with the competitive selection of a PI-led investigation.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

GLIDE will continue preliminary design and technology completion efforts with PDR and KDP-C planned for late FY 2022. NASA will complete the DYNAMIC AO competition and select the PI-led investigation to move into Phase A.

Program Schedule

Date	Significant Event
Q3 FY 2021	Announcement of Opportunity released for DYNAMIC
Q3 FY 2022	Initial selection of DYNAMIC proposals for Phase A studies

Program Management

Management of the STP Program has been assigned to the Goddard Space Flight Center (GSFC).

SOLAR TERRESTRIAL PROBES

Acquisition Strategy

In the acquisition of STP scientific instruments, spacecraft, and science investigations, NASA will use full and open competitions to the greatest extent possible. NASA may acquire certain instruments, missions, or mission systems without competition (e.g., through international partnerships or in-house builds) if there is a clear scientific, technological, or programmatic benefit to NASA.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	Feb 2019	Assess performance of program	Successful	Nov 2023
Program Independent Review	SRB	Nov 2023	Assess performance of program	TBD	N/A

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

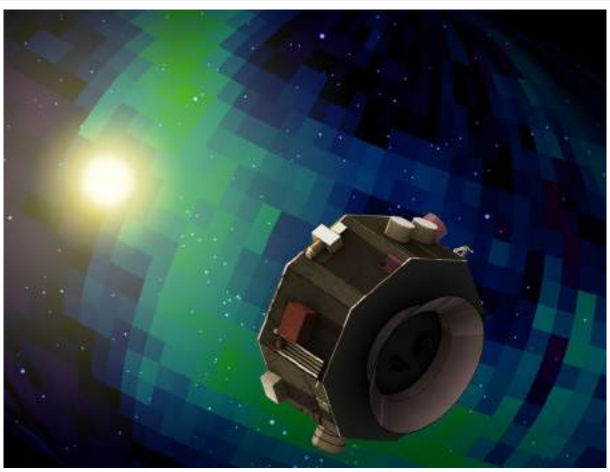
Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**52.0**	**66.2**	**169.6**	**151.6**	**112.2**	**67.4**	**15.2**
Change from FY 2021			**103.4**				
Percentage change from FY 2021			**156.2%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Artist's conception of the IMAP spacecraft.

PROJECT PURPOSE

The Interstellar Mapping and Acceleration Probe (IMAP) mission will help researchers better understand the boundary of the heliosphere, a magnetic bubble surrounding and protecting our solar system. This region is where the constant flow of particles from our Sun, called the solar wind, collides with material from the rest of the galaxy. This collision limits the amount of harmful cosmic radiation entering the heliosphere. IMAP will collect and analyze particles that make it through to the heliosphere.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The project entered its preliminary design and technology completion phase (Phase B) in January 2020 and is now included as a separate section in this budget request.

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

PROJECT PRELIMINARY PARAMETERS

IMAP is planned to launch in 2025. The mission will simultaneously investigate two of the most important issues in space physics today, the acceleration of energetic particles and interaction of the solar wind with the interstellar medium.

IMAP will study the interaction of the solar wind with the winds from other stars by directly sampling neutral atoms returning from the interstellar boundary and will elucidate how particles are accelerated to high energies in space environments. IMAP will be "parked" at the Earth-Sun L1 point, upstream of Earth at 1 percent of the distance to the Sun. IMAP's 10 instruments provide the first comprehensive in-situ and remote global observations to discover the fundamental physical processes that control our solar system's evolving space environment. The 10 instruments are described in a table below.

The mission Principal Investigator is from Princeton University. The Johns Hopkins University/Applied Physics Lab (JHU/APL) is responsible for project management and engineering. IMAP will launch on a SpaceX Falcon 9.

Up to four secondary rideshare payloads will accompany the IMAP mission, taking advantage of the excess performance capability of the launch vehicle. Heliophysics is currently planning to fly STP science (GLIDE) and technology demonstration (Solar Cruiser) missions of opportunity along with the National Oceanic and Atmospheric Administration (NOAA) Space Weather Follow-On (SWFO-L1) and the Planetary Science Lunar Trailblazer mission.

ACHIEVEMENTS IN FY 2020

The IMAP project completed its concept and technology development phase (Phase A) with a successful systems requirements review/mission design review in December 2019. The Agency approved the project to proceed to the preliminary design and technology completion phase (Phase B) in January 2020. Despite the impact of the COVID-19 pandemic, the project has made significant progress with completion of design trade studies, advancement of preliminary instruments, and subsystems modelling.

In September 2020, NASA awarded the IMAP launch vehicle contract to SpaceX, for a Falcon 9 full thrust rocket.

WORK IN PROGRESS IN FY 2021

The preliminary design and technology completion phase continues in FY 2021. Instrument and subsystem Preliminary Design Reviews (PDRs) began in November 2020, and the mission PDR occurred in May 2021. NASA will conduct the mission confirmation review, and the project will conduct significant component level procurement, fabrication, assembly, and testing.

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2022

In FY 2022, the project will complete instrument and subsystem Critical Design Reviews (CDRs). The lower level components will complete their respective integration and testing, in preparation for integration onto the spacecraft the following fiscal year. The project will conduct the mission CDR in the summer of 2022.

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2022 PB Request
Formulation Authorization	N/A	May 2018
KDP-B	N/A	Jan 2020
KDP-C	N/A	Jul 2021
KDP-D	N/A	May 2023
KDP-E	N/A	Jan 2025
Launch (or equivalent)	N/A	Feb 2025

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Current life-cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
January 28, 2020	707.7 - 776.3	Launch	February 2025

Project Management & Commitments

The Principal Investigator is from Princeton University. JHU/APL is responsible for the project management of IMAP.

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Spacecraft	Provides a controlled spinning platform at the L1 Lagrange point for an extensive payload of scientific instruments	Provider: JHU/APL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IMAP-Lo Instrument	Tracks the interstellar flow to precisely determine the species-dependent flow speed, temperature, and direction of the Local Interstellar Medium (LISM) that surrounds, interacts with, and determines the outer boundaries of the global heliosphere	Provider: University of New Hampshire Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
CoDICE Instrument	Determines the Local Interstellar Medium (LISM) composition and flow properties, to discover the origin of the enigmatic suprathermal tails and advance understanding of the acceleration of particles in the heliosphere	Provider: Southwest Research Institute Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IDEX Instrument	A high-resolution dust analyzer that provides the elemental composition, speed, and mass distributions of Interstellar Dust (ISD) particles	Provider: University of Colorado Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Solar Wind and Pickup Ions (SWAPI) Instrument	Delivers the high time and energy resolution required to identify local acceleration processes, fundamental to understanding the solar wind context, sources and acceleration of particles, PUIs, and the physical processes regulating the global heliosphere	Provider: Princeton University Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
IMAP Ultra Instrument	Images the emission of Energetic Neutral Atoms (ENAs) produced in the heliosheath and beyond	Provider: JHU/APL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
HIT Instrument	Delivers full-sky coverage of ion anisotropy measurements, observing the ramps of local shocks, anchoring the high-energy SEP ion spectra, and resolving particle transport in the heliosphere	Provider: GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
SWE Instrument	Measures in situ solar wind electrons at L1 to provide context for the ENA measurements and perform the in situ solar wind observations necessary to understand the local structures that can affect acceleration and transport	Provider: Los Alamos National Laboratory Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IMAP-Hi Instrument	Enables unprecedented, detailed studies of structure and evolution of source plasmas in the heliosphere-LISM interaction region	Provider: Los Alamos National Laboratory Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
GLOWS Instrument	Measures the heliospheric resonant backscatter glow of hydrogen and helium	Provider: Polish Academy of Science, Space Research Center Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Poland, Ministry of Science	N/A
Magnetometer Instrument	Allows new insight into waves and turbulence in the solar wind to frequencies near the electron gyrofrequency and maintains an accurate baseline for space weather applications	Provider: Imperial College of London Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): UK Space Agency	Yes

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Launch Vehicle	The Falcon 9 rocket will deliver the IMAP observatory and up to four rideshare secondary payloads to a proper orbital trajectory	Provider: SpaceX Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: Multiple payloads will be co-manifested to fly with IMAP, Then: There is a possibility of impact to the primary IMAP mission, programmatically or technically.	1) Development of Rideshare coordination processes; 2) Early identification of launch vehicle contractor; 3) Early development and strict adherence to Do-No-Harm requirements

Acquisition Strategy

NASA competitively selected the mission through the Solar Terrestrial Program-5 AO and the final down-selection was in 2018. The launch vehicle was selected through full and open competition via NASA's Launch Services Program at the Kennedy Space Center.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Mission Development	JHU/APL	Laurel, Maryland
SWAPI Instrument and Science	Princeton University	Princeton, New Jersey
IMAP-Hi and SWE Instruments	Los Alamos National Laboratory	Los Alamos, New Mexico
Launch Vehicle	SpaceX	Hawthorne, California

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

INDEPENDENT REVIEWS

All dates are preliminary.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Requirements Review/Mission Design Review	Standing Review Board	Dec 2019	SRR evaluates whether the functional and performance requirements are defined for the system. MDR evaluates whether the proposed mission/system architecture is responsive to the program mission/system functional and performance requirements.	Successful	PDR
Preliminary Design Review	Standing Review Board	May 2021	PDR demonstrates that the preliminary design meets all system of interest requirements with acceptable risk and within the cost and schedule constraints and establishes the basis for proceeding with detailed design.	TBD	CDR
Critical Design Review	Standing Review Board	Jun 2022	CDR demonstrates that the maturity of the design is appropriate to support proceeding with full-scale fabrication, assembly, integration, and test.	TBD	SIR

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Systems Integration Review	Standing Review Board	May 2023	SIR ensures segments, components, and subsystems are on schedule to be integrated into the system of interest, and integration facilities, support personnel, and integration plans and procedures are on schedule to support integration.	TBD	ORR
Operations Readiness Review	Standing Review Board	Nov 2024	ORR ensures that all system and support (flight and ground) hardware, software, personnel, procedures, supporting capabilities, and user documentation accurately reflect the deployed state of the system and are operationally ready.	TBD	N/A

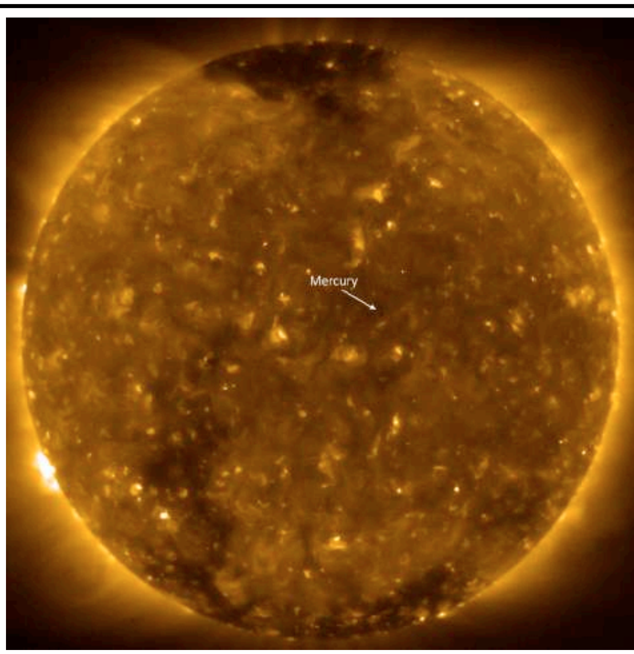
OTHER MISSIONS AND DATA ANALYSIS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Global Lyman-alpha Imager of the Dynamic	13.7	11.1	**22.1**	21.4	13.0	7.3	2.9
STP Program Management and Future Missions	10.6	17.8	**25.7**	42.7	68.8	89.9	71.0
Magnetospheric Multiscale (MMS)	26.0	26.0	**20.8**	20.8	18.7	16.8	15.2
Solar Terrestrial Relations Observatory (STEREO)	11.6	4.0	**6.0**	7.0	7.0	7.0	7.0
Hinode (Solar B)	8.5	5.5	**7.0**	6.5	6.5	6.5	6.5
TIMED	4.3	1.6	**2.1**	2.6	2.6	2.7	2.7
Total Budget	**74.7**	**66.0**	**83.8**	**101.0**	**116.6**	**130.3**	**105.2**
Change from FY 2021			**17.8**				
Percentage change from FY 2021			**27.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



The x-ray telescope on Hinode captured the transit of Mercury as it passed between Earth and the Sun, shown here, on November 11, 2019. Researchers can use transits like this one to measure the distance between Earth and the Sun.

The Solar Terrestrial Probes (STP) Other Missions and Data Analysis budget includes operating STP missions, program management, and funding for future missions launching in the next decade.

For more information, go to: http://stp.gsfc.nasa.gov

Mission Planning and Other Projects

STP PROGRAM MANAGEMENT AND FUTURE MISSIONS

STP Program Management and Future Missions provides the resources required to manage the planning, formulation, and implementation of all STP missions. The

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program office ensures successful achievement of STP program cost and schedule goals, while managing cross-project dependencies, risks, issues, and requirements as projects progress through formal key decision points. In addition, this project supports strategic planning for addressing the recommendations of the Heliophysics Decadal Survey.

Funding within this project is also provided to support pre-formulation work on the Dynamical Neutral Atmosphere-Ionosphere Coupling (DYNAMIC) mission, which will provide crucial insights into the coupling of the lower atmosphere to the upper atmosphere. While the National Academy of Sciences' 2013 Solar and Space Physics Decadal Survey recommended this mission as a stand-alone project, NASA plans to leverage the concurrent development of the Geospace Dynamics Constellation (GDC) mission and the fact that its measurements will be synergistic to those of DYNAMIC, to enable a more cost-effective solution to achieving the recommended DYNAMIC science objectives. DYNAMIC is planned to enter Phase A in FY 2022 with the competitive selection of a PI-led investigation.

GLOBAL LYMAN-ALPHA IMAGERS OF THE DYNAMIC EXOSPHERE (GLIDE)

In December 2020, NASA selected the GLIDE SmallSat mission as a STP Mission of Opportunity. GLIDE will study variability in Earth’s exosphere by tracking far ultraviolet light emitted from hydrogen. It will also gather observations at a high rate, with a view of the entire exosphere, ensuring a global and comprehensive set of data, which is currently lacking. GLIDE will help scientists better understand the ways in which Earth’s exosphere changes in response to influences of the Sun above or the atmosphere below, will provide us with better ways to forecast and, ultimately, mitigate the ways in which space weather can interfere with radio communications in space. GLIDE will be a rideshare payload on the IMAP mission, to be launched no earlier than February 2025.

Operating Missions

MAGNETOSPHERIC MULTISCALE (MMS)

The MMS mission, launched in 2015, investigates how the magnetic fields of the Sun and Earth connect and disconnect, explosively transferring energy from one to the other. This magnetic reconnection process occurs throughout the universe. MMS uses Earth’s magnetosphere as a natural laboratory to study the microphysics of magnetic reconnection, a fundamental plasma-physical process that converts magnetic energy into heat and charged particle kinetic energy. In addition to seeking to solve the mystery of the small-scale physics of the reconnection process, MMS investigates how the energy conversion that occurs in magnetic reconnection accelerates particles to high energies and what role plasma turbulence plays in reconnection events. Magnetic reconnection, particle acceleration, and turbulence occur in all astrophysical plasma systems. Researchers can only study them in-situ in the solar system, and most efficiently in Earth’s magnetosphere, where these processes control the dynamics of the geospace environment and play an important role in the phenomena known as space weather. MMS helps us understand reconnection elsewhere as well, such as the atmosphere of the Sun and other stars, near black holes and neutron stars, and at the boundary between our solar system's heliosphere and interstellar space.

The MMS mission consists of four identically instrumented spacecraft that measure particles, fields, and plasmas. The MMS instrument payload measures electric and magnetic fields and the plasmas found in

OTHER MISSIONS AND DATA ANALYSIS

the regions where magnetic reconnection occurs. Fast, multi-point measurements are enabling dramatically revealing direct observations of these physical processes. A highly elliptical orbit explores how Sun-Earth magnetic fields reconnect in Earth's neighborhood. The four spacecraft fly in a tetrahedron formation that allows them to observe the three-dimensional structure of magnetic reconnection events. The separation between the observatories is adjustable over a range of 6 to 250 miles during science operations in the area of interest.

For more information, go to: http://nasa.gov/mms

Recent Achievements

The Magnetospheric Multiscale mission is the first formation-flying satellite constellation. After five years in flight, with a near perfect record of continuous observation and 100 science instruments operating, MMS has solved many mysteries behind the phenomenon of magnetic reconnection. With findings published in over 600 peer-reviewed publications, the discoveries include the source of the reconnection electric fields, the rate at which reconnection proceeds, the acceleration of energetic particles, and the effects of turbulent electric and magnetic fields.

MMS recently discovered a new type of wave-particle interaction at work, low frequency waves. A density-slope produces the low-frequency waves that propagate through the electron reconnection region and accelerate particles there. This is likely triggering magnetic reconnection, a discovery that was only possible with the extremely high-resolution MMS data. Most surprising this year has been the discovery that magnetic reconnection occurs in many more regions around the Earth than previously thought possible. MMS found reconnection at the bow shock, which is the interface between the Earth's magnetosphere and the solar wind, and is analogous to a shock wave produced by a supersonic aircraft. The mission also found reconnection operating within plasma pile-up regions, known as dipolarization fronts, and within magnetic flux ropes, which are loops of magnetic field flung outward by reconnection events.

The reason we care about magnetic reconnection is that it efficiently converts magnetic energy to kinetic energy of charged particles, both in the form of directed motion (plasma jets) and random motion (increases in temperature). It occurs in space plasmas throughout the universe, including neutron stars, black holes, and solar flares; however, the near-Earth environment that MMS samples is the only region where we can investigate this universal phenomenon in-situ. Reconnection is the engine behind space weather, which poses threats to satellites, astronauts, and the Earth's electric power infrastructure.

MMS launched in March 2015 and entered its extended mission phase in September 2017. NASA has approved MMS to continue as an extended mission, and MMS will be invited to the 2023 Heliophysics Senior Review.

SOLAR TERRESTRIAL RELATIONS OBSERVATORY (STEREO)

STEREO, launched in 2006, enables studies of the origin of the Sun's coronal mass ejections (CME) and their consequences for Earth, other planets, and interplanetary space. The mission launched with two spacecraft, one Ahead of Earth (STEREO-A) and the other Behind Earth (STEREO-B) in its orbit. STEREO's instrumentation targets the fundamental process of energetic particle acceleration in the low solar corona and in interplanetary space. The mission can image the structure and evolution of solar storms as they leave the Sun and move through space toward Earth. The mission also provides the foundation for understanding space weather events and developing predictive models. The models, in

OTHER MISSIONS AND DATA ANALYSIS

turn, help to identify and mitigate the risks associated with space weather events. In addition, STEREO improves our space weather situational awareness not only for Earth and in low Earth orbit, but also throughout the solar system.

On October 1, 2014, NASA lost communication with STEREO-B, just as the spacecraft was about to orbit around the other side of the Sun. In late 2015, the spacecraft orbit finally carried it out from behind the Sun and NASA was able to re-establish contact with STEREO-B for a short period in 2016. NASA attempted to establish control of the spacecraft with limited success. Beginning in December 2017, the project team made monthly attempts to re-establish contact with the spacecraft, until October 2018, when attempts ceased. STEREO-A continues to operate nominally and is still providing significant science data.

Recent Achievements

SOHO, Parker Solar Probe, and STEREO-A recently observed multipoint studies of transients. The Wide-field Imager for Solar Probe (WISPR) instrument on Parker Solar Probe is now allowing NASA to image solar transients from a location very close to the Sun. However, interpretation of WISPR images benefits greatly from 1-AU images, including those from STEREO-A and SOHO. In addition, both radial and Parker Spiral alignments of PSP and STEREO-A allow studies of the propagation/transport of observed in-situ features and particle populations. These combinations of observations allow us to more completely characterize the structure and evolution of transients that leave the Sun and move out into the solar system, highly important for our long-term capability to predict the effects of solar transients such as coronal mass ejections and related phenomena, such as SEPs.

STEREO launched in October 2006 and entered its extended mission phase in January 2009. NASA has approved STEREO to continue as an extended mission, and STEREO will be invited to the 2023 Heliophysics Senior Review.

HINODE

Hinode, launched in 2006, is a joint JAXA and NASA mission. The mission consists of a coordinated set of optical, extreme ultraviolet, and X-ray instruments that are studying the basic heating mechanisms and dynamics of the active solar corona. Hinode explores the magnetic fields of the Sun to improve understanding of what powers the solar atmosphere and drives solar eruptions. By investigating the fundamental processes that connect the Sun's magnetic field and the solar corona, Hinode is discovering how the Sun generates magnetic disturbances and the high-energy particle storms that propagate from the Sun to Earth.

Hinode's solar optical telescope is the first spaceborne instrument to measure the strength and direction of the Sun's magnetic field on the Sun's surface, the photosphere. Combined with two other Hinode instruments, the Extreme Ultraviolet (EUV) imaging spectrometer and the X-ray/EUV telescope, the project designed the mission to understand the causes of eruptions in the solar atmosphere and relate those eruptions to the intense heating of the corona and the mechanisms that drive the constant outflow of solar radiation, the solar wind.

Recent Achievements

The Hinode spacecraft has been revealing the dynamics of the Sun for more than 13 years, accounting for the reversal of the polar magnetic fields and a full cycle of solar activity. The Hinode X-Ray Telescope

OTHER MISSIONS AND DATA ANALYSIS

has captured a full-Sun synoptic map of the hot solar atmosphere nearly every day since its launch in 2006, continuing the legacy of the Yohkoh mission (1991-2001).

Plotting the bright X-ray intensity with time shows a pattern that mimics the famous sunspot butterfly diagram, which researchers expect since hot coronal active regions necessarily coincide with cool sunspots at the surface. However, a close analysis of the X-ray trend reveals that lower emission X-rays from quiet Sun regions significantly contribute to the overall X-ray flux and solar activity. It points to unresolved magnetic fields that do not show up in sunspot butterfly diagrams and are largely missing from solar cycle activity predictions.

Predicting solar cycle activity is a critical need for our technologically driven society. Observations from Hinode's X-Ray Telescope enforce the need to include unresolved magnetic field proxies (which do not show up in standard sunspot butterfly diagrams) into cycle prediction models in order to improve their robustness.

Hinode launched in September 2006 and entered its extended mission phase in November 2009. NASA has approved Hinode to continue as an extended mission, and Hinode will be invited to the 2023 Heliophysics Senior Review.

THERMOSPHERE, IONOSPHERE, MESOSPHERE ENERGETICS AND DYNAMICS (TIMED)

The TIMED mission, launched in 2001, characterizes and studies the physics, dynamics, energetics, thermal structure, and composition of the least explored and understood regions of Earth's atmosphere: the mesosphere, the lower thermosphere, and the ionosphere, collectively known as the ionosphere-thermosphere-mesosphere (ITM) system. This ITM system, located between altitudes of approximately 35 to 100 miles above the surface of Earth, helps protect Earth from harmful solar radiation. It is a gateway between Earth's environment and space, where the Sun's energy first affects Earth's environment. Solar events, as well as temperature changes in the stratosphere, can perturb this region, but scientists do not understand the overall structure of and responses to these effects. Advances in remote sensing technology employed by TIMED enable us to explore this region on a global basis from space.

TIMED's 19-years of data provides scientists an unrivaled perspective on changes in the upper atmosphere. The long lifespan allows scientists to track the upper atmosphere's response to both quick-changing conditions, like individual solar storms, throughout the Sun's 11-year activity cycle, as well as longer-term trends, such as those related to climate change. All of TIMED's instruments are still producing data, enabling continuing studies of the upper atmosphere.

Recent Achievements

TIMED is making dramatic advances in establishing the relationships between solar activity and interplanetary disturbances, lower atmospheric weather, and the response of Earth's space environment. TIMED measurements have shown the direct connection between the observed variability of the lower atmosphere and ocean with the temporal and spatial changes of the ITM structure, including the effects of an earthquake-induced tsunami.

A new data product from TIMED is the geospace index, named the Thermosphere Climate Index (TCI). The TCI provides a quantitative measure of the total amount of infrared energy emitted by the thermosphere on a daily basis above 100 kilometers. This infrared energy is a primary component of the energy budget in this region and serves to cool the atmosphere. In this case, 16 years of TIMED and

OTHER MISSIONS AND DATA ANALYSIS

Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) measurements of nitric oxide (NO) cooling are expressed as functions of traditional geospace indexes and then extended back to the year 1947. The TCI showed that for most of 2018 (close to solar minimum), the thermosphere was in a "cold" state, approaching the solar minimum values last seen in 2009 and 1954. To date, the TCI has revolutionized scientists' view of solar variability. Rather than each solar cycle being different, the TCI shows that from the perspective of absorbed solar energy and emitted infrared energy, solar cycles 19-23 (1964-2008) were almost identical.

A collaboration between TIMED and AIM produced new findings about noctilucent clouds, which are the highest clouds in the Earth's atmosphere at approximately 85-kilometer altitude. They are of special interest, as they are sensitive to both global climate change and to solar/terrestrial influences. At higher altitudes, small changes in the atmospheric environment can lead to large changes in the properties of these clouds. Further, since these clouds form on condensation nuclei through cold temperatures and the presence of water vapor, carbon dioxide and methane tie to these properties of the mesosphere, the anthropogenic causes of climatic change may be linked with the presence of noctilucent clouds.

Simultaneous observations of Earth and Mars by TIMED and MAVEN provided a unique comparison of their ionospheres and thermospheres as they responded to solar flares in September 2017. The response of Earth's ionosphere and thermosphere to these large flares included strong enhancements of large-scale traveling atmosphere disturbances. The response of the Martian atmosphere to rapid heating from the flares included expansion of the thermosphere and enhanced ionosphere densities.

TIMED launched in December 2001 and entered its extended mission phase in January 2004. NASA has approved TIMED to continue as an extended mission, and TIMED will be invited to the 2023 Heliophysics Senior Review.

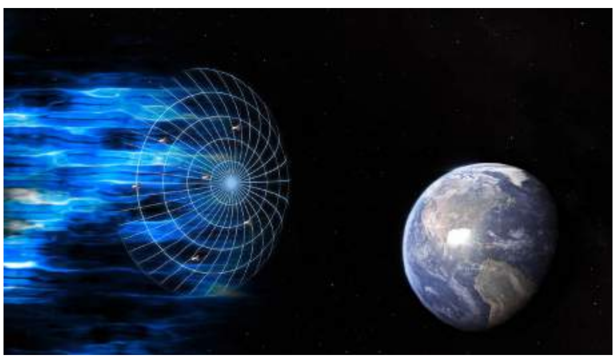
HELIOPHYSICS EXPLORER PROGRAM

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Other Missions and Data Analysis	184.1	170.7	**189.2**	151.6	157.9	162.9	226.3
Total Budget	**184.1**	**170.7**	**189.2**	**151.6**	**157.9**	**162.9**	**226.3**
Change from FY 2021			**18.5**				
Percentage change from FY 2021			**10.8%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



A coronal mass ejection (CME) erupts from the Sun and sends Type II radio bursts ahead of it. The Sun Radio Interferometer Space Experiment (SunRISE) measures the radio bursts and transmits the data to NASA's Deep Space Network. Type II radio bursts are the earliest indicators of shocks from a solar eruption and can provide information on solar energetic particle (SEP) events.

The Heliophysics Explorer Program provides frequent flight opportunities for world-class scientific investigations on focused and timely science topics. Explorers use a suite of smaller, fully competed missions that address these topics to complement the science of strategic missions of the LWS and STP programs. Competitive selections ensure accomplishment of the most current and best qualified missions.

The Explorers Program provides two classes (Medium-Class Explorers [MIDEX] and Small Explorers [SMEX]) of flight opportunities to accomplish the goals of the science program. These mission classes enable NASA to increase the number of flight opportunities in response to recommendations from the scientific community.

Explorers Missions of Opportunity (MO) are smaller investigations, typically an instrument, characterized as being part of a host space mission, sub-orbital flight, small complete mission, or new science investigation using existing spacecraft or ISS-attached payloads.

For more information, go to: https://explorers.gsfc.nasa.gov/

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Budget request includes new projects for recent mission selections: SunRISE, Electrojet Zeeman Imaging Explorer (EZIE), and Extreme Ultraviolet High-Throughput Spectroscopic Telescope (EUVST). Funding for the newly selected MAGnetometers for Innovation and Capability (MAGIC) technology demonstration is moved to the new Heliophysics Technology Program.

HELIOPHYSICS EXPLORER PROGRAM

ACHIEVEMENTS IN FY 2020

Following successful completion of extended Phase A studies, the Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) mission and the technology demonstration opportunity, MAGIC proceeded into Phase B preliminary design phase in April 2020. The Polarimeter to Unify the Corona and Heliosphere (PUNCH) mission and the Atmospheric Waves Experiment (AWE) completed their respective combined system requirements reviews.

In August 2020, NASA selected five proposals from the 2019 Heliophysics Explorers MIDEX AO for nine-month concept studies: Solar-Terrestrial Observer for the Response of the Magnetosphere (STORM), HelioSwarm: The Nature of Turbulence in Space Plasmas, Multi-slit Solar Explorer (MUSE), Auroral Reconstruction CubeSwarm (ARCS), and Solaris: Revealing the Mysteries of the Sun's Poles.

NASA launched the Ionospheric Connection Explorer (ICON) mission on October 10, 2019 and conducted the post-launch assessment review in December 2019. The ICON mission team released its first data set to the public in June 2020.

WORK IN PROGRESS IN FY 2021

AWE completed its preliminary design review and NASA approved the mission to enter the development phase. NASA made down-selections (Phase B) from proposals submitted to the 2018 Heliophysics Explorer Program MO AO: EZIE and EUVST. Both EZIE and EUVST will continue Phase B formulation activities in FY 2021. PUNCH and TRACERS will conduct their confirmation reviews and enter into final design and fabrication activities phase.

Following the completion of the MIDEX concept studies for the missions referenced above, NASA will choose up to two proposals to go forward to full mission implementation.

NASA will release the 2021 Heliophysics Explorer Program SMEX and MO draft AO.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

AWE will complete fabrication activities and prepare for launch.

Program Schedule

Date	Significant Event
FY 2021	MIDEX step 2 selections
FY 2021	SMEX/MO announcement of opportunity
FY 2022	SMEX/MO step 1 selections
FY 2023	SMEX/MO step 2 selections
FY 2024	MIDEX announcement of opportunity
FY 2025	MIDEX step 1 selections

HELIOPHYSICS EXPLORER PROGRAM

Program Management & Planned Cadence

The Heliophysics and Astrophysics Explorer Programs share a common program office at GSFC and a common management structure. The Explorer program manager resides at GSFC, reporting functionally to the Center Director and programmatically through the Heliophysics and Astrophysics Division Directors to the Associate Administrator for SMD.

The Heliophysics Explorer Program plan accommodates the Decadal Survey's recommendation of a two-to-three-year mission cadence.

Acquisition Strategy

NASA competitively selects new Explorer missions, releasing solicitations when available funding allows, with the expectation of a three-year cadence. NASA acquires launch vehicles through the Launch Services Program at KSC except when an international partner provides them under an approved agreement or when the Explorer mission is not a primary payload on the launch vehicle.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	Dec 2019	Assess performance of program	Successful	Jan 2024

OTHER MISSIONS AND DATA ANALYSIS

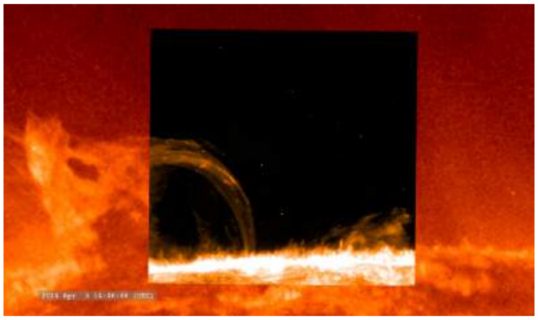
FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Electrojet Zeeman Imaging Explorer	3.8	9.6	**17.3**	14.7	14.1	5.4	2.2
Extreme Ultraviolet High-throughput Spec	3.1	5.7	**13.4**	10.7	10.6	6.7	4.6
Ionospheric Connection Explorer (ICON)	8.7	3.3	**4.7**	0.0	0.0	0.0	0.0
Global-scale Observations of the Limb and Disk (GOLD)	6.4	3.0	**3.8**	3.8	3.9	3.9	3.9
Heliophysics Explorer Future Missions	12.8	5.8	**32.1**	33.0	62.4	102.3	186.1
Heliophysics Explorer Program Management	10.8	17.4	**12.4**	16.2	12.9	13.1	7.3
Interface Region Imaging Spectogr (IRIS)	6.2	6.4	**6.4**	6.5	6.5	6.6	6.6
Interstellar Boundary Explorer (IBEX)	3.4	2.9	**2.9**	2.9	3.1	3.2	3.2
TWINS	0.3	0.1	**0.0**	0.0	0.0	0.0	0.0
Aeronomy of Ice in Mesophere (AIM)	4.0	1.7	**3.0**	3.0	3.0	3.1	3.1
THEMIS	6.0	4.0	**5.2**	5.5	5.3	5.3	5.3
Advanced Composition Explorer (ACE)	2.5	1.5	**2.5**	3.1	3.1	3.1	3.1
RHESSI	0.5	0.2	**0.0**	0.0	0.0	0.0	0.0
Polarimeter to Unify the Corona and Heliosphere (PUNCH)	65.4	53.4	**38.5**	12.8	15.8	1.5	0.0
Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS)	33.9	24.8	**25.1**	15.7	7.3	4.0	0.0
Atmospheric Wave Experiment (AWE)	9.4	10.9	**7.2**	4.8	5.1	4.8	1.0
Sun Radio Interferometer Space Experiment	6.9	20.0	**14.9**	18.7	4.7	0.0	0.0
Total Budget	**184.1**	**170.7**	**189.2**	**151.6**	**157.9**	**162.9**	**226.3**
Change from FY 2021			**18.5**				
Percentage change from FY 2021			**10.8%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Other Missions and Data Analysis



IRIS provided the first ever clear images of nanojets — bright, thin lights that travel perpendicular to magnetic structures in the solar atmosphere called the corona.

The Heliophysics Explorer Other Missions and Data Analysis budget includes operating Explorer missions, program management, missions in formulation and development with life cycle costs less than $250 million, and funding for future mission selections.

For more information, go to: https://explorers.gsfc.nasa.gov/

Mission Planning and Other Projects

Polarimeter to Unify the Corona and the Heliosphere (PUNCH)

The Polarimeter to Unify the Corona and Heliosphere (PUNCH) mission will focus directly on the Sun's corona and how the corona generates the solar wind. Comprised of four suitcase-size satellites, PUNCH will image and track the solar wind as it leaves the Sun. The spacecraft will also track coronal mass ejections (i.e., large eruptions of solar material that can drive large space weather events near Earth) to better understand their evolution and develop new techniques for predicting such eruptions. These observations will enhance National and international research by other NASA missions, such as Parker Solar Probe and the ESA/NASA Solar Orbiter. PUNCH will be able to image, in real time, the structures in the solar atmosphere that these missions encounter by blocking out the bright light of the Sun and examining the much fainter atmosphere. Together, these missions will investigate how the star we live with drives radiation in space.

NASA selected PUNCH under the 2016 Small Explorers (SMEX) Announcement of Opportunity (AO). PUNCH is in preliminary design and technology completion phase (Phase B) with the preliminary design review scheduled in May 2021 and an expected launch date in 2023.

Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS)

The Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) mission will observe particles and fields at the Earth's northern magnetic cusp region (i.e., the region encircling Earth's pole) where our planet's magnetic field lines curve down toward Earth. Here, the field lines guide particles from the boundary between Earth's magnetic field and interplanetary space down into the atmosphere. In the northern magnetic cusp area, with its easy access to our boundary with interplanetary space, TRACERS will study how magnetic fields around Earth interact with those from the Sun. In a process known as magnetic reconnection, the field lines explosively reconfigure, sending particles out at speeds that can approach the speed of light. Earth's magnetic field will guide some of these particles into the region where TRACERS can observe them.

Magnetic reconnection drives energetic events all over the universe, including coronal mass ejections and solar flares on the Sun. It also allows particles from the solar wind to push into near-Earth space, affecting its space weather. TRACERS will be the first space mission to explore this process in the cusp with two

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spacecraft, providing observations of how processes change over both space and time. The cusp vantage point also permits simultaneous observations of reconnection throughout near-Earth space. Thus, it can provide important context for NASA's Magnetospheric Multiscale mission, which gathers detailed, high-speed observations as it flies through single reconnection events at a time. TRACERS' unique measurements will help with NASA's mission to safeguard our technology and astronauts in space.

TRACERS entered its preliminary design phase in April 2020 following the successful completion of an extended Phase A study. NASA is exploring creative rideshare opportunities for TRACERS.

ATMOSPHERIC WAVE EXPERIMENT (AWE)

The Atmospheric Wave Experiment (AWE) will observe how atmospheric gravity waves in the lower atmosphere, caused by variations in the densities of different packets of air, affect the upper atmosphere. These observations will provide a broader understanding of space weather interactions, specifically the relation between terrestrial weather below and the solar wind. This interaction occurs in a dynamic region of the upper atmosphere, and is important to better understand due to the interference it can create in radio and GPS communications. NASA will attach AWE to the exterior of ISS, where it will focus on colorful bands of light in Earth's atmosphere, called airglow, to determine what combination of forces drive space weather in the upper atmosphere.

AWE completed preliminary design and technology (Phase B), and successfully passed Key Decision Point C review in December 2020, with an expected launch date of November 2022.

SUN RADIO INTERFEROMETER SPACE EXPERIMENT (SUNRISE)

The Sun Radio Interferometer Space Experiment (SunRISE) will use six solar-powered CubeSats – each about the size of a toaster oven – to simultaneously observe radio images of low-frequency emission from solar activity and share them via NASA’s Deep Space Network. The constellation of CubeSats will fly within six miles of each other above Earth's atmosphere, which otherwise blocks the radio signals SunRISE will observe. Together, the six CubeSats will create 3D maps to pinpoint where giant particle bursts originate on the Sun and how they evolve as they expand outward into space. This will help determine what initiates and accelerates these giant jets of radiation. The six individual spacecraft will also work together to map the pattern of magnetic field lines reaching from the Sun out into interplanetary space. This information will help improve understanding of how our solar system works, and can ultimately help protect astronauts traveling to the Moon and Mars by providing better information on how the Sun’s radiation affects the space environment through which they must travel.

SunRISE is in preliminary design and technology completion phase (Phase B) with a Key Decision Point C scheduled for late 2021, and an expected launch date of no earlier than 2023.

EXTREME ULTRAVIOLET HIGH-THROUGHPUT SPECTROSCOPIC TELESCOPE EPSILON MISSION (EUVST)

In December 2020, NASA selected the EUVST mission (proposed as an Explorer Mission of Opportunity), as a contribution to the Japan Aerospace Exploration Agency (JAXA) partner-led Epsilon Mission (Solar-C EUVST Mission), along with other international partners. Targeted for launch in 2026, EUVST is a solar telescope that will study how the solar atmosphere releases solar wind and drives

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eruptions of solar material. These phenomena propagate out from the Sun and influence the space radiation environment throughout the solar system. NASA's hardware contributions to the mission include an intensified UV detector and support electronics, spectrograph components, a guide telescope, software, and a slit-jaw imaging system to provide context for the spectrographic measurement.

ELECTROJET ZEEMAN IMAGING EXPLORER (EZIE)

In December 2020, NASA selected the Electrojet Zeeman Imaging Explorer (EZIE) mission (proposed as an Explorer Mission of Opportunity) to study electric currents in Earth's atmosphere linking aurora to the Earth's magnetosphere – one piece of Earth's complicated space weather system, which responds to solar activity and other factors. The Auroral Electrojet (AE) index is a common measure of geomagnetic activity levels, even though the details of the structure of these currents is not understood. EZIE will launch no earlier than June 2024.

EXPLORER FUTURE MISSIONS

Explorer Future Missions funding will support future Explorer missions that have yet to be selected. NASA has increased the cadence of Explorers-class mission selections and opportunities. The optimum balance for Explorers cadence is an average of two to three years between AOs with alternating SMEX and MIDEX selections. A SMEX AO is planned in 2022 and MIDEX AO in 2023.

EXPLORER PROGRAM MANAGEMENT

Explorer Program Management encompasses the program office resources required to manage Explorer projects. The program office is responsible for providing support and guidance to projects in resolving technical and programmatic issues and risks; for monitoring and reporting technical and programmatic progress of the projects; and for achieving Explorer cost, schedule, and technical goals and requirements. Support for the Science Office for Mission Assessments (SOMA) at Langley Research Center is also included in Explorer Program Management. SOMA is responsible for the technical and scientific evaluation of Explorer mission proposals.

Operating Missions

IONOSPHERIC CONNECTION EXPLORER (ICON)

Ionospheric Connection Explorer (ICON) is a single spacecraft mission launched in 2019 dedicated to understanding neutral-ion coupling in the Earth's upper atmosphere (i.e., the thermosphere). It will resolve both long-standing and newly emerging questions about the mechanisms that control the daily development of plasma in Earth's space environment.

ICON studies the ionosphere by simultaneously measuring altitude profiles of the thermosphere and ionosphere's neutral winds, composition, density, temperature, and ion density. It also makes in-situ plasma measurements. Understanding what drives variability in the ionosphere requires a careful look at a complicated system driven by both terrestrial and space weather. ICON studies the frontier of space, which is the dynamic zone high in our atmosphere where Earth's weather meets space weather. This is a hard-to-reach area that, despite being close to home, remains mysterious. ICON provides in-situ measurements of this complicated region of near-Earth space, which can be difficult to fly through given the variable drag on spacecraft. Better understanding of the ionosphere also has practical repercussions for our ever-increasing reliance on technology. Radio communications and GPS signals travel through the ionosphere, and variations in this region can result in distortions, or even complete disruption, of these signals. As spacecraft travel through this region regularly, improved knowledge will increase our situational awareness to protect satellites and astronauts.

ICON will help determine the physics of our space environment and pave the way for mitigating its effects on our technology, communications systems, and society.

Recent Achievements

ICON has fulfilled its mission success requirements relating neutral winds and ionospheric drifts, thereby verifying the ability to complete these important science requirements over the course of the mission. Mission success requirements define the science that must be achieved for NASA to declare the mission a success.

In the past year, new measurements from ICON's Ion Velocity Meter (IVM) detected unusual plasma density decreases near the magnetic equator that occurred just after midnight and persisted until dawn. ICON scientists combined the new high resolution IVM measurements with state-of-the-art models of the upper atmosphere and ionosphere to provide the first physical explanation for this type of plasma density decrease. This combination of ICON data with cutting edge models provides critical understanding of how electric fields generated by upper atmospheric variability can produce sudden changes in ionospheric plasma distribution that are known to affect global communication systems and GPS performance. Additionally, wind and temperature measurements between 90-300 km altitude from ICON's MIGHTI (Michelson Interferometer for Global High-Resolution Thermospheric Imaging) instrument were compared with coincident ground-based observations of upper atmospheric winds. The good agreement between MIGHTI and ground-based wind measurements demonstrates high confidence in the use of continued MIGHTI observations to learn how upper atmospheric wind and temperature fluctuations related to weather patterns near Earth's surface can drive large and unpredictable motions of charged particles within the ionosphere.

GLOBAL-SCALE OBSERVATIONS OF THE LIMB AND DISK (GOLD)

Global-scale Observations of the Limb and Disk (GOLD), launched in 2018, performs unprecedented imaging of Earth's thermosphere and ionosphere. GOLD is the first mission to study the weather of the thermosphere-ionosphere rather than its climate, and is the first NASA mission to fly as a hosted payload on a commercial communications satellite, pioneering cost-effective access to geostationary orbit. Capturing never-before-seen images of Earth's upper atmosphere, GOLD explores our space environment, which is home to astronauts. GOLD explorers radio signals used to guide airplanes and ships, and satellites that provide communications and GPS systems in detail.

For the first time, GOLD will answer fundamental scientific questions about how the thermosphere/ionosphere system responds to geomagnetic storms, solar radiation, and upward propagating waves and tides. Gathering observations from geostationary orbit above the Western Hemisphere, GOLD measures the temperature and composition of neutral gases in Earth's thermosphere. This part of the atmosphere co-mingles with the ionosphere's charged particles. Both the Sun from above and terrestrial weather from below can change the types, numbers, and characteristics of the particles found here, and GOLD helps track those changes.

Activity in this region is responsible for a variety of key space weather events. GOLD scientists are particularly interested in the cause of dense, unpredictable bubbles of charged gas that appear over the equator and tropics, sometimes causing communication problems. As we discover the very nature of the Sun-Earth interaction in this region, the mission could ultimately lead to ways to improve forecasts of such space weather and mitigate its effects.

Recent Achievements

The Equatorial Ionization Anomaly (EIA) and the bubbles that form within it have been the subject of decades of research because they have significant effects on communications and navigation systems. Yet scientists do not understand them sufficiently for reliable forecasting. Bubbles in the evening EIA from GOLD observations and self-consistent modeling that includes atmospheric gravity waves (GW) show agreement. However, the same models without GWs do not generate bubbles, offering evidence that GWs are a trigger for bubble generation.

GOLD has identified the signatures of atmospheric waves and tides from across a broad spectrum of scales and periods, all the way from atmospheric GWs with periods around 1 hour to multi-day planetary Rossby waves. The project used a special mode campaign to track the motion of GWs for over 2000 kilometers on the disk and identify their temperature amplitude as approximately 30 Kelvin. These results demonstrate the ability of GOLD to identify wave features, which are smaller in amplitude than those generated by geomagnetic storms.

New GOLD observations captured changes in the composition of the global thermosphere during the breakup of the polar stratospheric vortex. Theoretical models had previously hypothesized this connection between the weather of the polar stratosphere and the space weather of the thermosphere, but it could not be observed prior to GOLD. These observed changes in composition modify Earth's ionospheric plasma environment and imply a substantial impact of the lower and middle atmosphere on space weather.

GOLD launched in January 2018 and completed its prime mission in October 2020. NASA has approved GOLD to continue with its first extended mission, and GOLD will be invited to the 2023 Heliophysics Senior Review.

INTERFACE REGION IMAGING SPECTROGRAPH (IRIS)

Interface Region Imaging Spectrograph (IRIS), launched in 2013, joined a network of solar spacecraft and ground-based observatories to provide unprecedented insight into a little understood region of the Sun called the interface region. IRIS makes use of high-resolution observations and state-of-the-art computer models to unravel how matter, light, and energy move through the dense region of solar material at the bottom of the Sun's atmosphere. Understanding the interface between the Sun's surface and its atmosphere, the corona, is crucial to understanding what drives heat and energy into the corona, as well as what powers solar flares and coronal mass ejections.

IRIS provides key insights into all these processes, and thereby advances our understanding of the solar drivers of space weather from the corona to the far heliosphere by combining high-resolution imaging and spectroscopy for the entire chromosphere and adjacent regions.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

One key focus of IRIS research is using its unprecedented resolution to help unravel how plasma moves through the lower regions of the Sun's atmosphere and what drives the constant change in this dynamic region.

There has been a significant improvement in our ability to identify precursors to solar flares. By utilizing a recent deep neural network analysis of IRIS high resolution spectral data, researchers are now able to identify pre-flare spectra approximately 35 minutes prior to the flare onset with 80 percent accuracy. This is a major step forward in forecasting flares and will provide a new avenue of investigation and forecasting.

IRIS launched in June 2013 and entered its extended mission phase in July 2015. NASA has approved IRIS to continue as an extended mission, and IRIS will be invited to the 2023 Heliophysics Senior Review.

INTERSTELLAR BOUNDARY EXPLORER (IBEX)

IBEX, launched in 2008, is the first mission designed to image the edge of the solar system. As the solar wind from the Sun flows out beyond Neptune, it collides with the material between the stars, forming several boundaries. These interactions create energetic neutral atoms, particles with no charge that move very quickly. This region emits no light that conventional telescopes can see, so IBEX measures the particles that happen to be traveling inward from the boundary instead. IBEX contains two detectors designed to collect and measure energetic neutral atoms, providing data about the mass, direction of origin, and energy of these particles. From these data, researchers create maps of the boundary, creating a new map every six months. The mission's focused science objective is to discover the nature of the interactions between the solar wind and the interstellar medium at the edge of the solar system. This region is important because it shields a large percentage of harmful galactic cosmic rays from Earth and the inner solar system.

Recent Achievements

During FY 2020, IBEX continued to measure particles that travel from the Sun to the edges of the heliosphere and back in toward Earth. NASA previously reported that in late 2014, NASA spacecraft detected a substantial change in the solar wind. For the first time in nearly a decade, the solar wind pressure—a combined measure of its speed and density—had increased by approximately 50 percent and remained that way for several years thereafter. After detecting the first sign of this extended pressure pulse in returning neutral atoms in 2016, with the initial brightening in energetic neutral atoms arriving from approximately 20 degrees south of the upwind direction, indicating it as the closest point from Earth to the heliosheath, it has spread to regions that are further from the Sun during 2017, 2018, and 2019. In 2020, IBEX saw the first sign of brightening of the IBEX ribbon in response to the solar wind pressure pulse, thus confirming that this structure is further away than the heliopause, locating it firmly in interstellar space, and pointing to a process that requires solar wind ions to undergo three charge exchanges (i.e., to neutral, to ion, to neutral) in order to be detected by IBEX. In 2020, IBEX also completed observations of the interstellar boundary region over a full 11-year solar activity cycle. This completion will mark a starting point for IBEX, as it will be able to repeat measurements under similar solar activity conditions as they occurred at the beginning of the mission, allowing for further insights in temporal changes of the region that may be driven by causes other than solar activity.

OTHER MISSIONS AND DATA ANALYSIS

IBEX launched in October 2008 and entered its extended mission phase in January 2011. NASA has approved IBEX to continue as an extended mission, and IBEX will be invited to the 2023 Heliophysics Senior Review.

TWO WIDE-ANGLE IMAGING NEUTRAL ATOM SPECTROMETERS (TWINS)

Two Wide-Angle Imaging Neutral Atom Spectrometers (TWINS) provided stereo imaging of Earth's magnetosphere for 11 years, observing the region surrounding the planet controlled by its magnetic field and containing the Van Allen radiation belts and other energetic charged particles. TWINS provided a three-dimensional global visualization of this region, which led to a greatly enhanced understanding of the connections between different regions of the magnetosphere and their relation to solar variability. TWINS, a NASA-sponsored mission of opportunity has ended operations. Scientists are archiving all data and processing it for future research opportunities. The TWINS mission continues to transfer their final data and documentation to the NASA archives, which will conclude in September 2021.

Recent Achievements

Scientists combined TWINS, Van Allen Probe, and MMS observations to understand magnetic interactions at the end of Earth's magnetic field (magnetotail) with a solar event that occurred on August 10, 2016.

AERONOMY OF ICE IN THE MESOSPHERE (AIM)

Aeronomy of Ice in the Mesosphere (AIM), launched in 2007, is a mission to determine why polar mesospheric clouds form and why they vary. Polar mesospheric clouds (PMCs), Earth's highest-altitude clouds, form each summer in the coldest part of the atmosphere about 50 miles above the polar regions. When ice crystals form over tiny microparticles produced when meteors burn up in Earth's atmosphere, they create PMCs. These clouds have been steadily increasing over the past decade. These clouds are of particular interest, as the number of clouds in the middle atmosphere, or mesosphere, over Earth's poles has been increasing over recent years, possibly related to climate change. The spacecraft completed its prime mission in FY 2009 and is currently in extended phase.

Recent Achievements

AIM observations of more than 10 years, show that the solar cycle in PMCs is weak or absent in the 21st century, contrary to observations from 20 years ago. Scientists predicted PMCs were reduced at solar maximum due to increased heating and water vapor photolysis. Evidence suggests connection of the changing H2O in the mesosphere to the missing solar cycle response in PMCs, although scientists do not yet understand the underlying causes. A recent study using AIM and TIMED measurements revealed that geomagnetic (i.e., solar) storms can affect atmospheric temperature and dynamics to much lower altitudes and much more strongly than expected. Significant temperature increases occurred down to 94 kilometers during a large geomagnetic storm, likely below the heights of most geomagnetic energy deposits. Continuous observations in the polar cap reveal new pathways whereby geomagnetic storms can penetrate to lower altitudes and latitudes through changes in atmospheric circulation.

AIM launched in April 2007 and entered its extended mission phase in June 2009. NASA has approved AIM to continue as an extended mission, and AIM will be invited to the 2023 Heliophysics Senior Review.

OTHER MISSIONS AND DATA ANALYSIS

TIME HISTORY OF EVENTS AND MACROSCALE INTERACTIONS DURING SUBSTORMS (THEMIS)

Time History of Events and Macroscale Interactions during Substorms (THEMIS) is a MIDEX mission that launched in February 2007. Starting as a five-spacecraft mission, the three inner probes of THEMIS now focus on collecting data related to the onset and evolution of magnetospheric substorms, while the two outer probes (now referred to as ARTEMIS) have been repositioned into lunar orbits. Magnetospheric substorms are the explosive release of stored energy within the near-Earth space environment that can lead to space weather effects. The two ARTEMIS probes orbit the Moon's surface at approximately 100 miles in altitude and provide new information about the Moon's internal structure and its atmosphere. ARTEMIS provides two-point observations essential to characterizing the Moon's plasma environment and hazardous lunar radiation. THEMIS and ARTEMIS, among others in the Heliophysics portfolio, are examples of missions offering important dynamics knowledge useful for future human spaceflight. THEMIS is currently in extended operations.

Recent Achievements

In 2020, THEMIS helped reveal the nature of structured, bead-like auroral features that appear just before large auroral displays caused by geomagnetic substorms. These beads are tens of kilometers in size and researchers have observed them with many substorms. This small-scale size makes it difficult to identify the source mechanism. Previous studies have theorized on possibilities but have been unable to determine whether they are part of the substorm initiation process or a product of a process that precedes but does not trigger the substorm.

Combining THEMIS' ground-based all-sky imager observations, THEMIS' spacecraft observations, and state-of-the-art computer simulations, researchers observed the auroral beads at a time when the THEMIS spacecraft observed narrow plasma channels in the near-Earth magnetotail. The computer simulations were able to model both the global magnetosphere and this part of magnetosphere at a sufficiently high resolution, which is difficult to achieve but necessary for the study of these small-scale phenomena. This study showed that narrow plasma instabilities that form as the magnetotail reconfigures before a substorm generate these beads.

THEMIS launched in February 2007 and entered its extended mission phase in September 2009. NASA has approved THEMIS to continue as an extended mission, and THEMIS will be invited to the 2023 Heliophysics Senior Review.

ADVANCED COMPOSITION EXPLORER (ACE)

Advanced Composition Explorer (ACE), launched in 1997, observes particles of solar, interplanetary, interstellar, and galactic origins as they pass by its location near the L1 Lagrange point, located about one million miles from Earth toward the Sun. Changing conditions over the solar cycle are presenting new opportunities, including providing new insights relevant to space weather events.

In late 2019, NOAA requested that ACE be designated a permanent operational asset, supported by NASA. It will continue to provide essential and continuous space weather observations from its location at the Earth's L1 point. The spacecraft has enough propellant on board to maintain an orbit at L1 until approximately 2024.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

ACE provides near-real-time 24/7 continuous coverage of solar wind parameters and solar energetic particle intensities. Scientists continue to use ACE data to track and analyze the particles streaming toward Earth from the Sun—including the largest solar energetic particle (SEP) events, which can be hazardous to exposed astronauts and space-based instrumentation.

Using 20 years of ACE observations, a team of researchers recently found that suprathermal ion compositions for the two solar cycles were remarkably similar. Corotating interaction regions (CIR) have been found to be a major source of energetic particles in the interplanetary medium, are known to be able to trigger geomagnetic storms, and can affect the ionosphere/thermosphere at Earth, making them an important space weather phenomenon. As a faster solar wind stream overtakes preceding slower streams, a density "pile-up" of compressed plasma occurs, which can eventually form into a CIR.

Suprathermal ion composition associated CIRs exhibited a solar cycle variation during solar cycle 23 and the beginning of solar cycle 24. However, it was unclear if this behavior would continue over all solar cycle 24, or whether the CIR-associated suprathermal ion composition would change.

ACE launched in August 2007 and entered its extended mission phase in May 1998. During its extended mission phase, ACE was declared a national space weather asset and will participate in a programmatic review (outside of the Senior Review) in 2023.

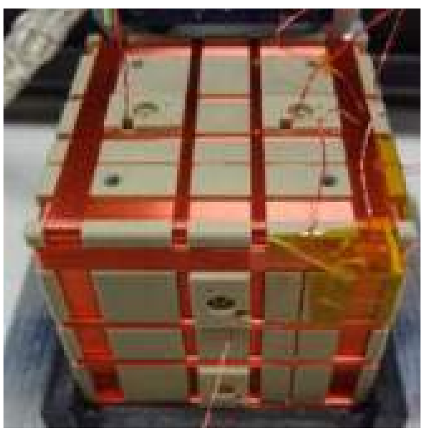
HELIOPHYSICS TECHNOLOGY

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**15.9**	**19.2**	**28.3**	**39.8**	**47.7**	**17.8**	**11.4**
Change from FY 2021			**9.1**				
Percentage change from FY 2021			**47.4%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



MAGnetometers for Innovation and Capability (MAGIC), pictured above, is a fluxgate magnetometer that will demonstrate a novel magnetic measurement capability without relying on the legacy ring-cores used by most other providers and can be scaled and tuned for other applications.

The future success of Heliophysics depends on the ability to produce novel and transformative technologies, capabilities, and mission concepts. The Heliophysics Technology Program will strategically invest in the development of instrument and technologies and methodically mature and demonstrate them to enable infusion into future missions. NASA's goal is to enable previously infeasible science investigations; improve existing measurement capabilities; reduce the cost, risk, and/or development times for Heliophysics science instruments and advanced space missions of the future; and yield applications to the broader economy (e.g., space weather).

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Heliophysics Technology Program is proposed as a new program in the FY 2022 budget. The program includes elements transferred from other programs, including Heliophysics Technology and Instrument Development for Science (HTIDeS) and Heliophysics Flight Opportunities Studies (HFOS; currently funded out of Heliophysics Research), as well as the Solar Cruiser technology demonstration mission of opportunity (currently funded under the Solar Terrestrial Probe program) and the Magnetometers for Innovation and Capability (MAGIC) technology demonstration mission, a technology demonstration rideshare project transferred from the Explorers program. Detailed project info is included below.

HELIOPHYSICS TECHNOLOGY

ACHIEVEMENTS IN FY 2020

Although the Heliophysics Technology Program is proposed to begin in FY 2022, several existing elements within the Heliophysics division budget will be transferred to this new program and are shown in this program section. The FY 2020 accomplishments for these elements are included below.

NASA competitively solicited, selected and matured technology efforts through the HTIDeS program element. In FY 2020 HTIDeS managed 48 technology projects and advanced these technologies by one or more Technical Readiness Level (TRL). Nearly 150 students nationwide were involved in these projects. The program added several projects into science measurements, sub-orbital and orbital, during the year. For example, ASHI - A Lightweight All Sky Imager for Future NASA Heliospheric Missions - was infused into the PUNCH SMEX mission. The ASHI instrument was developed and advanced through the HTIDeS program. Another example is the Small UV imager for Heliophysics science investigations which was infused into the GLIDE Mission of Opportunity. The imager was an HTIDeS project that built and qualified a small, relatively simple space-based UV imager which can be tuned/modified for a range of purposes.

MAGIC, a technology demonstration instrument that will be flown with the TRACERS Small Explorers (SMEX) mission, continued work in Phase B. MAGIC is a new tool suite designed to process magnetograms for use in models which require Solar Magnetic field as input and will fill a critical gap in technologies for Heliophysics science measurements. The Program Level Requirements document has been finalized and development is on schedule.

The Solar Cruiser technology demonstration mission of opportunity completed Phase A and NASA authorized continued work in Phase B. This technology demonstration is a rideshare with the IMAP mission.

To drive innovation for the next Heliophysics Decadal Survey (expected in 2023), the Heliophysics Division initiated a technology strategic working group to ensure that the next Decadal Survey makes maximum use of achievable technologies and that technology development leads to impactful science outcomes. In FY 2020 the technology strategic working group developed a technology strategic plan and an associated implementation plan to make technology investments more focused, impactful, and innovative. The implementation plan identifies near-, mid-, and long-term technology goals to guide the activities of the Heliophysics Technology Program in FY 2022 and beyond.

WORK IN PROGRESS IN FY 2021

In FY 2021 the technology strategic working group will continue the refinement of the technology implementation plan to prepare for implementing the Heliophysics Strategic Technology Office (HESTO) in FY 2022. One element of the Heliophysics Strategic Plan is the expansion of the HTIDeS solicitation to solicit more cutting-edge technologies ("high risk and high reward"). This work started in FY 2020, with 40 percent of the HTIDeS awards made in the high risk/high reward category.

As prescribed in the implementation plan, NASA will begin enhancement of the HFOS to include technology and mission concept studies to drive the technology needs for future missions.

The Solar Cruiser technology mission of opportunity will continue work under Phase B to complete the SRR.

HELIOPHYSICS TECHNOLOGY

The MAGIC technology demonstration will continue phase B formulation activities. It will complete the Science Requirements Review (SRR), Preliminary Design Review (PDR) and conduct a confirmation review before proceeding into the development phase.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

NASA will establish HESTO in FY 2022. As prescribed by the implementation plan, HESTO will develop a technology incubator program to advance promising technologies through maturation and demonstration, and to enable more purposeful technology infusion in future science missions. As prescribed by the strategic implementation plan, maturation of technologies will be achieved either in ground-based facilities or through orbital and suborbital flight. Partnership with NASA centers and Government agencies to facilitate use of ground-based facilities for technology maturation is a key element of this plan. Initiation of the Flight Opportunities for Technology Maturation (FOTM) solicitation is also a key element of this plan that will solicit technologies to be matured via suborbital and orbital flight opportunities.

HESTO will also expand the Heliophysics technology community by developing a solicitation for proposals from non-heliophysics technologists. An element of the strategic implementation plan, the goal is to infuse technology ideas from other disciplines into the heliophysics community to enhance innovation and advance future Heliophysics science.

HESTO will expand HFOS to include technology and mission concept studies and initiate a technology incubator program. HESTO will also establish key partnerships to maximize the return on our technology investments.

The Solar Cruiser mission will continue development under phase B, complete PDR and KDP-C and begin work under Phase C. MAGIC will complete its PDR. SPICES will complete engineering model testing in relevant environments and will conduct its preliminary design review.

Program Elements

TECHNOLOGY ANALYSIS AND MISSION DESIGN (TAMD)

Technology Analysis and Mission Design (TAMD) will invest in mission concept studies of novel and transformative applications of new technologies in future heliophysics flight missions. This includes and expands on HFOS. This project also conducts periodic technology gap analyses and analyses of trends in technology development/advancement to identify gaps in heliophysics technology. This will enable more focused solicitations in the Advanced Technology Development project.

ADVANCED TECHNOLOGY DEVELOPMENT (ATD)

Advanced Technology Development (ATD) will invest in the development of critical and innovative new instruments, technologies, and novel and transformative capabilities to achieve significant progress toward the scientific and technical challenges in heliophysics in the coming years. This includes and

HELIOPHYSICS TECHNOLOGY

expands on HTIDeS. This project will also establish an incubator process for the most promising early TRL technologies to proactively nurture and advance.

This project includes direct funding for critical technologies identified through the gap analysis, such as the SPICES technology. The SPICES technology demonstration instrument includes an unprecedented 50 KV High-Voltage Power Supply which would allow for future observations that could lead to breakthrough science advances in the understanding of pick-up ions and low-energy accelerated ions in space plasmas. This activity would provide a robust instrument design to be carried forward into future missions. The preliminary design would be fully tested and analyzed as an entire sensor assembly showing function of the instrument Engineering Model, would provide maximum preliminary design risk reduction for SPICES and provide the best path forward for eliminating risk to future spacecraft.

This project also includes the new Alternative Initiation of Technology Exploration (AITE) element to grow and diversify the Heliophysics technology development community. It will use competitive means to expand the heliophysics technology community, and to tap into other disciplines to solve our most critical science questions.

TECHNOLOGY PATHFINDER (TP)

With Technology Pathfinder (TP), NASA will advance technologies and instruments from a proof of concept (technology development) to demonstration, maturing transformational technologies across the critical gap that resides between early stage concepts and flight demonstration. Access to relevant flight demonstration environments will be achieved using ground-based facilities, flight-based platforms such as orbital SmallSats and CubeSats, and suborbital balloons and rockets through the new HFOTM element.

This project will also utilize rideshare opportunities for flight demonstration of more mature technologies to increase the potential for future infusion into larger heliophysics missions. Examples of these include Solar Cruiser and MAGIC.

MAGNETOMETERS FOR INNOVATION AND CAPABILITY (MAGIC)

MAGnetometers for Innovation and Capability (MAGIC) is a five-year project to develop key fluxgate magnetometer technology and to design, build, test and fly a next-generation spaceflight fluxgate. MAGIC is a technology demonstration payload on the TRACERS mission and both will launch in 2024. MAGIC will demonstrate a novel magnetic measurement capability without relying on the legacy ring-cores used by most other providers and can be scaled and tuned for other applications.

SOLAR CRUISER

Solar Cruiser, a SmallSat mission to be launched with IMAP in 2025, is a technology demonstration mission of opportunity. Solar Cruiser will demonstrate a large (1700 square meter) solar sail. If successfully demonstrated, such solar sails can be used to propel spacecraft and can enable spacecraft to collect observations from novel vantage points that are difficult to reach and sustain. Specifically, Solar Cruiser will maintain a position sunward of Lagrange point L1—the position where Earth's and the Sun's gravity are balanced along the Sun-Earth-Line. Solar Cruiser will also demonstrate technologies that will enable future missions to improve space-weather monitoring, prediction, and science.

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Program Schedule

Date	Significant Event
Q2 FY 2021	Solar Cruiser SRR, MAGIC SRR and PDR
Q4 FY 2021	MAGIC PDR, KDP-C
Q4 FY 2021	ROSES-2020 HFOS selections no earlier than six months after receipt of proposals
Q1 FY 2022	Solar Cruiser PDR and KDPC, MAGIC CDR
Q1 FY 2022	SPICES Preliminary Design Review (PDR)
Q1 FY 2022	ROSES-2022 HTIDeS, HFOS and HFOTM solicitations
Q1 FY 2022	ROSES-2021 HTIDeS and HFOS selections no earlier than six months after receipt of proposals
Q2 FY 2022	ROSES-2021 HFOTM selections no earlier than six months after receipt of proposals
Q4 FY 2022	Solar Cruiser CDR
Q1 FY 2023	ROSES-2023 HTIDeS, HFOS and HFOTM solicitations
Q1 FY 2023	ROSES-2022 HTIDeS and HFOS selections no earlier than six months after receipt of proposals
Q2 FY 2023	ROSES-2022 HFOTM selections no earlier than six months after receipt of proposals
Q2 FY 2023	MAGIC KDP D
Q4 FY 2023	Solar Cruiser SIR
Q1 FY 2024	Solar Cruiser KDP D
Q1 FY 2024	ROSES-2024 HTIDeS, HFOS and HFOTM solicitations
Q1 FY 2024	ROSES-2023 HTIDeS and HFOS selections no earlier than six months after receipt of proposals
Q2 FY 2024	MAGIC FRR
Q2 FY 2024	ROSES-2023 HFOTM selections no earlier than six months after receipt of proposals
Q4 FY 2024	Solar Cruiser Flight Readiness Review
Q4 FY 2024	MAGIC launch with TRACERS

HELIOPHYSICS TECHNOLOGY

Program Management & Commitments

HESTO at NASA Headquarters will provide program management for all technology activities.

Program Element	Provider
Technology Analysis & Mission Design (TAMD)	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): None
Advanced Technology Development (ATD)	Provider: Various Lead Center: HQ Performing Center(s): TBD Cost Share Partner(s): None
Technology Pathfinder (TP)	Provider: Various Lead Center: HQ Performing Center(s): TBD Cost Share Partner(s): None
Solar Cruiser	Provider: MSFC Lead Center: GSFC Performing Center(s): MSFC Cost Share Partner(s): None
MAGIC	Provider: University of Iowa Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): None

Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA Centers, industry, and academia as well as other Government agencies, Federally Funded Research and Development Centers, and nonprofit organizations. NASA may directly fund critical technologies identified through a gap analysis.

MAJOR CONTRACTS/AWARDS

None.

HELIOPHYSICS TECHNOLOGY

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	National Academies of Science, Committee for Solar and Space Physics (CSSP)	2021	Independent assessment of targeted technology development priorities for Heliophysics Technology	TBD	2023

BIOLOGICAL AND PHYSICAL SCIENCES

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**5.0**	**79.1**	**109.1**	**118.1**	**128.0**	**137.9**	**147.8**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Biological and Physical Sciences

BIOLOGICAL AND PHYSICAL SCIENCES

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**5.0**	**79.1**	**109.1**	**118.1**	**128.0**	**137.9**	**147.8**
Change from FY 2021			**30.0**				
Percentage change from FY 2021			**37.9%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Astronauts are shown here growing plants in space aboard the International Space Station (ISS).

Conducting research in space provides scientists with the unique opportunity to observe natural phenomenon in ways not possible on Earth. By studying biological and physical systems under extreme conditions, such as altered gravity and radiation, scientists can better understand how biological and physical systems work. This knowledge can contribute to important scientific discoveries and technology advancements that not only enable space exploration, but also benefit life on Earth.

Biological and Physical Sciences (BPS) is conducted via competitively awarded research grants to scientists at NASA centers, universities, and research institutions across the country. BPS develops critical equipment and processes to support new experiments and shares research results with academia, commercial industry, and other government agencies.

The BPS Division has two areas of focus:

- Space Biology, which seeks to understand how living organisms respond to and evolve in the spaceflight environment. For example, BPS researchers investigate how microbes (e.g., viruses, bacteria, and fungi) behave in space so that scientists can develop new treatments, tools, or countermeasures to address them.
- Physical Sciences, which seeks to understand the fundamental laws of the universe, as well as determine how physical systems react in spaceflight environments. For example, BPS researchers study combustion in space to improve fuel efficiency and reduce pollutant emissions.

For more information about BPS, please visit: https://science.nasa.gov/biological-physical

BIOLOGICAL AND PHYSICAL SCIENCES

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Budget provides a $30 million increase over the FY 2021 enacted budget to accelerate transformative science at the frontiers of biological and physical sciences research in space. Some examples include additional grant awards, accelerating development of the Lunar Exploration Instrument for space biology Applications (LEIA), and upgrades to the Cold Atom Lab (CAL). In FY 2022, BPS will facilitate a major shift in research strategy from a broad to a focused portfolio. This shift in strategy will enable BPS to make significant investments in three research areas: Thriving In Deep Space (TIDES), Quantum Physics, and Soft Matter. The planning for this shift is beginning in FY 2021.

ACHIEVEMENTS IN FY 2020

Deciphering the Immune System:

Spaceflight is known to have a dramatic influence on immune response, but there is little research on its effect following an actual challenge to the body's immune system. The Rodent Research-12 (RR-12) study was completed on the International Space Station (ISS) in FY 2020. It investigated a mouse model with an immune system that closely parallels that of humans, to understand how the immune system functioned in space after it was challenged by tetanus toxin. This study will provide a basis for developing measures designed to prevent compromised immune systems in space and help to enable crew health during long-duration exploration missions. Future analysis of the study results may also help to improve response to vaccines and antibody production, increasing the effectiveness of vaccines and other therapies for treating diseases.

Assessing Radiation Damage to Cells:

In FY 2020, researchers completed an investigation on the ISS (called Rad-Dorm) into how cryogenically preserved ("frozen") mouse cells responded to long-duration exposure to space radiation. Future analysis of this data will provide valuable information for evaluating the cumulative cell DNA damage from long-duration radiation exposure. This study, conducted in collaboration with the Mayo Clinic, will potentially benefit regenerative medicine and immune response research on Earth, giving researchers a better understanding of how cells respond to the radiation exposure.

Exploring the Fifth State of Matter:

Quantum mechanics is the branch of physics that focuses on the behaviors of atoms and subatomic particles, and it is a foundational part of many components found in modern technologies, including cell phones and computers. NASA's CAL, which is housed on the ISS, has enabled scientists to explore a fifth state of matter, called a Bose-Einstein Condensate (BEC) in ways that are not possible on Earth. During FY 2020, NASA completed over 10,000 test runs that study BECs, installed an Atom Interferometry upgrade (an experimental tool), and was featured on the cover of the publication "Nature."

Studying Combustion in Space:

The Advanced Combustion via Microgravity Experiments (ACME) activity uses the ISS to research ways to improve fuel efficiency and reduce pollutant emissions by studying the flammability of materials. The primary objective of the ACME series of investigations is to improve life on Earth and a secondary objective is to improve fire prevention, particularly on spacecraft. In FY 2020, researchers executed two experiments on the ISS using the Combustion Integrated Rack: (1) ACME Burn-Rate Emulator (BRE) and (2) Structure and Response of Spherical Diffusion Flames (s-Flame).

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WORK IN PROGRESS IN FY 2021

In preparation for increased FY 2022 funding, BPS is beginning the initial planning for a program-wide effort to focus research in three areas, as opposed to the current broad research approach which was defined by the previous Decadal Survey. The three focus areas are described below:

1. Thriving In Deep Space (TIDES) focuses on the study of biological systems to understand the direct and indirect effects of the deep space environment on humans in order to prepare for long duration spaceflight.
2. Quantum science focuses on expanding our knowledge of quantum mechanical phenomena, testing the Einstein Equivalence Principle, and using dark energy signatures to understand the nature of the universe.
3. Soft matter focuses on understanding phenomena where forces are not in equilibrium. These systems exhibit complex dynamics and cooperative behavior where constituents self-organize, signal, and communicate with each other. They include liquids, colloids, polymers, foams, gels, granular materials, and several biological materials.

While the program continues the re-planning effort, BPS continues to support the planned research areas below in FY 2021.

Understanding Muscle Loss:

Astronauts lose muscle mass during space travel; fortunately, nematode worms, which are multicellular insects with smooth, unsegmented bodies, are an excellent, cost-effective model for studying muscle loss in humans. The Micro-16 experiment, which will complete development in FY 2021 for eventual launch and operation on the ISS, seeks to look at the physiological mechanisms that may cause muscle loss by studying worms in space. This study will advance knowledge about muscle mechanics and physiological performance affected by the spaceflight environment. Findings will be used to address risks for human performance deterioration and to develop countermeasure strategies for maintaining muscle strength. This study will also increase the understanding of mechanisms that may be associated with aging, bed rest, and disease on Earth.

Gardening in the Galaxy:

NASA researchers will conduct a series of plant biology experiments on the ISS to investigate how plants respond and adapt to the space environment to enable space crop production. Advanced Plant Experiments (APEX-07 and 08) will study the effects of environmental conditions on plant growth to identify novel genetic engineering strategies for improving plant adaptation in space and on Earth. The Biological Research In Canisters experiment (BRIC-24) will focus on plants' defense mechanisms against stressors (e.g., lack of oxygen, low amounts of water). The Plant Habit (PH-02) experiment will investigate the effects of spaceflight on radishes. This knowledge will be essential for the transition from Earth-bound cultivation of plants to growth conditions in space, and to enable the development of nutritionally valuable food crops that can be reliably grown in a space environment. Space Biology is also collaborating with the Human Research Program to study both the psychological benefits to humans of having plants in space, as well ways to improve the taste of space-grown food on ISS.

BIOLOGICAL AND PHYSICAL SCIENCES

Life Beyond Low Earth Orbit:

Bio-Expt-1, aboard the Artemis I mission, will contain the first biological experiments to be conducted beyond the Van Allen Belts since the Apollo missions. The full design and validation of the experiment and hardware will be conducted in FY 2021. Four investigations will study the impact of deep-space radiation and microgravity on seeds, yeast, fungus, and algae.

Studying How Mixtures "Settle" in Space:

A colloid is a mixture in which one substance can be divided into minute particles and dispersed throughout a liquid, such as a gel, sol, or emulsion. Commercial industry and other researchers study colloids with the intent of extending the "shelf life" of these mixtures; that is, prolonging the period of time before the substance separates. During FY 2021, NASA expects to complete the Advanced Colloids Experiment (ACE) series of experiments using the Fluids Integrated Rack (FIR). These investigations will explore how a colloid with two different-sized particles can create novel structures for advanced batteries and medical implants.

Studying Combustion in Space, Improving Fire Safety:

NASA will complete the development of the Solid Fuel Ignition and Extinction (SoFIE) payload, which will study the combustion of solid materials in space, and lead to critical insights into how fire propagates (spreads) in a microgravity environment.

Advancing Scientific Study of Diseases:

Understanding how fibrils form can aid the development of preventative treatments for neurodegenerative disorders and can also help improve the safety of drug manufacturing processes and delivery protocols. The Ring-Sheared Drop (RSD) investigation facilitates the study of amyloidogenesis (the formation of amyloid fibrils) and flow in a microgravity environment. Amyloid fibrils are abnormal protein deposits linked to various diseases in the human body, such as Alzheimer’s. During FY 2021, NASA expects to execute the RSD experiment on the ISS.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

BPS expects to begin formulation activities for new projects that align with the three focus areas established in FY 2021, while continuing to complete existing projects and grants that are already approved, as well as mature hardware developments.

Studying Microbes:

NASA plans to execute the MVP Cell-02 investigation, which seeks to understand how organisms adapt to the space environment.

Researching the Effects of Space on Mice:

A joint study with the Human Research Program will enable researchers to directly compare mice exposed to microgravity in space with those subjected to simulated gravity in space using a centrifuge. This will allow scientists to uncover which physiological changes are due to microgravity alone versus the ones that are due to other spaceflight factors such as radiation. Other activities will include studying the effects of partial gravity on rodents, as will be encountered on the surface of Moon and Mars, and an investigation into oxidative stress and its impact on the retina of mice and whether or not anti-oxidants prevent space-induced eye changes that could impact vision in astronauts.

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Studying Changes in Brain Neurons:

As humans age, the organization of the brain structure changes and deteriorates. Studying neuronal cells under the harsh radiation and altered gravity conditions in space for long periods of time could enable researchers to make discoveries as to how these cells respond and survive under stressful conditions as well as prevent space-induced damage. In FY 2022, NASA plans on conducting operations in the Mobile Lab on ISS. Insights could be used to develop countermeasures to protect astronauts' health on long missions, as well as for therapeutic interventions on Earth.

Exploring the Fifth State of Matter:

In FY 2022, CAL will deploy an upgrade to ISS that will utilize a new microwave source to improve the evaporation of rubidium atoms from a mixture of rubidium and potassium, thus enabling a test of part of Einstein's general relativity theory. (See Achievements in FY 2020 section for details.)

Studying Combustion in Space:

During FY 2022, NASA researchers plan to install and operate the SoFIE experiment in the Combustion Integrated Rack. (See Achievements in FY 2020 section for details.)

Improving Thermal Management Systems in Space:

Long-duration human exploration space missions will demand additional power and heat dissipation requirements compared to current space missions. To reduce size and weight, the transition from single-phase (liquid only) to more efficient two-phase (liquid and gas) thermal management systems may be necessary. Boiling and condensation data in microgravity are needed to validate numerical simulation tools that will be used to design these new thermal management systems. To obtain that data, NASA plans to install and operate the Flow Boiling and Condensation Experiment (FBCE) within the Fluids Integration Rack on the ISS.

Program Elements

BPS PROGRAM MANAGEMENT

This project funds BPS's institutional and crosscutting activities including: National Academies studies, proposal peer review processes, printing and graphics, information technology, the NASA Postdoctoral Fellowship program, National Research and Educational Support Services (NRESS), working group support, independent assessment studies, communications, and other administrative tasks.

SPACE BIOLOGY

The main objective of the Space Biology project is to build a better understanding of how spaceflight affects living systems in spacecraft (e.g., ISS) or in ground-based experiments that mimic aspects of spaceflight, and to prepare for future human exploration missions far from Earth. The experiments researchers conduct on these platforms examine how plants, microbes, and animals adjust or adapt to living in space. Researchers study the processes of metabolism, growth, stress response, physiology, and development. The program studies how organisms repair cellular damage and protect themselves from infection and disease in conditions of microgravity while being exposed to space radiation—and across

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the spectrum of biological organization, from molecules to cells, from tissues and to organs, and from systems to whole organisms, to communities of microorganisms.

In addition to providing useful information on how living organisms adapt to spaceflight, the discoveries NASA researchers make in space have enormous implications for life on Earth. Space Biology's research into the virulence of pathogens in space, loss of bone density, and the changes in the growth of plants can impact the development of drugs that promote wound healing or tissue regeneration, treatments designed to counter osteoporosis on Earth, and high-tech fertilizers that increase crop yield.

PHYSICAL SCIENCES

NASA’s experiments in the various disciplines of physical science reveal how physical systems respond to the near absence of gravity. They also reveal how other forces that, on Earth, are small compared to gravity, can dominate system behavior in space. BPS's physical science research is organized into six disciplines: Biophysics, Combustion Science, Complex Fluids, Fluid Physics, Fundamental Physics, and Materials Science. Conducted in a nearly weightless environment, experiments in these disciplines reveal how physical systems respond to the near absence of buoyancy-driven convection, sedimentation, or sagging. They also reveal how other forces, such as capillary forces, which are small compared to gravity, can dominate the system behavior in space. The data acquired from these investigations is stored in NASA's Physical Sciences Informatics (PSI) system and is available to the public.

Research across these six disciplines makes contributions in two distinct ways. The first, basic research, investigates physical phenomena in the absence of gravity and fundamental laws of the universe, and provides new knowledge of scientific value and societal benefit. The second way is applied research, which contributes to the basic understanding of underlying space exploration technologies such as power generation and storage, space propulsion, life support systems, and environmental monitoring and control.

Program Schedule

Date	Significant Event
Q2 FY 2021	BPS 2022 - 2032 Decadal Survey initiated
Q4 FY 2021	Annual Physical Sciences Informatics NRA selection
Q4 FY 2021	Annual Space Biology NRA selection
Q4 FY 2021	Flow Boiling Condensation Experiment NRA selection
Q1 FY 2022	Annual Space Biology NRA solicitation release
Q4 FY 2022	Annual Space Biology NRA selection
FY 2023	Delivery of Decadal Survey on Biological and Physical Sciences Research in Space

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Program Management & Commitments

The Human Exploration and Operations Mission Directorate (HEOMD), through the ISS Program Vehicle Office, will retain responsibility for the sustainment, maintenance, and operation of multi-user hardware that supports the life and physical sciences research portfolio through at least FY 2024, and will reassess this support as commercial LEO capabilities evolve. Additionally, HEOMD, through the ISS Program Research Integration Office, will retain responsibility to fund the Mission Integration and Operations (M&IO) work for BPS investigations.

Program Element	Provider
Space Biology (animal biology, microbiology and open science)	Provider: Various Lead Center: Ames Research Center (ARC) Performing Center(s): ARC, Kennedy Space Center (KSC) Cost Share Partner(s): n/a
Space Biology (plant biology, cell and molecular biology, plant microbiology)	Provider: Various Lead Center: KSC Performing Center(s): ARC, KSC Cost Share Partner(s): n/a
Physical Sciences (fluids, complex fluids and combustion, Fluids Integrated Rack, Combustion Integrated Rack)	Provider: Various Lead Center: Glenn Research Center (GRC) Performing Center(s): Jet Propulsion Lab (JPL), GRC, Marshall Space Flight Center (MSFC) Cost Share Partner(s): n/a
Physical Sciences (materials and biophysics, Materials Science Research Rack)	Provider: Various Lead Center: MSFC Performing Center(s): JPL, GRC, MSFC Cost Share Partner(s): n/a
Physical Sciences (fundamental physics, Cold Atom Lab)	Provider: Various Lead Center: JPL Performing Center(s): JPL, GRC, MSFC Cost Share Partner(s): n/a

Acquisition Strategy

BPS research is competitively selected via NASA Research Announcements (NRAs). Once selected, the principal investigator is paired with a field center that possesses the appropriate expertise to facilitate the implementation of the project.

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INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Independent Review Board (IRB)	Oct 2020	Assess and approve Micro-16 for final science verification testing	Successful	Jan 2021
Performance	JSC Flight Safety Review Panel	Dec 2020	Review and approve FBCE Phase III	TBD	Mar 2021
Performance	IRB	Jan 2021	Flight Readiness Review: Assess and approve Micro-16 for delivery for launch to the ISS	TBD	N/A
Performance	IRB	Mar 2021	System Acceptance Review: Review and approve FBCE for delivery for launch to the ISS	TBD	N/A
Relevance	National Academies of Sciences, Engineering and Medicine	Jan 2023	Provide Decadal Survey recommendations for BPS Division	TBD	2033

AERONAUTICS

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Airspace Operations and Safety Program	96.2	92.0	**104.5**	106.3	108.1	108.1	108.1
Advanced Air Vehicles Program	188.1	211.4	**243.7**	254.6	270.9	288.5	269.5
Integrated Aviation Systems Program	261.5	278.7	**301.5**	305.5	310.7	309.2	349.9
Transformative Aero Concepts Program	121.1	129.7	**148.0**	150.3	147.4	152.4	152.4
Aerosciences Evaluation and Test Capabilities	117.0	116.9	**117.0**	117.0	117.0	117.0	117.0
Total Budget	**783.9**	**828.7**	**914.8**	**933.7**	**954.1**	**975.2**	**996.8**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

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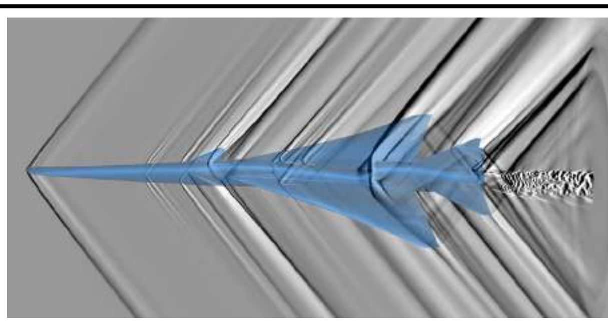
FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Airspace Operations and Safety Program	96.2	92.0	**104.5**	106.3	108.1	108.1	108.1
Advanced Air Vehicles Program	188.1	211.4	**243.7**	254.6	270.9	288.5	269.5
Integrated Aviation Systems Program	261.5	278.7	**301.5**	305.5	310.7	309.2	349.9
Transformative Aero Concepts Program	121.1	129.7	**148.0**	150.3	147.4	152.4	152.4
Aerosciences Evaluation and Test Capabilities	117.0	116.9	**117.0**	117.0	117.0	117.0	117.0
Total Budget	**783.9**	**828.7**	**914.8**	**933.7**	**954.1**	**975.2**	**996.8**
Change from FY 2021			**86.1**				
Percentage change from FY 2021			**10.4%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



This image of the X-59 supersonic aircraft is the product of a complex computer simulation involving supersonic shockwaves. This supersonic aircraft is designed to generate sonic booms that are so quiet that people on the ground will hear them as thumps – if they hear anything at all.

The first "A" in NASA stands for "Aeronautics." NASA Aeronautics explores technologies that reduce aircraft noise and fuel use, get you from gate-to-gate safely and on time, and transform aviation into an economic engine at all altitudes. Aeronautics researchers, engineers, and pilots use world-class NASA facilities to keep U.S. aviation the global leader in safety, efficiency, and innovation.

NASA Aeronautics directly benefits an aviation sector that annually generates more than $1.8 trillion of total U.S. economic activity[1] and the largest positive trade balance of any U.S. manufacturing sector totaling nearly $78 billion.[2] The aviation sector supports more than 10.9 million direct and indirect jobs, including more than one million high-quality manufacturing jobs. In 2019, U.S. airlines carried 926 million passengers and 21.3 billion tons of cargo.[3] The numbers above reflect pre-COVID statistics.

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[1] *"The Economic Impact of Civil Aviation on the U.S. Economy," Federal Aviation Administration, January 2020*
[2] *"Leading Indicators for the U.S. Aerospace Industry," International Trade Administration, March 15, 2019*
[3] *"Preliminary Estimated Full Year 2019 and December 2019 U.S. Airline Traffic Data," U.S. Bureau of Transportation Statistics, April 30, 2020*

AERONAUTICS

Investments in NASA's cutting-edge aeronautics research support U.S. global leadership in emerging capabilities, such as:

- Ultra-efficient transport aircraft built by U.S. industry that move more people and goods with increased sustainability;
- Quiet commercial supersonic flight over land;
- An advanced air mobility system that is all electric, highly-automated, and environmentally friendly to serve public-good missions and move commuters and packages in and around the world's urban and regional areas; and
- A transformed airspace system that is safe and secure and supports all these new vehicles.

Four Transformations for Sustainability, Greater Mobility, and Economic Growth

To ensure that research focuses on enabling this aviation transformation, NASA's Aeronautics Research Mission Directorate (ARMD) guides its efforts with a strategic implementation plan. The plan lays out NASA's approach to addressing growing demand for global air mobility, the increasing demands of energy efficiency and environmental sustainability, and the opportunity for convergence between traditional aeronautical disciplines and technology advances in information, communications, energy, and other rapidly evolving technologies. The strategic implementation plan identifies six research thrusts:

Thrust 1: Safe, Efficient Growth in Global Operations

A modernized air transportation system that allows much greater capacity and operational efficiency, while maintaining safety, is essential for the Nation. ARMD will contribute specific research and technology to support the Federal Aviation Administration's (FAA) transformation of the National Airspace System (NAS) to accommodate more diverse vehicles and increasingly complex operations in a safe and affordable manner.

Thrust 2: Innovation in Commercial Supersonic Aircraft

The U.S. aviation industry has an opportunity to lead the development of a new commercial supersonic transcontinental and intercontinental aircraft that will generate major economic and societal benefits. ARMD will flight test an X-plane that will demonstrate quiet supersonic flight and provide the data needed by regulatory agencies to reassess the regulations that currently ban overland supersonic flight. ARMD will develop technologies that aim to overcome the major environmental and efficiency barriers to a new supersonic market.

Thrust 3: Ultra-Efficient Subsonic Transports

The U.S. aviation industry faces increasing global competition in the subsonic commercial aircraft market, which represents the largest segment of the industry. To remain as the global leader, the U.S. aviation industry strives for competitive advantages in aircraft efficiency, noise, and emissions. ARMD will develop critical technologies to enable revolutionary improvements in these economic and environmental performance measures for subsonic transport aircraft.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

In the coming years, travelers may have the option to utilize flight to carry out their day-to-day activities when vertical lift enables ubiquitous air travel. These systems may also provide revolutionary new capability to public-good missions, like increasing access to medical care. ARMD will develop critical technologies and knowledge to support regulations and standards that enable realization of extensive use of vertical lift vehicles for transportation and services, including new missions and markets.

Thrust 5: In-Time System-Wide Safety Assurance

To realize the projected growth in air traffic, the U.S. will require the ability to identify and reduce safety risks quickly and accurately. ARMD will work with the FAA and industry to create advanced safety capabilities needed in the future air transportation system. These new capabilities will create a safety net that utilizes system-wide information to provide alerting and mitigation strategies in time to address emerging risks.

Thrust 6: Assured Autonomy for Aviation Transformation

Ever-increasing levels of automation are improving the cost and efficiency of aviation and this trend will accelerate in the future. ARMD is leading the research and development of intelligent machine systems capable of operating in complex environments. To pave the way for increasingly autonomous airspace and vehicles, ARMD will explore new human-machine teaming, modeling, measuring, and testing that enable the effective evaluation of autonomous systems in aviation applications.

For more information on the overall Aeronautics strategic plan, go to: http://www.aeronautics.nasa.gov/strategic-plan.htm

The FY 2022 Budget Request for Aeronautics research and development will enhance U.S. competitiveness in the global aviation industry by accelerating the development and maturation of technologies that will enable highly efficient, next generation airliners. Below are three major cross-program initiatives:

NASA is initiating a Sustainable Flight National Partnership (SFNP) to accomplish the aviation community's aggressive climate change agenda and enhance America’s global leadership in aviation. NASA Aeronautics' cost-sharing partnership with U.S. industry will enable the next generation single-aisle transport, expected by the early 2030s, to be a game-changing, ultra-efficient and low-carbon emitting design at least 25 percent more fuel-efficient than today. The SFNP will demonstrate the first-ever high-power hybrid electric propulsion system for large transport aircraft, ultra-high efficiency long and slender wings, advanced composite structures and advanced engine technologies developed from NASA-industry innovation. Its centerpiece will be a full-scale sustainable flight demonstrator X-plane to validate integrated systems and their benefits. This partnership is based on more than a decade of research conducted by NASA in partnership with U.S. industry and universities. The first contracts for electrified powertrain flight demonstrations will be awarded later this year. NASA will advance integrated ground and flight-based technologies for trajectory optimization through every phase of flight, reducing fuel burn, CO_2 emissions, contrail formation and ozone impact. NASA will also work with our nation’s universities to pioneer next generation technologies for a net-zero carbon emissions aviation future. The SFNP is NASA’s response to increasing challenges from international entities to the Nation’s long-term leadership in commercial aircraft manufacturing and will strengthen U.S. industry's ability to take the lead in developing the next generation sustainable subsonic transport. This effort will create good paying jobs which provide the free and fair choice to join a union and bargain collectively. The Advanced Air Vehicle and Integrated Aviation System programs fund and execute NASA's SFNP work.

NASA's Low-Boom Flight Demonstration (LBFD) mission will enable U.S. industry to lead the development of a new commercial supersonic market. The LBFD mission aims to create a body of evidence that enables supersonic flight over land. NASA will flight test an X-plane over communities, collect the noise and community response data, and provide the data to U.S. and international regulators. The LBFD mission is funded and executed by the Advanced Air Vehicle and Integrated Aviation Systems programs.

NASA's Advanced Air Mobility (AAM) mission aims to ensure U.S. leadership in an emerging aviation market that studies have projected to generate an annual market value of $115 billion by 2035. NASA is establishing partnerships with industry to mature AAM system concepts and technologies for safe operations and prepare for National Campaign demonstrations by industry of their vehicles and airspace management technologies. Later this year, NASA Aeronautics will also conduct first flights of its X-57 all-electric aircraft to better inform standards development for smaller air vehicles that will be common to an AAM environment. The Airspace Operations and Safety, Advanced Air Vehicles, and Integrated Aviation Systems programs fund and execute NASA's AAM mission.

EXPLANATION OF MAJOR CHANGES IN FY 2022

NASA increased funding to accelerate and expand key components of the SFNP, including the sustainable flight demonstrator, electrified powertrain flight demonstrations, subsonic technology research, aircraft operations, and university research into net-zero carbon emissions aviation technologies. With the additional funding, NASA will accelerate the first flight of the sustainable flight demonstrator to FY 2026, ensure funding for at least two major electrified powertrain demonstrations, speed up subsonic technology development by up to two years, and enhance air traffic management automation tools that will safely and reliably put future aircraft on flight paths optimized for minimal environmental impact. NASA also increased funding to work with our nation’s universities to pioneer revolutionary, beyond next-generation zero-emissions aircraft concepts and technologies through the University Leadership Initiative. By accelerating and expanding these activities, NASA will ensure that the technologies will be ready by the mid to late 2020s to transition into U.S. industry's next generation single-aisle transport aircraft, as we engage and inspire future generations of diverse scientists and engineers who will lead the nation to a net-zero carbon emissions aviation future.

ACHIEVEMENTS IN FY 2020

Thrust 1: Safe, Efficient Growth in Global Operations

NASA demonstrated a comprehensive suite of tools that improve aircraft arrival, surface movement and departure efficiencies reducing fuel consumption. This demonstration included multiple airlines and Air Traffic Management facilities at the Charlotte Douglas International Airport in Charlotte, NC. The demonstrations are planned for expansion to the Dallas/Fort Worth TX area when air traffic returns to pre-COVID-19 levels.

For additional Thrust 1 achievements, see the Airspace Operations and Safety Program (AOSP) section.

Thrust 2: Innovation in Commercial Supersonic Aircraft

NASA through its contractor, Lockheed Martin, began assembling the X-59 supersonic aircraft, which will demonstrate quiet supersonic flight. NASA developed techniques to collect noise and performance data from the X-59 supersonic aircraft.

For additional Thrust 2 information, see the Advanced Air Vehicle Program (AAVP), Integrated Aviation Safety Program (IASP), and Low-Boom Flight Demonstrator sections.

Thrust 3: Ultra-Efficient Subsonic Transports

In partnership with industry, NASA successfully tested promising technologies that may be incorporated in the U.S. industry's next generation of commercial aircraft. One such technology tested is a truss-braced wing concept. The tests evaluated wing components such as flaps, slats, and other control surfaces.

NASA developed a testing capability at the NASA Electric Aircraft Testbed facility to test megawatt-scale aircraft electrical components and powertrains under flight altitude conditions. This capability is the first of its kind in the world and is critical for understanding how to design hardware that can safely perform at flight altitudes. With this testing and coordination with the FAA and industry, NASA is setting the stage for larger aircraft to use electric propulsion systems.

For additional Thrust 3 information, see the AAVP, IASP, and Transformative Aeronautics Concepts Program (TACP) sections.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

NASA developed vehicle test capabilities, noise analysis tools, and models of human response to fleet noise. For example, NASA demonstrated a multirotor test bed, which is a new wind tunnel test capability for multirotor (up to six rotors) vertical-lift aircraft configurations to gather data on individual rotor loads. This test data will help validate simulations of multirotor systems and improve predictions of multirotor performance.

For additional Thrust 4 information, see the AAVP section.

Thrust 5: In-Time System-Wide Safety Assurance

NASA developed models and metrics for operations of new urban air vehicles that will enable safe integration into the NAS. The models and techniques will reduce the costs and improve effectiveness of autonomous systems which are critical to successfully opening of this new market.

For additional Thrust 5 information, see the AOSP section.

Thrust 6: Assured Autonomy for Aviation Transformation

NASA completed the Unmanned Aircraft Systems Traffic Management Project, which matured capabilities needed to safely manage small, unmanned vehicles in urban airspace. NASA transferred the data analysis and final research products to the FAA.

NASA completed the Unmanned Aircraft Systems (UAS) integration into the NAS Project. NASA provided the final research deliverables on mid-size UAS to the RTCA, a key aviation standards-making organization. This research will be used to develop minimum operating performance standards for Detect and Avoid; and Command and Control systems.

For additional Thrust 6 information, see the AOSP and IASP sections.

Cross-Cutting Capabilities

NASA completed a materials, structures, and manufacturing analysis that prioritized research needs. The priorities aligned resources and investments with the most critical research needs addressing both traditional and emerging aviation markets.

NASA completed acoustic characterization tests of the NASA Glenn Research Center's Low-Speed Wind Tunnel. The tests verified that the improvements reduced tunnel background noise to enable testing of more advanced aircraft engine fan technologies.

For additional cross-cutting capabilities information, see the TACP and Aerosciences Evaluation and Test Capabilities sections.

Hypersonic Capabilities

NASA developed technologies that will enable expanded use of air-breathing hypersonic and re-usable hypersonic flight. One such technology will enable the transition from a turbine engine to a scram or ram jet. NASA conducted experiments to improve the understanding of how to design such systems.

For additional hypersonic capabilities information, see the AAVP section.

WORK IN PROGRESS IN FY 2021

Thrust 1: Safe, Efficient Growth in Global Operations

NASA will complete the Airspace Technology Development Project and transition tools and data to industry and the FAA. NASA will complete a demonstration of a comprehensive suite of tools designed to improve aircraft arrival, surface management and departure efficiencies. The final demonstration includes multiple airlines and several Air Traffic Management facilities in the Dallas/Fort Worth, TX, area.

Thrust 2: Innovation in Commercial Supersonic Aircraft

NASA through its contractor, Lockheed Martin, will complete final assembly and final system checkout of the X-59 supersonic aircraft. The aircraft will then be shipped to the Lockheed Martin facility in Fort Worth, TX to perform the ground proof loads test. NASA will complete delivery of required Government Furnished Equipment including the newly developed systems for flight test instrumentation, power distribution, and external vision.

Thrust 3: Ultra-Efficient Subsonic Transports

NASA will initiate the Sustainable Flight National Partnership to further develop and mature technologies for the next generation commercial aircraft.

NASA plans to award at least two contracts to demonstrate in-flight one-megawatt class electric powertrain systems necessary to achieve hybrid electric propulsion systems for use in the design of large propulsion systems for single aisle transports. These first-generation hybrid electric propulsion systems can increase propulsion efficiency by five percent while also substantially reducing maintenance costs.

NASA will complete preparations and conduct the first flight of the X-57 all-electric aircraft in late 2021. In conjunction with the flight testing, NASA is supporting the development of manufacturing standards for electrified aircraft systems that will help U.S. companies develop more electric aircraft.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

NASA will deliver an initial set of data to help inform standards for electric vertical takeoff and landing vehicles based on testing and evaluations. NASA will engage directly with standard-setting organizations to provide technically sound, valuable data for use in setting industry standards of practice.

Thrust 5: In-Time System-Wide Safety Assurance

NASA will develop techniques that process vehicle operating performance data to predict system safety and evaluate potential mitigations. NASA will demonstrate these predictive techniques for AAM vehicles. NASA will evaluate the use of a tool to actively monitor components while in operation to constrain the behavior of machine learning-enabled system components. This evaluation will enable the FAA to develop requirements for certification of autonomous systems.

Thrust 6: Assured Autonomy for Aviation Transformation

With industry partners, NASA will conduct development tests for the AAM National Campaign (NC) to demonstrate the maturity of key systems and infrastructure. In support of the NC test series, NASA will develop airspace management capabilities to enable Urban Air Mobility (UAM) operations.

Cross-Cutting Capabilities

NASA will complete new combustion models that reduce time and costs of certifying sustainable aviation fuels. This new modeling capability can reduce or eliminate combustor testing of the new fuels saving vendors testing costs and months of time.

NASA will complete a feasibility assessment of a free bonding adhesive that will enable improvements in manufacturing rates of composite airframes. The adhesive uses a joining method with mechanical fasteners to improve the reliability and manufacturability of composite structures.

NASA is returning 12 large wind tunnels to full operation after a long duration shutdown stemming from the COVID-19 pandemic.

Hypersonic Capabilities

NASA will mature new design capabilities to predict performance of turbine-based, combined cycle propulsion systems for use on re-usable hypersonic vehicles. NASA will conduct an experiment with automatic transitioning between a real-time turbojet engine simulator and a dual mode ram jet simulator in a combined cycle engine system. These experiments will establish the control theory and methodology for such a transition. Automated control ensures operability, while maximizing system performance, and successful operation of a combined cycle system.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

Thrust 1: Safe, Efficient Growth in Global Operations

NASA will work with industry partners to demonstrate a cloud-based trajectory management service that allows flight operators to identify efficient departure routes to enable efficient and environmentally sustainable operations, which will reduce fuel burn and emissions.

Thrust 2: Innovation in Commercial Supersonic Aircraft

NASA will conduct a series of airworthiness and flight safety reviews of the X-59 supersonic aircraft. The aircraft will also undergo a series of ground tests including the ground vibration test, engine runs, and taxi tests. After successfully completing these reviews and tests, NASA will conduct the first flight of the X-59 supersonic aircraft in the summer of 2022.

Thrust 3: Ultra-Efficient Subsonic Transports

NASA will conduct design and readiness reviews for each electric powertrain flight demonstration team. For each demonstration team, NASA will conduct a joint NASA-Industry Preliminary Design Review and a Critical Design Review. NASA will evaluate technical design maturity, as well as the ability to conduct the flight demonstrations, according to the contract performance schedule.

NASA will solicit industry proposals for preliminary designs for a Sustainable Flight Demonstrator.

NASA will complete a critical design review of a turbofan engine test to determine the impact of large-scale power extraction from both high-and low-pressure engine spools. This test will ensure that megawatt-class power extraction from turbofan engines will not adversely affect overall electrified aircraft propulsion system performance.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

NASA will develop a reconfigurable UAM electric powertrain test cell. NASA will use a 150-kilowatt electromechanical test rig to assess the performance and reliability of electric propulsion powertrain components. NASA will use this test data to validate predictive models, explore potential failure modes, and develop mitigation strategies. NASA will share this data with regulatory agencies (e.g., FAA) for developing compliance standards.

Thrust 5: In-Time System-Wide Safety Assurance

NASA will evaluate the potential benefits of including non-traditional data sources (e.g., ground data, maintenance data, human performance data) together with traditional safety data to evaluate overall safety risk profiles.

Thrust 6: Assured Autonomy for Aviation Transformation

NASA will partner with industry to develop and evaluate novel air traffic management capabilities for AAM vehicles in flight. These capabilities will undergo rigorous development and testing in a controlled environment before transitioning to field demonstrations.

Based on National Campaign development testing in FY 2021, NASA will share lessons learned and identified gaps with the FAA and industry.

Cross-Cutting Capabilities

NASA will develop advanced design and optimization tools to support multi-disciplinary design, analysis, and optimization for new revolutionary vehicles. These new tools will shorten the design cycle of new vehicles.

NASA will continue to develop and demonstrate efficient, eddy-resolving computational modeling tools that can predict the maximum lift coefficient for the take-off and landing configuration of transport aircraft accurately enough to enable a reduction in the number of flight tests required for aircraft certification.

NASA will improve integration of computational fluid dynamics and experimental testing, which will allow more efficient optimized testing. NASA will assess the accuracy and efficiency of computational analysis compared to testing in the Langley Research Center Unitary Plan Supersonic Wind Tunnel of multiple models having a wide spectrum of aerodynamic prediction challenges.

Hypersonic Capabilities

NASA will develop cutting-edge methods to design hypersonic aircraft and make decisions under uncertainty, using validated models and flight performance predictions. NASA will investigate high-temperature, durable materials to advance state of the art material systems and improve performance. This will enable the hypersonic airbreathing research community to make informed decisions in their designs.

Programs

AIRSPACE OPERATIONS AND SAFETY PROGRAM

AOSP develops and explores fundamental concepts, algorithms, and technologies to increase throughput and efficiency of the NAS safely. The program works in close partnership with the FAA and the aviation community to enable and extend the benefits of NextGen, the Nation's program for modernizing and transforming the NAS to meet evolving user needs; and stablish a vision for future airspace operations. Integrated demonstrations of these advanced technologies will lead to clean air transportation systems and gate-to-gate efficient flight trajectories. The program researches increasingly autonomous aviation systems, including innovation in the management of UAS traffic and other novel aviation vehicles and business models. The program is also pioneering the real-time integration and analysis of data to support system-wide safety assurance, enabling proactive and prognostic aviation safety assurance. The program takes lead responsibility for three of ARMD's Strategic Thrusts:

- Thrust 1: Safe, Efficient Growth in Global Operations;
- Thrust 5: In-Time, System-Wide Safety Assurance; and
- Thrust 6: Assured Autonomy for Aviation Transformation (co-lead).

ADVANCED AIR VEHICLES PROGRAM

AAVP develops the tools, technologies, and concepts that enable new generations of civil aircraft that are safer, more energy-efficient, and have a smaller environmental footprint. The program focuses on enabling major leaps in the safety, efficiency, and environmental performance of subsonic fixed and rotary wing aircraft to meet challenging and growing long-term civil aviation needs; pioneering low-boom supersonic flight to achieve new levels of global mobility; and advancing fundamental hypersonic research while sustaining hypersonic competency for national needs. In partnership with academia, industry, and other Government agencies (e.g., FAA), AAVP pioneers fundamental research and matures the most promising technologies and concepts for transition to system application by the aviation industry. The program works in partnership with the Department of Defense (DoD) to ensure that NASA and DoD vehicle-focused research is fully coordinated and leveraged. The program takes lead responsibility for three of ARMD's Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft;
- Thrust 3: Ultra-Efficient Subsonic Transports; and
- Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles.

INTEGRATED AVIATION SYSTEMS PROGRAM

IASP focuses on experimental flight research and the spirit of integrated, technological risk-taking that can demonstrate transformative innovation. Therefore, the program complements both AOSP and AAVP by conducting research on the most promising concepts and technologies at an integrated system-level. The program explores, assesses, and demonstrates the benefits of these potential technologies in a relevant environment. The program supports the flight research and demonstration needs across all six ARMD Strategic Thrusts, but it shares lead responsibility with AOSP for the following Strategic Thrust:

- Thrust 6: Assured Autonomy for Aviation Transformation (co-lead).

TRANSFORMATIVE AERONAUTICS CONCEPTS PROGRAM

TACP cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation and harnesses convergence in aeronautics and non-aeronautics technologies to create new opportunities in aviation. The program's goal is to demonstrate initial feasibility of internally and externally originated concepts to support the discovery and initial development of new, transformative solutions for all six ARMD Strategic Thrusts. The program provides flexibility for innovators to explore technology feasibility and provide the knowledge base for transformational aviation concepts by using sharply focused activities. The program solicits and encourages revolutionary concepts, creates the environment for researchers to become immersed in trying out new ideas, performs ground and small-scale flight tests, allows failures and learns from them, and drives rapid turnover into new concepts. The program also supports research and development of major advancements in cross-cutting computational tools, methods, and single discipline technologies to advance the research capabilities of all aeronautics programs.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

The aerosciences ground test research capabilities (e.g., facilities, systems, workforce, and tools) necessary to develop future air and space vehicles require efficient and effective investment, use, and management of NASA's suite of world-class wind tunnels. Efforts in this area preserve and enhance those specific ground test capabilities that are necessary to achieve the missions. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels and propulsion test facilities at the Ames Research Center in Mountain View, CA, the Glenn Research Center in Cleveland, OH, and the Langley Research Center in Hampton, VA. These test facilities and capabilities also serve the needs of non-NASA users. NASA also offers research customers high-quality data that accurately reflect the simulated test environment and the interactions of test articles in those test environments in conjunction with the ground experimentation capabilities. Furthermore, NASA expertise helps ensure safe and successful use of the assets and high-quality of the research outcomes. The project is cross-cutting and supports all ARMD Strategic Thrusts as well as other Agency efforts and those of key industry partners.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**96.2**	**92.0**	**104.5**	**106.3**	**108.1**	**108.1**	**108.1**
Change from FY 2021			**12.5**				
Percentage change from FY 2021			**13.6%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

In collaboration with Boeing, NASA demonstrated increasingly autonomous capabilities for digital trajectory negotiation in flight tests of the ecoDemonstrator aircraft. This work, completed in 2020, will help to establish research requirements for enabling autonomous vehicle operations in the national airspace.

The U.S. air transportation system is one of the most efficient and safest systems in the world. NASA has substantially contributed to the Federal Aviation Administration (FAA)-led NextGen modernization effort that will meet growing air traffic demand by enabling efficient passage through the increasingly crowded skies. However, there are additional opportunities for reducing fuel burn, aircraft emissions, and environmental impacts through increased operational efficiency.

Moreover, the integration of new vehicles and types of missions into the National Airspace System (NAS) will require advanced concepts and capabilities to efficiently and safely accommodate the volume, diversity, and complexity of operations in a digitally integrated environment.

Advanced automation technologies are foundational for safe and efficient operations in this complex and dynamic environment. This automation must work in an integrated fashion across multiple domains and stakeholders and in harmony with human operators. NASA is working with FAA to develop a long-term vision for the future NAS and looking to ensure that the system will accommodate these diverse and increasingly complex operations in a safe and affordable manner for service providers, vehicle operators, passengers, and cargo. In the coming years, the sustained, integrated efforts of the FAA and its many stakeholders will systematically transform the systems and processes of today's NAS to accommodate these new operations. NASA will play a critical role in this transformation through its research and development of autonomous technologies for aircraft as well as tools and technologies for managing the airspace to support increasingly diverse operations.

The Airspace Operations and Safety Program (AOSP) performs research and technology to develop transformational air traffic management and operational safety concepts. These technologies benefit the public by increasing capacity, decreasing fuel consumption, and reducing the total cost of air transportation. Increased operational efficiency at the vehicle-, fleet-, and system-levels reduces fuel burn

AIRSPACE OPERATIONS AND SAFETY PROGRAM

and emissions; and integrated ground and flight-based technologies will enable trajectory optimization through every phase of flight. With the FAA, industry, and academic partners, AOSP conceives, develops, and demonstrates technologies to improve the safety of current and future aircraft systems that will operate in the NAS. Furthermore, the program develops advanced technologies for a service-oriented and federated NAS architecture to enable seamless integration of emergent vehicles (e.g., unmanned aircraft systems [UAS] and advanced air mobility [AAM] vehicles) with present-day aircraft. AOSP also works with other Aeronautics Research Mission Directorate (ARMD) programs to define safe NAS operational requirements for the next generation of vehicles, mature new transformative seedling concepts, and demonstrate integrated systems. AOSP directly supports three of the ARMD Strategic Thrusts:

- Thrust 1: Safe, Efficient Growth in Global Operations
- Thrust 5: In-Time System-Wide Safety Assurance
- Thrust 6: Assured Autonomy for Aviation Transformation

EXPLANATION OF MAJOR CHANGES IN FY 2022

With the successful completion of the Unmanned Aircraft Systems Traffic Management (UTM) Project in FY 2021, AOSP will focus on two projects that work on: transformation of the NAS for sustainable aviation operations; development of in-time, system-wide safety management capabilities; and requirements for the safe integration of increasingly automated vehicles and operations into the NAS.

As part of NASA's initiation of the Sustainable Flight National Partnership, AOSP will begin new activities to improve aircraft operations. These new activities will build upon NASA-developed trajectory management capabilities to provide integrated trajectories and operations tailored to minimize fuel burn, noise, and emissions for reduced environmental impact. This effort will also define requirements for advanced flight deck capabilities to improve system predictability and trajectory compliance. By expanding these activities, NASA will ensure that the technologies will be ready to support the integration of U.S. industry's next generation single-aisle transport aircraft.

At the end of each achievement identified in this document, there is a mapping to link it to the related Strategic Research Thrust and Program Element.

ACHIEVEMENTS IN FY 2020

- NASA completed preparations for a field demonstration of efficient surface and departure operations (ATM Technology Demonstation-2 [ATD-2]) at the Fort Worth Air Route Traffic Control Center and the Terminal Radar Approach Control and Air Traffic Control Tower facilities at the Dallas/Fort Worth and Dallas Love Field airports. The Airspace Technology Demonstrations (ATD) Project provided deliverables to the FAA research transition team. Field test data collection will continue into FY 2021 due to delays from the COVID-19 pandemic. The project maintained its support of the ATD-2 system at the Charlotte Douglas International Airport jointly with FAA for continued demonstrated reduction of fuel, CO2, engine runtime, and crew time costs. (Thrust 1/ATD)
- NASA completed data analysis from a UAS traffic management demonstration of Technical Capability Level 4 and transferred final technical products to FAA Research Transition Team working groups focused on: Concepts, Data Exchange, and Architecture; Sense and Avoid; and Communications and Navigation. The Unmanned Aircraft Systems Traffic Management (UTM)

Project supported the FAA for the UTM Pilot Program and provided data to standards organizations. (Thrust 6/UTM)

- NASA developed models and metrics that characterize the safe operations of AAM vehicles and that allow the safe integration and operation of these emergent users into the NAS. In addition, NASA analyzed the safety of overall system designs that enable autonomy and the effectiveness of their backup strategies in the event of automation failure. Building on recent studies with industry partners, NASA developed additional tools and techniques to reduce the costs and enable the verification of autonomous systems. (Thrust 5/System Wide Safety [SWS])
- In collaboration with external partners, NASA conducted a human-in-the-loop evaluation to assess AAM operations and airspace integration suitable for ARMD's AAM National Campaign demonstrations. In one such partnership, NASA collaborated with Uber to develop safe and efficient air transportation in highly populated U.S. cities. AAM operations modeling and simulation enabled establishment of the concept of operations for these emergent vehicles, new airspace procedural requirements, and new automation technologies. (Thrust 6/Air Traffic Management eXploration [ATM-X])
- NASA conducted a flight test on Boeing's ecoDemonstrator aircraft to determine requirements for digital trajectory negotiations, data exchange, and concepts of operations. Test results demonstrated automated digital advisories sent from a ground management system to the flight deck, showing a complete digital connection for aircraft trajectory negotiation. This successful test will help establish future research requirements for autonomous operations in the NAS. (Thrust 6/ATM-X)

WORK IN PROGRESS IN FY 2021

- NASA will conduct the ATD-2 Phase 3 demonstration at the Fort Worth Air Route Traffic Control Center and the Terminal Radar Approach Control and Air Traffic Control Tower facilities at the Dallas/Fort Worth and Dallas Love Field airports. The demonstration will also involve American Airlines and Envoy Air facilities at Dallas/Fort Worth and Southwest Airlines facilities at Dallas Love Field. Phase 3 will be a high-fidelity demonstration of all Integrated Arrival/Departure/Surface system capabilities. This demonstration aims to validate the use of strategic surface metering during periods of significant demand/capacity imbalance to reduce fuel burn and emissions for more sustainable aviation operations. (Thrust 1/ATD)
- After providing ATD-2 field demonstration final deliverables and research documentation to the FAA Research Transition Team, NASA will formally close out the ATD Project. With this project close-out, NASA's ATD-1, ATD-2, and ATD-3 contributions to the FAA's NextGen effort will be complete. NASA technologies deployed as part of FAA's NextGen will help airlines realize significant operational benefits and reduce fuel consumption. (Thrust 1/ATD)
- NASA completed the final closeout of the UTM Project. NASA and FAA will issue a joint final report of the UTM Pilot Program. (Thrust 6/UTM)
- NASA will develop and deliver airspace management capabilities to enable AAM operations and airspace integration suitable for the AAM National Campaign demonstrations. This airspace and traffic management capability for AAM vehicles is critical to the demonstrations. (Thrusts 1 and 6/ATM-X)

AIRSPACE OPERATIONS AND SAFETY PROGRAM

- NASA will evaluate a tool that actively monitors machine learning-enabled components while in operation to constrain the overall behavior of an autonomous system. This evaluation will enable the FAA to develop requirements for certification of autonomous systems. (Thrust 6/SWS)
- NASA will develop techniques that process relevant vehicle and operational environment information to monitor and make predictions about system safety in order to evaluate potential courses of action. This research is critical to the development of an advanced in-time system-wide safety assurance system that would enable automated monitoring, assessment, and mitigation of risks. (Thrust 5/SWS)

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- NASA will deliver draft evidence and recommendations to industry standards committees and safety and regulatory partners on the use of run-time monitoring for automated components and the robustness of remote operators as a backup in case of automation failure. (Thrust 6/SWS)
- NASA will evaluate the potential benefits of including non-traditional data sources, such as maintenance data and/or human performance data, together with traditional aviation safety data to evaluate overall risk. (Thrust 5/SWS)
- Partnering with industry, NASA will conduct a human-in-the-loop simulation to address lost communication link and contingency management requirements to support remotely operated and increasingly autonomous vehicles. (Thrust 1/ATM-X)
- NASA will enable efficient, environmentally sustainable operations by working with industry partners to demonstrate a cloud-based trajectory management service that allows flight operators to identify efficient departure routes. (Thrust 1/ATM-X)
- NASA will partner with industry to develop and evaluate novel air traffic management capabilities for AAM vehicles in flight. These capabilities will undergo rigorous validation in a controlled environment before transitioning to field demonstrations. (Thrust 6/ATM-X)
- In partnership with FAA, NASA will complete a joint document that describes characteristics of NAS operations in 2045. The principal stakeholders who plan to operate and provide services in the future NAS will help to inform the creation of this document. (Thrust 1/ATM-X)

Program Elements

AIR TRAFFIC MANAGEMENT – EXPLORATION (ATM-X)

The Air Traffic Management - eXploration (ATM-X) Project will transform the air traffic management system to accommodate the growing demand of new entrants with new mission requirements while also allowing established, large commercial aircraft operators to fly more user-preferred routes with improved predictability. The project is exploring challenging use cases in an open airspace management system architecture to establish key performance parameters and prioritize technical challenges. An example exercise is the definition of requirements for high-density vertical lift vehicle operations for AAM. ATM-X will provide an early demonstration of emerging market operations by simulating higher levels of industry-provided services to validate the potential for more rapid modernization by incorporating innovations at "industry" speeds. ATM-X is developing airspace requirements for managing AAM aircraft for ARMD's AAM National Campaign.

The ATM-X Project is focused on demonstrating, through an open architecture approach, that integration of air traffic technologies, system-wide data use, advances in human-machine teaming, and increasingly autonomous decision-making will provide comprehensive situational awareness, coordinated decision-making, and improved disruption management. This demonstration will incorporate advanced, machine-learning and artificial intelligence capabilities for air traffic management and contingency management that will enable flexible, user-preferred, predictable, and robust airspace operations. ATM-X is also exploring advanced trajectory management services and advanced flight deck capabilities to enable efficient, environmentally sustainable operations. The project will validate and transfer key concepts and technologies to FAA and industry stakeholders to enable transformation of the NAS.

SYSTEM-WIDE SAFETY (SWS)

The System-Wide Safety (SWS) Project develops tools, methods, and technologies to enable capabilities envisioned by ARMD's Strategic Thrust 5 (In-Time System-Wide Safety Assurance). The SWS Project performs research to explore and understand the impact on safety of the complexity introduced by technology advances, particularly those aimed at improving the efficiency of flight, broadening access to airspace, and expanding the types of service provided by air vehicles. The project also develops and demonstrates innovative solutions that enable the aviation transformation envisioned by ARMD through proactive mitigation of risks in accordance with target levels of safety. The following are drivers of increased system safety awareness:

- increased access to relevant data;
- integrated analysis capabilities;
- improved real-time detection and alerting of hazards at the domain-level;
- decision support; and,
- in some cases, automated mitigation strategies.

The SWS Project also addresses the need, identified in Strategic Thrusts 1 and 6, for safety-related advances in methods used for the verification and validation of machine learning-enabled components and advanced, increasingly autonomous systems.

Program Schedule

Date	Significant Event
Feb 2021	UTM – Completed final concept of operations and project closeout.
Sep 2021	SWS – Evaluate costs and benefits given a demonstrated automated evaluation of safety risk considering multiple simultaneous events and utilizing non-traditional data. ATM-X – Conduct a simulation and/or flight with an external partner to understand interacting operations using a service-oriented UTM-inspired initial AAM airspace management system that can be used in ARMD's National Campaign with air vehicles.
Sep 2021	ATD – Complete final research documentation of the ATD-2 field demonstration and conduct project closeout.

Date	Significant Event
Sep 2022	SWS – Complete simulations and flight tests of automated in-flight safety/risk assessment with alternate proactive and fail-safe mitigation methods. ATM-X – Provide data from a human-in-the-loop simulation to address lost communication link and contingency management requirements to support remotely operated and increasingly autonomous vehicles. This simulation will inform work of a standards-development group (RTCA SC-228) on lost link procedures. ATM-X – Conduct an initial simulation of trajectory management services to enable efficient, environmentally sustainable operations.

Program Management & Commitments

Program Element	Provider
Air Traffic Management - Exploration (ATM-X)	Provider(s): Ames Research Center (ARC), Langley Research Center (LaRC), Glenn Research Center (GRC) Lead Center: ARC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, Boeing, General Electric (GE), Uber, American Airlines, Port Authority of New York and New Jersey, German Aerospace Center (DLR)
System-Wide Safety (SWS)	Provider(s): ARC, LaRC, GRC Lead Center: LaRC Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): FAA, Department of Homeland Security, Department of Defense (DoD) Naval Medical Research Unit, DoD Air Force Research Laboratory, National Research Council, Networking and Information Technology Research and Development Program, Defense Advanced Research Projects Agency, MITRE, Collins Aerospace, Honeywell, Boeing Flight Services, GE Global Research, American Airlines, Southwest Airlines, Swiss International Airlines, easyJet, Denver International Airport, Commercial Aviation Safety Team, Unmanned Aircraft Safety Team, Association for Unmanned Vehicle Systems International, RTCA, French Aerospace Lab (ONERA), DLR

Acquisition Strategy

AOSP research and technology spans from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a wide array of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages teaming among large companies, small businesses, and universities.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

MAJOR CONTRACTS/AWARDS

AOSP awards multiple smaller contracts, which are generally less than $5 million and widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance (Annual)	Expert Review	Oct 2020	The 12-month review is a formal independent peer review. Experts from other Government agencies report on their assessment of technical and programmatic risk and/or program weaknesses.	Determined that the projects made satisfactory progress in meeting technical challenges and all annual performance indicators.	Oct 2021

ADVANCED AIR VEHICLES PROGRAM

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**188.1**	**211.4**	**243.7**	**254.6**	**270.9**	**288.5**	**269.5**
Change from FY 2021			**32.3**				
Percentage change from FY 2021			**15.3%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Pictured above is NASA's High-lift Common Research Model in the NASA Langley Research Center's 14-by-22-foot Subsonic Tunnel. Acoustic testing started in October 2020.

The Advanced Air Vehicles Program (AAVP) develops knowledge, technologies, tools, and innovative concepts to enable safe new aircraft that will fly faster, cleaner, and quieter and use fuel far more efficiently than in the past. All major modern U.S. aircraft incorporate NASA research and technology. The type of research performed by AAVP will prime the technology pipeline, enabling continued U.S. leadership, competitiveness, and high-quality jobs in the future. These advanced, integrated technologies and capabilities improve vehicle performance and intrinsic safety by reducing fuel consumption, noise, and emissions. Fuel efficiency and environmental factors will play an increasingly significant role as the aviation market grows in capacity. AAVP develops a broad range of technologies that help ensure continued U.S. industrial leadership that will benefit both the economy and the environment. Across the program, NASA will continue to engage partners from industry, academia, and other government agencies to maintain a broad perspective on technology solutions to these challenges, to pursue mutually beneficial collaborations, and to leverage opportunities for effective technology transition. AAVP directly supports three of the ARMD Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft
- Thrust 3: Ultra-Efficient Subsonic Transports
- Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

EXPLANATION OF MAJOR CHANGES IN FY 2022

As part of NASA's initiation of the Sustainable Flight National Partnership, AAVP will accelerate development of key subsonic technologies including hybrid thermally efficient core engines, high rate composite manufacturing, transonic truss-braced wing aircraft designs, and model-based systems engineering efforts. By accelerating and expanding these activities, NASA will ensure that the technologies will be ready by the mid- to late-2020s to transition into U.S. industry's next generation single-aisle transport aircraft.

At the end of each achievement identified in this document, there is a mapping to link it to the related Strategic Research Thrust and Program Element.

ACHIEVEMENTS IN FY 2020

- NASA provided a suite of prediction tools to support timely and accurate validation of the noise levels produced by the Low-Boom Flight Demonstrator (LBFD) aircraft, the X-59. NASA also verified the suitability of the tools as a Pre-Flight Capability prior to the LBFD aircraft acoustic validation. NASA led a sonic boom prediction workshop to share these efforts in noise prediction with the international community. (Thrust 2/Commercial Supersonic Technology [CST])
- NASA completed the development of models for predicting exterior pressure loads, building structural vibrations, and indoor acoustic fields caused by sonic booms. NASA also completed development of models of the human response to sonic boom noise in both indoor and outdoor environments and quantified the effects of the atmosphere on sonic booms. These predictive models will help in defining the methodologies and test protocols for sonic boom community response field studies. (Thrust 2/CST)
- NASA developed a computational capability to predict icing in turbofan engines flying in ice crystal environments. This tool provides industry with a physical understanding of the core icing phenomenon and provides a means to address certification of current and future designs through analysis tools. (Thrust 3/Advanced Air Transport Technology [AATT])
- NASA used simulations to predict the acoustic benefit of quiet high-lift technology concepts using active flow control techniques to reduce aircraft noise. Simulations also increased test efficiency and defined the placement of instrumentation during the early FY 2021 wind tunnel testing in the 14-foot x22-foot Wind Tunnel. (Thrust 3/AATT)
- NASA completed a suite of technology development activities that can potentially increase the aspect ratio of cantilever aircraft wings by 50 percent and braced aircraft wings by 100 percent. These technologies, called Higher Aspect Ratio Optimal Wing, can dramatically increase aircraft efficiency and reduce fuel burn. (Thrust 3/AATT)
- In partnership with industry, NASA developed new compressor designs and technologies, which advances this critical component of the next generation of fuel-efficient turbofan engines. (Thrust 3/AATT)
- NASA developed a capability at the NASA Electric Aircraft Testbed (NEAT) facility to test megawatt-scale aircraft electrical components and powertrains under flight altitude conditions. This capability will enable testing of these types of components in future aircraft systems, while ensuring safe and efficient operations under flight conditions. (Thrust 3/AATT)
- NASA conducted testing that identified initial human response metrics for optimized vertical flight vehicle designs and operations. Information on how humans respond to different noise sources will guide design of low noise rotors and advanced vertical-lift air vehicle configurations. (Thrust 4/Revolutionary Vertical Lift Technology [RVLT])

ADVANCED AIR VEHICLES PROGRAM

- NASA demonstrated the Multirotor Test Bed (MTB), which is a new wind tunnel test capability for multirotor (up to six rotors) vertical-lift aircraft configurations to gather data on individual rotor loads. Data from MTB testing will help to validate simulations of multirotor systems and eventually lead to better predictions of multirotor performance. (Thrust 4/RVLT)
- NASA demonstrated an analysis tool to assess the collective noise of a fleet of Advanced Air Mobility (AAM) vehicles. This tool will help the AAM community better understand the cumulative noise impacts of AAM vehicle operations and will help establish a consistent assessment process for evaluation of noise impacts by both NASA and external users. (Thrust 4/RVLT)
- NASA implemented calculations for the noise of a rotor blade passing through air into the premier NASA acoustic prediction software for use by NASA and many external users. The addition of this type of noise improves the accuracy of calculations of the noise generated by vehicles that have multiple rotors. (Thrust 4 /RVLT)
- NASA used internal AAM reference vehicle models to simulate various crash scenarios with different impact surfaces to determine occupant injury potential. These simulations highlighted energy-absorbing vehicle structures and design changes that can reduce occupant injury. (Thrust 4/RVLT)
- NASA collaborated with the Federal Aviation Administration (FAA) to conduct a community workshop on crashworthiness of AAM electric vertical-lift vehicles. The workshop was the first of several planned workshops to inform the community of vehicle design choices that can mitigate occupant injury during impacts. (Thrust 4/RVLT)
- NASA developed and integrated analysis tools for aircraft propulsion, electrical power, and thermal management to enable multi-disciplinary design and analysis of turboelectric, hybrid-electric, and all-electric vertical lift aircraft. (Thrust 4/ RVLT)
- NASA developed a new icing test rig designed to collect data to validate analyses that predict ice formation on multirotor vehicles. NASA expects that AAM vehicles will have the ability to operate across the globe and to locations where surviving an inadvertent encounter with icing conditions is a major concern. (Thrust 4/RVLT)
- NASA developed and documented new approaches to perform Uncertainty Quantification (UQ) model validation by applying UQ analysis to computational modeling and hypersonic aerodynamic, aerothermodynamic, and propulsion ground test data for hypersonic applications. Improved UQ helps identify the most fruitful areas for targeted investment and can lead to higher performing and/or more robust hypersonic vehicle designs. (Hypersonic Technology [HT])
- In order to meet performance metrics for high-Mach vehicle concepts with horizontal take-off and landing, a Turbine-Based Combined Cycle (TBCC) propulsion system capable of propelling an aircraft from the runway to hypersonic speeds using state-of-the-art technologies, an off-the-shelf turbine, and no thrust augmentation (other than the turbine afterburner) was designed. This design will also serve as a point of departure for a baseline design for a commercial hypersonic vehicle. (HT)
- NASA completed the Advanced Composites project, which produced accurate strength and life prediction tools, rapid inspection methodologies, and efficient manufacturing processes for complex composite structures. This project also studied defect formation to help manufacturers use software to solve predicted defects prior to production. The technologies developed are applicable directly to high-performance composite structures for commercial and military aircraft, urban air mobility, space launch vehicles and satellites. More generally, the technologies will also support composite structure

applications in automobiles, wind turbines, and naval ships and submarines (e.g., superstructures, bulkheads, propellers). (Thrust 3)

WORK IN PROGRESS IN FY 2021

- NASA will conduct a sonic boom wind tunnel test using a 1.6 percent scale model of the LBFD. The wind tunnel test will support development and validation of tools and inform researchers how to best measure X-59 flight noise. (Thrust 2/CST)
- NASA will identify and procure the noise measurement systems and prepare plans for the Low-Boom Flight Demonstrator Validation in support of the Low-Boom Flight test. (Thrust 2/CST)
- NASA will build a contractor support team with subject matter experts to support planning and testing with the LBFD and continue engaging the international community on standards and certification procedures for en route noise. (Thrust 2/CST)
- NASA will conduct wind tunnel tests on a 10 percent scale aircraft research model that includes high-lift features and "common" attributes that enable it to test at multiple facilities across the U.S. The "High Lift Common Research Model" will help establish the feasibility of quiet high-lift technology concepts using advanced flow control techniques. These technologies will fill the gaps between aircraft wing leading- and trailing-edge flaps and slats, which produce a large fraction of aircraft noise on approach. This research will help advance wing designs integral to future quiet aircraft. (Thrust 3/AATT)
- NASA will complete testing and analysis of components for advanced, fuel-efficient turbofan engines developed in partnership with industry, including advanced compressor components and high-temperature disks and seals. These technologies are critical for advancing small-core turbofan engines with higher engine bypass and pressure ratios to improve fuel efficiency. (Thrust 3/AATT)
- NASA will demonstrate a testing capability at the NASA NEAT facility to test megawatt (MW)-scale aircraft electrical powertrains and flight-weight, flight-like inverters under flight altitude conditions. This test will be the first of a MW-class electrified powertrain under conditions representing a flight altitude of 30,000 feet. The test will also establish the practicality of employing these types of components in future aircraft systems while ensuring safe and efficient operations under flight conditions. (Thrust 3/AATT)
- NASA will complete an assessment of noise reduction technologies, including advanced aircraft wing slats/flaps and turbine engine acoustic liners, that target noise reduction of approximately 25 percent from existing technology. These technologies will benefit the aviation industry by ensuring quiet operation of aircraft near airports. (Thrust 3/AATT)
- NASA will calculate multirotor vehicle noise for AAM by modeling the individual rotors and their interactions with the airframe. These interactions are a major contributor to aircraft noise. (Thrust 4/RVLT)
- NASA will establish a test environment for demonstration and improvement of reliability for electric powertrain configurations applicable to AAM vertical-lift vehicles. (Thrust 4/RVLT)
- NASA will conduct experiments of hovering rotors to provide detailed aerodynamic data for computational method validation. Establishing an accurate hover performance prediction capability

for AAM is important because the hover performance usually establishes the size of the vehicle. (Thrust 4/RVLT)

- NASA will measure the noise of AAM vehicles during flight tests. This data will validate prediction methods and establish baseline noise levels for AAM vehicles. (Thrust 4/RVLT)
- NASA will study AAM vehicle ride quality by exploring the trade-offs of vehicle handling qualities and passenger acceptability. NASA will conduct a flight simulation of a NASA multirotor reference vehicle sized to carry six passengers for a reference mission of 75 miles. This flight simulation will explore the vehicle handling qualities and assess how the vehicle's motion can affect passenger ride comfort. The AAM market success will be dependent on repeat passengers, and passengers will expect comfortable rides. (Thrust 4/RVLT)
- NASA will study AAM vertical-lift vehicle crashworthiness with the emphasis on occupant protection to address a fundamental safety issue for AAM vehicles and provide information to standards organizations. (Thrust 4/RVLT)
- NASA will conduct multiple wind tunnel experiments of different single and multirotor configurations, providing data to validate several computational methods. (Thrust 4/RVLT)
- NASA will engage directly with standard-setting organizations to provide a broad range of technically sound, valuable data for use in setting industry standards of practice for AAM vehicles, including areas of aircraft noise measurement and modeling (e.g., high-voltage power quality, aircraft icing). (Thrust 4/RVLT)
- NASA will experiment with automatically transitioning between a real-time turbojet engine simulator and a dual mode ram jet simulator in a combined cycle engine system. These experiments will establish the control theory and methodology for such transition. Automated control, which ensures operability while maximizing system performance, is required for successful operation of a combined cycle system. (HT)
- NASA will apply calibrated models to predict hypersonic flight test performance with quantified uncertainty. NASA will develop an approach to optimize design, with quantified uncertainties, and then apply this approach to a TBCC propulsion component. This uncertainty quantification (UQ) methodology will be available for use on future design and analysis efforts. (HT)
- NASA will implement its calibrated UQ methodology, along with Computational Fluid Dynamics (CFD) design and analysis, to design a TBCC propulsion component. Fabrication and ground testing of the component will occur in the 4-foot x 4-foot Unitary Plan Wind Tunnel. Performing CFD predictions before high speed testing provides an initial assessment of test data accuracy. (HT)
- NASA will provide experiments on surface roughness effects on boundary layer transition for two sounding rocket flights by the Air Force Office of Scientific Research. Using these flights, NASA will study hypersonic boundary layer transition on complex, three-dimensional geometries, which will reduce vehicle-level uncertainty and maximize performance. (HT)
- The new High-Rate Composite Aircraft Manufacturing (HiCAM) Project will build on the successful Advanced Composites Project work to increase airframe structure production rates for aircraft entering service in the 2030s. NASA will set project requirements and screen technologies for future development. (Thrust 3/HiCAM)
- The new Hybrid Thermally Efficient Core (HyTEC) Project will build on small core gas turbine work previously pursued in the AATT Project to accelerate the development of highly efficient turbofan

engine technologies. NASA will set project requirements and select small core technologies for initial development and will complete Preliminary Design Review of a turbofan engine test to determine the impact of large-scale power extraction from both high- and low-pressure engine spools. (Thrust 3/HyTEC)

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- NASA will validate its prediction tools in order to use them for the X-59 validation process. These tools will predict noise values measured during future flights. (Thrust 2/CST)
- NASA will complete a Critical Design Review (CDR) of a turbofan engine test to determine the impact of large-scale power extraction from both high- and low-pressure engine spools. This test will ensure that Megawatt-class power extraction from turbofan engines will not adversely affect overall Electrified Aircraft Propulsion (EAP) system performance. (Thrust 3/HyTEC)
- NASA will use test data to demonstrate that high-lift airframe noise reduction concepts successfully reduced noise by at least 4 decibels with minimal impact on weight and performance. (Thrust 3/AATT)
- In partnership with industry, NASA will conduct buffet testing of a Transonic Truss-Braced Wing (TTBW) design to help understand the aerodynamics of the concept. This will advance the technology readiness level of the TTBW for potential flight testing and future market opportunities. (Thrust 3/AATT)
- In partnership with industry, NASA will demonstrate feasibility of fault management devices for Megawatt-class, Kilovolt-class electrified aircraft powertrains. This will overcome one of the key challenges to certification of future large-scale electrified aircraft. (Thrust 3/AATT)
- NASA will establish a reconfigurable AAM electric powertrain test cell. NASA will use a 150-kilowatt electromechanical test rig to assess the performance and reliability of electric propulsion powertrain components. NASA will use this test data to validate predictive models, explore potential failure modes, and develop mitigation strategies. NASA will share this data with regulatory agencies, such as the FAA, for developing compliance standards. (Thrust 4/RVLT)
- NASA will demonstrate improved noise and performance tools for evaluating AAM configurations, providing the AAM community with design tools and guidelines that will increase the likelihood that new aircraft designs will meet noise goals before the development and construction of a full-scale vehicle. (Thrust 4/RVLT)
- NASA will complete a noise assessment methodology for evaluating the noise impact of AAM fleet operations. NASA will provide this methodology to government and industry for use in minimizing the overall noise impacts of AAM operations. (Thrust 4/RVLT)
- NASA will develop cutting-edge methods to design hypersonic aircraft while accounting for predictive uncertainty, using validated models and flight performance data. NASA will further investigate high temperature, durable materials to advance state of the art material systems and improve performance. This will enable the hypersonic, airbreathing research community to make informed decisions in their designs. (HT)

- NASA will select an initial set of high-rate composite manufacturing technologies and conduct experimental evaluations at the coupon and element level, in preparation to down-select technologies for further development at the larger-scale structural panel level. (Thrust 3/HiCAM)

Program Elements

ADVANCED AIR TRANSPORT TECHNOLOGY (AATT)

The Advanced Air Transport Technology project enables revolutionary advancements in future aircraft performance. Research explores solutions to advance knowledge, technologies, and concepts, enabling major steps in energy efficiency and environmental compatibility and resulting in reductions to fuel burn, harmful emissions, and noise around airports. The research also benefits U.S. industrial competitiveness in the subsonic transport aircraft market, as well as, potentially opening new markets for U.S. entrants in the regional jet and smaller size classes. The knowledge gained from this research in the form of experiments, data, system studies, and analyses, is critical for conceiving and designing more efficient, quieter aircraft. Advanced air transport research directly supports ARMD Strategic Thrust 3 and focuses on developing advanced technologies and tools for future generations of commercial transport – including the emerging area of electrified aircraft propulsion and the supporting engine core research needed to develop new engines that will ultimately power the new vehicles. Although this project focuses on the long-term technology timeframe, it also contributes to both near- and mid-term development by demonstrating interim technology advancements.

REVOLUTIONARY VERTICAL LIFT TECHNOLOGY (RVLT)

The Revolutionary Vertical Lift Technology project develops, demonstrates, and validates tools, technologies, and flight operations methods that reduce vertical take-off and landing (VTOL) aircraft noise and improve safety. Thereby, the project enables expanded use of VTOL aircraft in an integrated airspace environment. The unique ability of vertical lift vehicles to hover has significant applications in the civil market for human and cargo transportation and delivery systems as evidenced by the emerging AAM industry. Additionally, advanced vertical lift technologies and capabilities are directly relevant to vehicles for inspection and surveillance missions, oil and gas exploration, disaster relief, and many more critical operations. RVLT research advances technologies that will increase safety and reduce noise and annoyance to overcome significant barriers for the emergence of a new AAM market. To accomplish this research, NASA uses advanced computer-based, multi-fidelity prediction methods, unique NASA facilities, and state-of-the-art experimental techniques. RVLT considers current and future vertical lift vehicles of many classes and sizes, ranging from small-unmanned configurations to configurations that are viable as inter- and intra-city transportation. The RVLT project primarily supports ARMD Strategic Thrust 4 and the Advanced Air Mobility Mission.

COMMERCIAL SUPERSONIC TECHNOLOGY (CST)

Supersonic vehicle research includes tools, technologies, and knowledge that will help eliminate today's technical barriers to practical, commercial supersonic flight. These barriers include sonic boom noise, supersonic aircraft fuel efficiency, airport community noise, high-altitude emissions, vehicle aeroservoelastic design, supersonic operations, and the ability to design vehicles in an integrated, multidisciplinary manner. The Commercial Supersonic Technology (CST) project directly supports ARMD Strategic Thrust 2: Innovation in Commercial Supersonic Flight. CST leverages the X-59 Low-Boom Flight Demonstrator to gather data on the human responses to low-level sonic booms. This human community response data informs national and international regulatory organizations' efforts to define certification standards that commercial aircraft manufacturers can follow to create new supersonic aircraft markets. In preparation for the use of the X-59, CST research will establish the necessary approaches and techniques for objectively measuring the level of supersonic overflight noise acceptable to communities living near future commercial supersonic flight paths. These approaches, techniques, and resulting data will be the foundation for establishing the sonic boom acoustic limits as part of the international certification standards.

HYPERSONIC TECHNOLOGY (HT)

NASA focuses on fundamental research that explores key challenges in hypersonic flight and maintains unique, specialized facilities and experts. The Hypersonic Technology Project focuses on hypersonic propulsion systems, reusable vehicle technologies, high-temperature materials, and systems analysis. NASA applies its expertise to understand and assess the potential for future commercial hypersonic markets. In addition, this project coordinates closely with partners in the Department of Defense (DoD), so NASA can leverage DoD investment in ground and flight activities to develop and validate advanced physics-based computational models. At the same time, DoD benefits from NASA expertise, analyses, testing capabilities, and computational models. NASA can support U.S. industry's emerging interest in commercial hypersonic vehicles, while also supporting DoD needs.

HIGH-RATE COMPOSITE AIRCRAFT MANUFACTURING (HICAM)

The High-Rate Composite Aircraft Manufacturing (HiCAM) project will demonstrate manufacturing approaches and associated technologies that enable large, composite primary airframe structure production rates four to six times faster than 2020 best-in-class production rates without increasing component cost or weight. The project focus will be airframe structural components for single-aisle transport aircraft expected to enter service in the early 2030s. The findings and techniques developed will generally advance manufacturing technology applicable to a variety of composite structures, including aircraft engine applications, urban air mobility vehicles, and space launch vehicle applications. The findings and techniques may also contribute to future in-space construction and assembly of composite structures. HiCAM will develop model-based engineering tools to rapidly mature and optimize high-rate composite manufacturing and assembly with reduced equipment and tooling costs. NASA will team with partners to share expertise, facilities, and resources to accelerate technology maturation efforts. HiCAM will use advanced manufacturing and structural behavior simulation, including already established methods and rapid prototype and evaluation of manufacturing concepts, to down-select technologies at smaller scales, which will more rapidly mature larger scale technologies. HiCAM primarily supports ARMD Strategic Thrust 3.

HYBRID THERMALLY EFFICIENT CORE (HYTEC)

The Hybrid Thermally Efficient Core (HyTEC) project will develop small core turbofan engine technologies aimed at achieving up to 20 percent power extraction at altitude and a 5-10 percent fuel burn reduction compared to 2020 best-in-class turbofan engines, culminating in an advanced core demonstration in the 2026 timeframe. As part of this effort, HyTEC will advance design capabilities for small core combustors for effective and efficient operability on high-blend (50-100 percent) sustainable alternative jet fuels. NASA will collaborate with industry in a cost-sharing arrangement on key technologies and will accelerate these key technologies to strengthen the U.S. industry position on small core-enabling technology and integrated systems for a future single aisle aircraft. HyTEC primarily supports ARMD Strategic Thrust 3.

Program Schedule

Date	Significant Event
Jan 2021	AATT – Complete a conceptual design and validate the performance of compressor and core concepts for a compact high Operating Pressure Ratio (OPR) gas generator concept, enabling reduced size/flow high-pressure compressors and high-temperature disk/seals that are critical for 50+ OPR gas generators with minimal impact on noise and component life.
Jun 2021	HyTEC – Complete a Preliminary Design Review of a turbofan engine test to determine the impact of large-scale power extraction from both high- and low-pressure engine spools.
Sep 2021	CST – Completion of a Pre-Flight Prediction Capability Review supporting timely and accurate pre-flight exposure planning for community response testing.
Sep 2021	RVLT – Complete an evaluation of three AAM configurations assessing the impact of low-noise design on the vehicle performance.
Nov 2021	HiCAM – Complete initial materials and process requirements definition for high-rate manufacturing of large aircraft structures.
Dec 2021	AATT – Completion of an advanced fan and high-lift noise concept to reduce fan (lateral and flyover) and high-lift system (approach) noise on a component basis by four decibels (which represents approximately a 25 percent reduction in perceived noise) with minimal impact on weight and performance.
Jan 2022	HyTEC – Completion of a Critical Design Review of a turbofan engine test to determine the impact of large-scale power extraction from both high- and low-pressure engine spools.
Mar 2022	CST – Assessment of pre-test prediction capabilities by using prediction validation tools in preparation of the Low-Boom Flight Demonstrator Validation Process.
Aug 2022	RVLT – Validation testing of hover performance for AAM aircraft noise and performance tool chain.
Sep 2022	RVLT – Completion of second generation AAM fleet operations noise assessment.
Sep 2022	HiCAM – Initial selection of technologies and technical concepts for continued research and advancement.
Sep 2022	HT – Development of tools for hypersonic design and decision making under uncertainty.

Program Management & Commitments

Program Element	Provider
Advanced Air Transport Technology (AATT)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: GRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): U.S. Air Force, Boeing, Pratt & Whitney, Northrop Grumman, General Electric Aviation, Aurora, United Technologies Corporation, Rolls Royce/Liberty Works, Honeywell, FAA, Lockheed Martin, U.S. Navy, Department of Energy
Revolutionary Vertical Lift Technology (RVLT)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: LaRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): FAA, U.S. Army, U.S. Air Force, U.S. Navy, Technologies Research Center, Moog Surefly, A&P Technologies, DLR, ONERA, QuesTek, Ohio State University--Gearlab and Smart Vehicle Concept Center, Pennsylvania State University – Applied Research Laboratory, University of Illinois--Power Optimization of Electro-thermal Systems, University of Maryland, Georgia Institute of Technology
Commercial Supersonic Technology (CST)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: LaRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): Gulfstream Aerospace, FAA, JAXA, Rockwell Collins, ONERA, The University of Washington, Boeing Research and Technology, U.S. Navy
Hypersonic Technology (HT)	Provider(s): AFRC, GRC, LaRC Lead Center: LaRC Performing Center(s): AFRC, GRC, and LaRC Cost Share Partners: DoD, John Hopkins University/Applied Physics Laboratory, The Spaceship Company, Hermeus, Stratolaunch, Boeing
High-Rate Composite Aircraft Manufacturing (HiCAM)	Provider(s): AFRC, ARC, GRC, LaRC Lead Center: LaRC Performing Center(s): AFRC, ARC, GRC, LaRC Cost Share Partners: FAA, Industry and Academic Partners
Hybrid Thermally Efficient Core (HyTEC)	Provider(s): AFRC, ARC, GRC, LaRC Lead Center: GRC Performing Center(s): AFRC, ARC, GRC, LaRC Cost Share Partners: U.S. Industry

Acquisition Strategy

AAVP research and technology spans from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages teaming among large companies, small businesses, and universities.

MAJOR CONTRACTS/AWARDS

AAVP awards multiple smaller contracts, which are generally less than $5 million and widely distributed across academia and industry with a few exceptions. AAVP anticipates awarding larger contracts to support the HyTEC and HiCAM projects' large technology development and demonstrations.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2020	The 12-month review is a formal independent peer review. Experts from other NASA programs report on their assessment of technical and programmatic risk and/or program weaknesses.	The Panel provided favorable reviews to the projects. The Panel also gave constructive comments and recommendations.	Oct 2021

INTEGRATED AVIATION SYSTEMS PROGRAM

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Low Boom Flight Demonstrator	126.5	97.3	**74.6**	36.8	15.3	0.0	0.0
Electrified Powertrain Flight Demonstration	25.0	76.9	**91.2**	128.6	98.6	25.0	0.0
Integrated Aviation Systems Program	110.0	104.5	**135.7**	140.1	196.8	284.2	349.9
Total Budget	**261.5**	**278.7**	**301.5**	**305.5**	**310.7**	**309.2**	**349.9**
Change from FY 2021			**22.8**				
Percentage change from FY 2021			**8.2%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Shown here is an artist's rendering of NASA's X-59 Quiet Supersonic Technology (QueSST) aircraft that could transform aviation by enabling new commercial markets for supersonic travel over land.

Flight research creates a bridge between fundamental research and a level of technology readiness that enables technology transfer to the aviation community. Specifically, flight research advances technology readiness to the levels required for incorporation of new technologies into future air vehicles and operational systems.

The focus of the Integrated Aviation Systems Program (IASP) is to demonstrate integrated concepts and technologies in a relevant environment and establish a level of maturity that enables these technologies' transition to the aviation community. To support this goal, IASP focuses on the rigorous execution of highly complex flight campaigns and related experiments for the benefit of the Nation and U.S. flying public. IASP flight campaigns support all research maturity levels and often facilitate cross-cutting flight test activities. For technologies at low-Technology Readiness Levels (TRLs), IASP flight research accelerates the development and determines the technology feasibility. For more mature technologies, flight research will reduce risks and accelerate transition of those technologies to industry.

IASP supports three critical cross-program efforts: Sustainable Flight National Partnership (SFNP), Low-Boom Flight Demonstration Mission, and the Advanced Air Mobility Mission. In support of SFNP, IASP leads the Sustainable Flight Demonstrator (SFD) and Electrified Powertrain Flight Demonstration projects. IASP also leads the Low-Boom Flight Demonstrator (LBFD) project to build, assemble, and conduct flight validation tests for the X-59 supersonic aircraft and will lead flight operations in support of the X-59 community response testing. Additionally, IASP leads the Advanced Air Mobility (AAM) project, which will conduct developmental testing activities in preparation for the National Campaign (NC) series and provide key knowledge and data to both the aviation community and FAA.

INTEGRATED AVIATION SYSTEMS PROGRAM

IASP directly supports three of the ARMD Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft
- Thrust 3: Ultra-Efficient Subsonic Transports
- Thrust 6: Assured Autonomy for Aviation Transformation

EXPLANATION OF MAJOR CHANGES IN FY 2022

As part of NASA's initiation of the Sustainable Flight National Partnership (SFNP), IASP will establish a new SFD Project with a goal of achieving a first flight in FY 2026 and expand the electrified powertrain flight demonstrations to include two major awards. Through these targeted activities, in support of SFNP, NASA will ensure that technologies will be ready by the mid- to late-2020s to transition into U.S. industry's next generation of single-aisle transport aircraft.

At the end of each achievement identified in this document, there is a mapping to link it to the related Strategic Research Thrust and Program Element.

ACHIEVEMENTS IN FY 2020

- NASA completed in-situ measurement system design and ground vibration testing of an in-flight optical observation system. The intent of these systems is to observe the X-59 aircraft shockwave structure in flight. (Thrust 2/Flight Demonstrations and Capabilities [FDC])
- NASA completed flight testing of a new control and non-payload communications radio. The test demonstrated command and control capability in flight and contributed to standards development that will define how Unmanned Aerial Systems (UAS) can operate safely in the National Air Space (NAS). (Thrust 6/UAS-NAS)
- NASA completed the UAS integration into the NAS project. NASA provided the final research deliverables to RTCA, a key aviation standard making organization, for mid-size UAS. This research will enable the development of minimum operating performance standards for Detect and Avoid (DAA) and Command and Control (C2) systems. (Thrust 6/UAS-NAS)
- NASA successfully completed the Systems Integration and Operationalization (SIO) activities within the UAS integration into the NAS Project. With industry partners, NASA worked to solve challenges that prevent routine commercial UAS operations, such as development, integration, and certification of unmanned aircraft and avionics. The SIO activity included multiple flight demonstrations that focused on UAS missions at altitudes greater than 500-feet above ground level and included integrated DAA and C2 technologies. (Thrust 6/UAS-NAS)
- NASA prepared for upcoming AAM NC events, such as the Development Testing (early FY 2021) and NC 1 (FY 2022). (Thrust 6/AAM)

WORK IN PROGRESS IN FY 2021

- NASA will initiate planning for a new SFD project, including consultations and risk reduction activities with industry, to further develop and mature technologies for the next generation of commercial aircraft. (Thrust 3, SFD)

- In preparation for X-59 flight operations, NASA will deliver a validated F-15-based test capability that enables precise, near-field probing of the LBFD shockwave structure. This capability ensures that the shockwave structure produced by the X-59 aircraft in flight is easily comparable with current simulations during the flight test campaign. (Thrust 2/FDC)
- NASA will complete preparations for the first flight of the all-electric X-57 Maxwell aircraft in early FY 2022. Preparations include ground systems testing of the integrated electric motors, avionics, and power distribution system and taxi tests. (Thrust 3/FDC)
- NASA completed final closeout activities for the UAS integration in the NAS project during the first quarter of FY 2021 and archived research findings regarding technology demonstrations and simulations. (Thrust 6/UAS-NAS)
- NASA will conduct NC Development Testing with an industry partner to demonstrate the maturity of key systems and infrastructure that will be employed for the National Campaign series beginning with NC 1 in FY 2022. In preparation for the future NC demonstrations, NASA will be establishing key agreements with NC industry participants. (Thrust 6/AAM)

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- NASA will conduct flight test operations in support of X-59 supersonic aircraft first flights. (Thrust 2/FDC)
- NASA will solicit industry proposals and award contracts for preliminary designs for a SFD. (Thrust 3/SFD)
- NASA will conduct the first flight of the all-electric X-57 Maxwell aircraft. In conjunction with the flight test, NASA will support the development of manufacturing standards for electrified aircraft systems to enable progress for U.S. companies to develop more electric aircraft. (Thrust 3/FDC)
- NASA will continue to focus on investigating barriers of entry into new emerging markets in aviation. This project will closely coordinate with other related NASA research on both airspace operations and vehicle technologies to help prioritize and deliver on the key enabling technical challenges that are most appropriate for NASA to work. Based on National Campaign Development Testing conducted in FY 2021, NASA will share lessons learned and identified gaps with the FAA and industry. The AAM Project will conduct focused research in key areas, such as autonomy required to achieve NASA's vision for urban air mobility. (Thrust 6/AAM)

Program Elements

The Electrified Powertrain Flight Demonstrations and Low-Boom Flight Demonstrator projects within IASP are lifecycle controlled and reported in separate sections.

FLIGHT DEMONSTRATIONS AND CAPABILITIES (FDC)

NASA's FDC Project validates the benefits of various technologies and demonstrates the feasibility and maturity of new technologies through flight testing in a relevant environment. The flight experiments are campaigns focused on aggressive, success-oriented schedules utilizing the most appropriate set of assets available to accomplish experimental objectives, while leveraging collaborative partnerships (as appropriate) from across the aeronautical industry. While many of the technologies are at relatively high-TRLs, the FDC project supports all phases of technology maturation. The FDC project also operates and maintains a support aircraft fleet that enables safety chase and in-flight experimental measurements in support of a variety of NASA missions.

One such flight experiment is NASA's first all-electric X-plane, the X-57 Maxwell. The X-57 effort will test and determine the airworthiness of electrified aircraft technologies, with strong applicability to a broad range of electric aircraft configurations. This effort will result in the development of applicable manufacturing standards and establishing certification pathways for electric aircraft, such as those needed for emerging advanced air mobility markets.

ADVANCED AIR MOBILITY (AAM)

The Advanced Air Mobility (AAM) project focuses on helping to enable a new market in urban air mobility. This project closely coordinates with ARMD's other programs on both airspace operations and vehicle technologies to help prioritize and deliver on the key enabling technical challenges that are most appropriate for NASA to work on. The AAM project will conduct focused research in key areas, such as autonomy required to achieve NASA's vision for urban air mobility. One of the primary functions of the project is to execute a series of AAM National Campaign demonstrations that will help the entire community better assess the advances of key technologies and systems and help identify where future research needs to focus. AAM works closely with other government and commercial entities to achieve this objective. Another important function of the AAM project is to mature NASA's strategic vision for urban air mobility. This vision will not only help NASA prioritize its research but also facilitate planning and development in the private sector to help ensure U.S. leadership in this emerging market.

SUSTAINABLE FLIGHT DEMONSTRATOR (SFD)

One of the key components of the Sustainable Flight National Partnership is the Sustainable Flight Demonstrator Project. SFD will be a large-scale integrated flight demonstration with objectives to reduce fuel burn, emissions, and noise. The potential technologies to test include a hybrid electric propulsion system, new aircraft configuration such as a truss-braced wing, and new composite materials produced at a high rate. The aircraft, notionally planned for flight in FY 2026, will deliver matured technologies to industry for use in the next generation commercial transport aircraft.

Program Schedule

Date	Significant Event
Feb 2021	AAM - Release Announcements of Collaborative Opportunity for NC 1 and NC 2
May 2021	AAM - Complete AAM National Campaign Developmental Testing
Sep 2021	FDC - F-15D Ready for LBFD
Oct 2021	FDC - Complete X-57 Mod II First Flight
Jun 2022	FDC - Begin Schlieren Airborne Measurements and Range Operations for Quest support of X-59 flight operations

INTEGRATED AVIATION SYSTEMS PROGRAM

Date	Significant Event
Sep 2022	AAM - Complete AAM National Campaign 1
Sep 2022	SFD - Complete contract award

Program Management & Commitments

Program Element	Provider
Flight Demonstrations and Capabilities (FDC)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: AFRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): DoD, Air Force Research Laboratory, Lockheed Martin, ESAero
Sustainable Flight Demonstrator (SFD)	Provider(s): TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD
Advanced Air Mobility (AAM)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: HQ Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): TBD

Acquisition Strategy

IASP research and technology development focuses on integrated system capabilities. The program uses a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions NASA strongly encourages teaming among large companies, small businesses, and universities.

MAJOR CONTRACTS/AWARDS

IASP awards multiple smaller contracts, which are generally less than $7 million and widely distributed across academia and industry for efforts supporting advanced air mobility and small-scale flight demonstrations. IASP awards substantially larger contracts for the design and build of large-scale flight demonstration such as EPFD, SFD, and LBFD.

INTEGRATED AVIATION SYSTEMS PROGRAM

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Annual Performance	Expert Review	Dec 2020	The purpose of 12-month review is for tracking and documenting the projects' progress made towards the Strategic Thrusts and outcomes during the fiscal year.	The Review Panel acknowledged the projects were on-track and expressed appreciation for the work done by all projects to remain relevant to their stakeholders. There were no findings.	Dec 2021

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	BTC	Total
Formulation	100.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	100.5
Development/Implementation	206.2	126.5	97.3	**74.6**	27.7	0.0	0.0	0.0	0.0	532.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	9.1	15.3	0.0	0.0	0.0	24.4
2021 MPAR LCC Estimate	**306.6**	**126.5**	**97.3**	**74.6**	**36.8**	**15.3**	**0.0**	**0.0**	**0.0**	**657.1**
Total Budget	**306.6**	**126.5**	**97.3**	**74.6**	**36.8**	**15.3**	**0.0**	**0.0**	**0.0**	**657.1**
Change from FY 2021				**-22.7**						
Percentage change from FY 2021				**-23.3%**						

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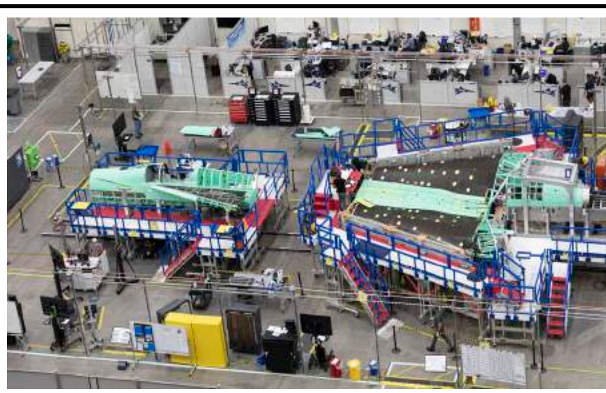
FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



This picture shows the wing and cockpit sections of NASA's X-59 QueSST vehicle coming together at Lockheed Martin's factory in Palmdale, California.

PROJECT PURPOSE

Over the past decade, fundamental research and experimentation has demonstrated the possibility of supersonic flight with greatly reduced sonic boom noise. The Low-Boom Flight Demonstrator (LBFD) Project will demonstrate these advancements in flight by utilizing a purpose-built experimental aircraft designated the X-59 Quiet Supersonic Technology (QueSST). It will provide validation of design tools and technologies applicable to low sonic boom aircraft. The Low-Boom Flight Demonstration Mission (LBFD Mission) will create a database of community response information supporting the development of a noise-based standard for supersonic overland flight.

The Advanced Air Vehicles Program (AAVP) and the Integrated Aviation Systems Program (IASP) co-lead the LBFD Mission. The AAVP's Commercial Supersonic Transport (CST) project is responsible for conducting the assessments of community responses to the X-59 low noise sonic-boom, IASP's LBFD project provides the flight vehicle, and IASP's Flight Demonstrations and Capabilities (FDC) project will

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

conduct flight test operations with the X-59. The three-phase LBFD Mission aims to produce an aircraft that generates a low-noise sonic boom signature and provides crucial data that could enable commercial supersonic passenger air travel over land. After test flights to validate the predicted low-noise acoustics of the X-59, NASA researchers will gather data on public acceptance of the noise levels by flying over a handful of U.S. cities. In FY 2027, NASA will provide the finalized data to the Federal Aviation Administration and the International Civil Aviation Organization. Using these data, the regulatory organizations will be in a place where it could develop and adopt new rules to allow commercial supersonic flight over land. If a new standard is established, the U.S. aviation industry will be in position to lead the commercial supersonic market, and passengers will benefit from significantly shorter travel times.

Phase 1 of the LBFD Mission includes the LBFD aircraft development activities, which are led by the LBFD project. These activities start with the detailed design, continue through fabrication, and conclude with functional checkouts and supersonic envelope expansion. In Phase 2, a NASA-led team will perform low-boom acoustic validation flights of the X-59 aircraft. These flights will characterize and evaluate the near-field, mid-field, far-field, and ground sonic boom signatures from the X-59 aircraft. All three LBFD Mission projects (CST, LBFD, and FDC) will work collaboratively to conduct Phase 2 of the LBFD Mission. For Phase 3, a NASA-led CST team will lead low-boom community response studies with multiple test flight campaigns using the LBFD aircraft over varied locations with aircraft operations conducted by the FDC project. Following the completion of acoustic validation at the end of the Phase 2, the X-59 QueSST aircraft will transfer from the LBFD project team to the FDC project to conduct planned Phase 3 flight operations. The LBFD project concludes at the end of Phase 2.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The LBFD project updated the costs and schedule based on Lockheed Martin's replan completed in July 2020. The replan addressed schedule delays due to staffing and supplier issues and added an incentive fee plan to mitigate future delays. NASA also established processes for additional management oversight and insight into Lockheed Martin's performance in order to support on-schedule performance. The replan impacts and additional impacts due to COVID-19 moved the first flight milestone from January 2022 to June 2022.

PROJECT PARAMETERS

The LBFD project is responsible for building and flight validation of the X-59 QueSST aircraft. The X-59 aircraft is NASA’s newest experimental supersonic aircraft designed to reduce the sonic boom noise levels to a level acceptable to the general public. The vehicle will enable low-boom community response overflight studies with multiple test campaigns over varied locations as part of the LBFD Mission. The mission ends in FY 2027 with the delivery of the final set of community response data to the International Civil Aviation Organization and the Federal Aviation Administration.

ACHIEVEMENTS IN FY 2020

NASA continued the development and integration of the X-59 aircraft. After the successful completion of the aircraft Critical Design Review (CDR), the LBFD Project team received approval to enter Phase D

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

and proceed with Assembly, Integration, and Test. The project also held a Delta CDR for the Flight Test Instrumentation System and the Power Distribution System. NASA delivered significant aircraft components such as the nose, vertical tail, and engines to the contractor. In addition, the contractor completed the first subsystem checkout on the aircraft.

NASA approved Lockheed Martin to perform a re-plan in January after significant delays due to staffing, supplier issues, and COVID-19 impacts. The re-plan effort, approved at a Delta KDP-D meeting in July 2020, allowed the project to proceed with updated plans for cost and schedule to improve confidence in Lockheed Martin's planned performance.

WORK IN PROGRESS IN FY 2021

NASA will complete the final assembly and system checkouts of the X-59 aircraft. Next, the shipment of the X-59 aircraft to a Lockheed Martin facility in Fort Worth will occur in order to perform the ground proof loads test. NASA will complete delivery of the subsystems (e.g., Flight Test Instrumentation System, Power Distribution System, and External Vision System) and all Government Furnished Equipment (GFE) required to develop the aircraft. LBFD project will perform the air data probe calibration test in the Glenn Research Center (GRC) 8-foot by 6-foot wind tunnel and complete the emergency oxygen system testing.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

NASA will conduct a series of airworthiness and flight safety reviews of the X-59 supersonic aircraft. The aircraft will also undergo a series of ground tests including the ground vibration test, engine runs, and taxi tests. After successfully completing these reviews and tests, NASA will conduct the first flight of the X-59 supersonic aircraft in the summer of 2022.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Baseline Date	FY 2022 PB Request
Key Decision Point-B (KDP-B)	Aug 2016	Aug 2016
Formulation Authorization	Sep 2016	Sep 2016
Acquisition Strategy Meeting	Nov 2016	Nov 2016
Preliminary Design Review (PDR)	Jun 2017	Jun 2017
Delta PDR	Jul 2018	Jul 2018
KDP-C	Oct 2018	Oct 2018
Critical Design Review	Aug 2019	Sep 2019
KDP-D	Oct 2019	Dec 2019
Lockheed Re-Plan Complete	-	Jul 2020

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Milestone	Baseline Date	FY 2022 PB Request
Delta KDP-D	-	Jul 2020
X-59 Ship to LM Ft. Worth for Loads Test	-	Jul 2021
Flight Readiness Review	Oct 2021	Dec 2021
First Flight Complete	Jan 2022	Jun 2022
System Acceptance Review (Phase 1) Flight Testing Complete	Jan 2023	May 2023
Acoustic Validation (Phase 2) Complete	Oct 2023	Jan 2024
Aircraft Transfer Review to FDC (Phase 2)	Oct 2023	Feb 2024
LBFD Project Close-Out Complete	Apr 2024	Aug 2024

Development Cost and Schedule

The LBFD Project completed a successful Delta KDP-D on July 15, 2020, and the project received authority to implement the updated cost and schedule profile. The LBFD Project lifecycle includes aircraft concept refinement studies, aircraft preliminary design, aircraft final design and build, and acoustic validation flight testing. These activities span from FY 2014 to FY 2024 (Phase 1 and Phase 2 of the LBFD Mission).

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	467.743	70%	2021	532.218	+13.8%	First Flight	Jan 2022	Jun 2022	5

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time of development. Estimates that include combined cost and schedule risks denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**467.7**	**532.2**	**+64.5**
Flight Sciences	19.5	21.8	+2.3
Flight Systems	17.0	23.6	+6.6
Aircraft	230.9	335.0	+104.0
Aircraft Operations	45.1	56.4	+11.3
Other Direct Project Costs	155.2	95.4	-59.8

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Flight Sciences	Vehicle sonic boom, aerodynamics, propulsion, structures, and mission performance NASA in-house flight simulation tools, and analysis of vehicle handling qualities and control laws	Provider: Ames Research Center (ARC), Armstrong Flight Research Center (AFRC), Glenn Research Center (GRC), Langley Research Center (LaRC) Lead Center: LaRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): N/A	N/A
Flight Systems	Design, development, and test of Power Distribution System (PDS), Flight Test Instrumentation System (FTIS), and eXternal Vision System (XVS)	Provider: AFRC, LaRC Lead Center: AFRC Performing Center(s): AFRC, LaRC Cost Share Partner(s): N/A	N/A
Aircraft	Design, build and initial test of a single-piloted X-plane by the end of 2021	Provider: Lockheed Martin Lead Center: AFRC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Aircraft Operations	Demonstrate airworthiness of aircraft, flight operations, and develop key aircraft subsystems - including life support and crew escape systems Provide Government Furnished Equipment (GFE) to construct the research aircraft, support and maintain F414 engine, and perform insight/oversight of Ops-related tasks that the vehicle Contractor performs	Provider: AFRC, LaRC Lead Center: AFRC Performing Center(s): AFRC, LaRC Cost Share Partner(s)/subcontractors: GE, Northrop, Honeywell, and Lockheed Martin	N/A

Project Risks

Risk Statement	Mitigation
Sonic Boom Level is Not Acceptable for Community Overflight Research Given that achieving a fully shaped sonic boom ground signature in the 70-75 PLdB range requires a complex and integrated design solution that is sensitive to outer mold line changes, there is a possibility that the mission requirements related to ground signature loudness may not be achievable - resulting in an aircraft that may not be fully acceptable for community response studies.	NASA will ensure that all configuration assessments use the latest and most mature aircraft configuration and periodically assess any updates to the aircraft configuration, such as the outer mold line or performance characteristics.
Reduced Aircraft Performance Could Impact Mission Effectiveness Given the aircraft and propulsion system selection and integration complexity, there is a possibility of reduced aircraft performance resulting in loss of mission effectiveness and leading to longer duration time to meet flight parameter(s), increased costs, and limitations of flight test points to standard-day conditions.	NASA will ensure that the contractor has sufficient margin for aircraft weight growth with propulsion configuration; assess contractor aircraft performance and thrust predictions (both computationally and experimentally) over the aircraft flight envelope; and perform a trade study on engine performance during demanding conditions.

Acquisition Strategy

The acquisition strategy for LBFD is to acquire through an industry partner the detailed design/build/test of the experimental low-boom demonstrator aircraft. NASA will provide in-house support that will include in-flight and ground systems, instrumentation and operations, simulation, wind tunnel testing, and safety and mission assurance. NASA supplies aircraft components and systems as GFE whenever feasible and considered to add value to the development of the LBFD aircraft.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
LBFD Aircraft - Design, Build, and Initial Testing	Lockheed Martin	Palmdale, CA
F414-GE-100 Engine	General Electric Aviation	Lynn, MA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	LBFD Independent Review Board (IRB)	Jun 2017	PDR	Successfully Completed	Jul 2018
Performance	LBFD IRB	Jul 2018	Delta PDR, Assess readiness for KDP-C	Successfully Completed	Sep 2019
Performance	LBFD IRB	Sep 2019	CDR, Assess readiness for KDP-D	Successfully Completed	Dec 2021
Performance	LBFD Flight Readiness Review (FRR) Board	Dec 2021	FRR	TBD	N/A

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATION

Formulation	Development	Operations

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**25.0**	**76.9**	**91.2**	**128.6**	**98.6**	**25.0**	**0.0**
Change from FY 2021			**14.3**				
Percentage change from FY 2021			**18.6%**				

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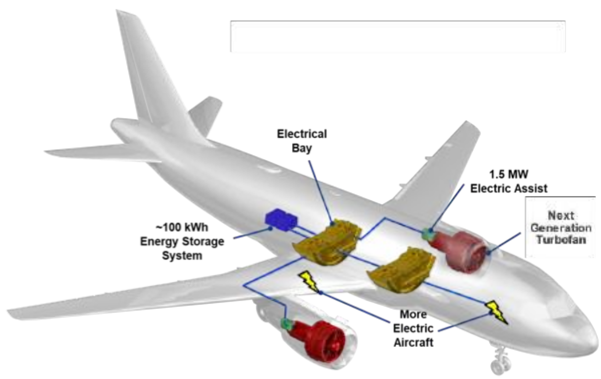
FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



This picture depicts a notional hybrid-electric powertrain demonstration architecture applied to single-aisle class aircraft.

PROJECT PURPOSE

The purpose of the Electrified Powertrain Flight Demonstration (EPFD) project is to mature integrated Megawatt (MW)-class electrified powertrain systems and components, thereby accelerating the introduction of these systems to the U.S. commercial transport fleet. In partnership with U.S. industry, NASA will design, build, integrate, and perform ground and flight-tests of MW-class powertrain systems. These new systems will reduce fuel consumption by up to five percent and reduce harmful emissions. EPFD is a critical component of the Sustainable Flight National Partnership and supports ARMD Strategic Thrust 3: Ultra-Efficient Subsonic Transport.

As the benefits of electrified aircraft propulsion technology become realized, electrified aircraft propulsion research and development should rapidly gain momentum and transition into production and operations. Electrified powertrain systems will provide significant benefits in terms of reduced fuel/energy consumption and emissions. Such advances could pave the way for more cost-effective commercial aviation, while also reducing adverse societal impacts.

Through public-private partnerships with industry teams, EPFD will:

- Demonstrate in-flight integration of MW-class electric powertrain, power distribution, and energy storage systems; and

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATION

Formulation	Development	Operations

- Identify and address technical barriers, integration risks, and regulatory and standards gaps associated with such systems.

EXPLANATION OF MAJOR CHANGES IN FY 2022

As part of NASA's initiation of the Sustainable Flight National Partnership, the EPFD budget includes funding sufficient for at least two major electrified powertrain demonstrations. With increased funding for this activity, NASA will ensure that the technologies will be ready by the mid-to-late 2020s to transition into U.S. industry's next-generation single-aisle transport aircraft.

PROJECT PRELIMINARY PARAMETERS

EPFD is a technology demonstration project that will flight demonstrate and evaluate the performance of MW-class hybrid-electric propulsion system technologies for commercial aircraft. Incorporating this technology could lead to lower operating costs, higher fuel efficiency, and reduced noise and emissions for commercial aircraft. The EPFD project will reduce risks for key critical technologies and address specific gaps in regulations and standards associated with introducing electrified propulsion into commercial aircraft.

EPFD will mature MW-class electrified powertrain systems through flight demonstrations applicable to the short-haul, regional, or thin-haul market segments and accelerate the U.S. industry's readiness to introduce these innovative electrified systems into the next generation of aircraft. This acceleration may occur by:

- Contributing to the development of next generation commercial subsonic transports by focusing on integrated MW-class powertrain system technology;
- Focusing on next generation single-aisle (150 – 200 passenger seat class) commercial transport aircraft;
- Ensuring an appropriate mix of potentially disruptive concepts and commercial transport products; and
- Directly engaging U.S. industry to facilitate timely integrated MW-class electrified powertrain system development and transition from government to industry.

EPFD will plan and conduct at least two integrated MW-class powertrain system flight demonstrations, identifying and addressing regulation and standards gaps in addition to identifying and retiring barrier technical and integration risks.

ACHIEVEMENTS IN FY 2020

EPFD successfully completed several key reviews including the Mission Concept Review (MCR), Technology Toll Gate, Acquisition Strategy Meeting (ASM), Key Decision Point (KDP)-A, and Systems Requirement Review (SRR). These successful reviews authorized the project to proceed with six awards to industry teams to initiate risk reduction efforts.

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATION

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2021

- EPFD successfully completed KDP-B and the Procurement Strategy Meeting (PSM).
- EPFD continued maturation and risk reduction of MW-class electrified powertrain system components under the risk reduction contracts.
- EPFD released the request for proposal solicitation in February 2021 for the flight demonstration. Responses are due in May 2021 and selections are planned for late FY 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

For each selected industry team proposal, the EPFD Project will conduct a Delta SRR, Integrated Baseline Review (IBR), and KDP-C. For each industry team, joint NASA-Industry design reviews (i.e., PDR, CDR) will occur. NASA will evaluate technical design maturity, as well as the ability to conduct the flight demonstrations according to the contract performance schedule. The intent is for two industry teams to continue to the flight demonstration phase. The plan is to finalize the preliminary dates after the award of the industry contracts. The following schedule reflects a range of dates in depicting each engineering review milestone:

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2022 PB Request
KDP-A	Jun 2020	Jun 2020
Acquisition Strategy Meeting (ASM)	Jul 2020	Jul 2020
System Readiness Review (SRR)	Sep 2020	Sep 2020
Key Decision Point (KDP-B)	Oct 2020	Oct 2020
Procurement Strategy Meeting (PSM)	Oct 2020	Oct 2020
Delta SRR	TBD	TBD
Preliminary Design Review (PDR)	Feb 2022 - Aug 2022	Feb 2022 - Aug 2022
KDP-C	Mar 2022	Mar 2022
Critical Design Review (CDR)	Feb 2023 - Aug 2023	Feb 2023 - Aug 2023*
KDP-D	Jul 2023 - Jan 2024	Jul 2023 - Jan 2024*
Flight Readiness Review (FRR)	Nov 2023 - Jul 2024	Nov 2023 - Jul 2024*
First Flight	Dec 2023 - Aug 2024	Dec 2023 - Aug 2024*

**The project is still in Formulation. These dates will be formalized and updated at KDP-C.*

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATION

Formulation	Development	Operations

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

The formulation agreement documents project costs at approximately $340.3 million over the next five years during the design and build phase. The life cycle cost of $412 million includes pre-Formulation and Formulation costs and related technology maturation activities conducted by the Advanced Air Transport Technology Project, which occurred between FY 2017 and FY 2020.

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project reaches KDP-C, which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
October 7, 2020	$312M - $470M	First Flight	Dec 2023-Aug 2024

Project Management & Commitments

The following section will be updated when the FY 2021 industry contract awards occur.

Element	Description	Provider Details	Change from Formulation Agreement
MW-class electric powertrain, power distribution, and energy storage systems.	Flight demonstration and evaluation of the performance of MW-class hybrid-electric propulsion system technologies for commercial aircraft.	Provider: TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD	N/A

Project Risks

Assessment and mitigation of project risks provides the project with the ability to understand the technical scope and associated risks to achieve a successful mission execution. EPFD’s Risk Management Process, per NASA’s NPR 8000.4B, positions IASP and EPFD to be agile and responsive from Formulation through Implementation to enable achievement of the project’s technical performance goals and objectives within the project’s lifecycle cost and schedule.

During Phase A, EPFD's Risk Management Process identified and matured specific risks related to the MW-class powertrain flight demonstrations. Risk identification and mitigations continue to be developed during Phase B. These efforts are led by three risk working groups: technical (system and component); safety and mission assurance (including airworthiness); and, cost, schedule, and acquisition. The EPFD project has a risk registry containing all active risks stored in a document management system. Mitigation plans will be determined and funded (where necessary) to mitigate technical, cost, schedule, and safety likelihood and consequences.

By managing these risks during Formulation, the project can be proactive in reducing barriers to technology insertion and establish MW-class powertrain system performance by specifically, validating component-level design and obtaining preliminary test data at the component- and subsystem-level.

The following tables shows the top risks and current mitigation steps:

Risk Statement	**Mitigation**
Title: Acquisition: Constrained Supply Base for Critical Components: Given that the performance requirements of critical components exceed those of standard, commercially available parts, there is the possibility that the engineering and manufacturing suppliers will not be able to supply these components on schedule/in budget, resulting in a schedule delay and/or cost increase.	Mitigation Steps: Given the impacts of COVID-19, continue market research with potential vendors to explore viability of supplier base. Given the impacts of COVID-19, award limited sources contract(s) to existing EPFD industry teams to keep Primes and critical suppliers engaged for the period between October 2020 and March 2021.
Title: Acquisition: Cost Share Strategy with Contractor(s) Given the relative success of the project depends on cost sharing with the contractor(s), there is a possibility that cost sharing may not be a viable option for certain contractors.	Mitigation Step: Given the impacts of COVID-19, the acquisition strategy was adjusted to shift cost share requirement to after CDR, with the intent to fully fund industry efforts through CDR. Potential vendors will deliver cost share plans as a part of the Request for Proposal response that addresses the period from CDR to Closeout.

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATION

Formulation	Development	Operations

Risk Statement	Mitigation
Title: Contractor(s) May Not be Able to Provide Sufficient Test Data to Demonstrate Technology Maturation Given that NASA will execute ground and flight tests with Industry Partners through a contract, there is a possibility that the Industry Partner test plan will fulfill the contract requirements but not all the data requirements for project success, resulting in a lack of data to validate EAP technologies, to mature those technologies and ultimately to make the project successful.	Mitigation Steps: Define Data needed to measure performance against Key Performance Parameters (Vision Vehicle) and TPMs (Flight Demonstrations); measure advancement of TRL levels of MW-class powertrains; measure progress against Barrier Technical Risk (Vision Vehicle) based on progress against related Specific Technical Risks (Flight Demonstrations) Define data needed to support regulations and standards. Define data needed to provide validation data for NASA and Industry tools and research. The use of validation data will reduce uncertainty in model estimation of EAP system performance in configurations not previously developed, tested, and evaluated. The following programs/projects will help support this effort: Advanced Air Vehicles Program's Advanced Air Transport Technology and Hybrid Thermally Efficient Core projects, and Transformative Aeronautics Concepts Program's Transformational Tools and Technologies project and the EPFD team. Create a Data Management Plan (preliminary) to address the data identified in the previous steps. Be sure this coincides with the Technology Development Plan and requirements for a Master Measurement List. Communicate data needs to industrial partners through Data Requirements Descriptions (DRDs).

Acquisition Strategy

The acquisition strategy for EPFD is to collaborate with U.S. industry to design, build, integrate, and perform ground and flight tests of MW-class powertrain systems.

To conduct the necessary ground and flight demonstrations, EPFD will award at least two contracts using full and open competition. EPFD will conduct integrated ground and flight demonstrations of MW-class electrified powertrain technologies and systems to identify and address electrified powertrain certification gaps during the ground-based and flight test demonstrations.

MAJOR CONTRACTS/AWARDS

During FY 2021, the release of the Request for Proposal, proposal selection, and award will occur.

Element	Vendor	Location (of work performance)
EPFD Flight Demonstration Contracts	TBD	TBD

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATION

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	EPFD Independent Review Board (IRB)	Sep 2020	System Requirements Review (SRR)	Successfully completed	TBD
Performance	EPFD IRB	TBD	Delta SRR	TBD	Feb 2022
Performance	EPFD IRB	Feb 2022 - Aug 2022	Preliminary Design Review	TBD	Feb 2023
Performance	EPFD IRB	Feb 2023 - Aug 2023	Critical Design Review (CDR)	TBD	Nov 2023
Performance	EPFD IRB	Nov 2023 - Jul 2024	Flight Readiness Review (FRR)	TBD	Jun 2024
Performance	EPFD IRB	Jun 2024 - Feb 2025	Post-Flight Assessment Review(s) (PFAR)	TBD	N/A

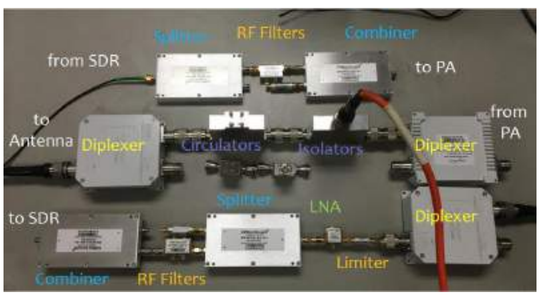
Transformative Aero Concepts Program

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**121.1**	**129.7**	**148.0**	**150.3**	**147.4**	**152.4**	**152.4**
Change from FY 2021			**18.3**				
Percentage change from FY 2021			**14.1%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



The University of South Carolina is a University Leadership Initiative (ULI) awardee working on technologies that will significantly improve communication and networking for air traffic management. As an example of the ULI's work transitioning from government research to use by industry, a dual-band radio designed by the University of South Carolina (pictured above), will be flight tested with a commercial partner.

The Transformative Aero Concepts Program (TACP) cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation. TACP fosters innovative solutions to aviation challenges by capitalizing on advancements in the aeronautics and non-aeronautics sectors to create new opportunities in aviation. One major goal of the program is to reduce or eliminate technical barriers and infuse revolutionary concepts into the aviation community.

TACP creates advanced and improved computational tools, technologies, and experimental capabilities for use by other aeronautics programs, industry partners, and Government collaborators.

TACP's activities offer flexibility for innovators to explore technology feasibility and provide the knowledge for radical transformation. The program creates an environment for researchers to try out new ideas, test their concepts, and learn lessons from unsuccessful experiments. TACP addresses the need for computational and experimental tools that are critical for supporting technology development and enabling aviation transformation. Therefore, TACP's investments are in brand-new areas that can provide paradigm-shifting analysis and experimental capabilities. To get buy-in and foster the rapid adoption of program research products, TACP aggressively engages both the traditional aeronautics community and new, non-traditional entities through tailored partnerships.

Explanation of Major Changes in FY 2022

NASA increased funding to work with our Nation's universities to pioneer revolutionary, beyond next-generation zero-emissions aircraft concepts and technologies through the University Leadership Initiative.

At the end of each achievement identified in this document, there is a mapping to link it to the related Strategic Research Thrust and Program Element.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

ACHIEVEMENTS IN FY 2020

- NASA completed advanced high-fidelity computational analyses using turbulent heat flux studies to improve modeling techniques for flow and heat exchange around aircraft engine turbines. Current computational tools do not adequately model the complex, turbulent flows associated with the mixture of hot combustion gases with forced cooling air required to protect turbine blades. The studies provided crucial flow data around an engine nozzle, allowing modelers to verify that their tools accurately represent the flow conditions. These models will help validate detailed experimental measurements to improve the design of new, high-efficiency propulsion systems. (Cross-Cutting/Transformational Tools & Technologies [TTT])
- NASA completed its first-generation prototype system in the development of shape memory alloy vortex generators. NASA developed and flight tested these generators to validate drag reduction, which will reduce fuel burn. This technology will enhance the development of future generations of ultra-efficient air vehicles to minimize environmental impact. (Cross-Cutting/TTT)
- NASA completed an analysis of ARMD research in materials, structures, and manufacturing. The analysis provided an investment strategy and will help align resources to the most critical research needs addressing both traditional and emerging aviation markets. (Cross-Cutting/TTT)
- NASA completed a successful feasibility assessment for the certification of a trustworthy multi-agent autonomous system. The system was based on Explainable Artificial Intelligence, which developed a system design for Unmanned Aircraft Systems (UAS) vehicles. Based on the results of this assessment, NASA will further develop this concept. (Cross-Cutting/Convergent Aeronautics Solutions [CAS])
- In support of autonomous aircraft, NASA completed an assessment of ways to harness the power of quantum computing to optimize and assure reliability of communications needed for traffic management of autonomous aircraft networks. The assessment shows that this activity has potential benefits and justifies further research. (Cross-Cutting/CAS)
- NASA selected new University Leadership Initiative (ULI) awards, addressing technical barriers inherent in achieving ARMD's strategic outcomes. (Cross-Cutting/University Innovation [UI])
    - Oklahoma State University will address the challenges of managing UAS traffic congestion during weather events in both rural and urban environments. This ULI Award will address emerging need for real-time weather forecasting, improving the safety of low-altitude aircraft operations through the integration of measurements from autonomous systems.
    - Stanford University will develop tools that ensure and test machine learning in autonomous systems used by unmanned Advanced Air Mobility (AAM) aircraft. A focus for this award is verification of real-time system performance, as well as employing fault detection and recovery methods, particularly in situations involving taxiing, landing, and collision avoidance.
    - University of Delaware will use a composite supply method, already developed under a Defense Advanced Research Project Agency (DARPA) program, to demonstrate production of aerospace-quality components at a rate comparable to the automotive industry.
    - The North Carolina Agricultural and Technical State University team will develop an innovative integration of secure and safe autonomous systems used on unmanned AAM aircraft. The team will mature the system to be ready for transition to industry.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

WORK IN PROGRESS IN FY 2021

- NASA will complete combustion modeling that will reduce time and costs associated with certifying sustainable aviation fuels. Working with industry, NASA will develop a capability to predict the impact of new/alternative fuels on Lean Blowout, which can save thousands of gallons of fuel and months of time during the fuel certification process by reducing/eliminating sector or full-annular combustor tests. (Cross-Cutting/TTT)
- NASA will develop human-autonomy teaming solutions for future-aviation applications, including simplified vehicle operations for UAM and remote supervisory operations for air cargo flights. (Cross-Cutting/TTT)
- NASA will develop advanced-computational models to characterize materials, systems, manufacturing processes, and enable an integrated approach toward vehicle design, manufacture, and certification. The use of NASA Research Announcement awards helps to engage the university community in support of this research. Both transport aircraft and AAM vehicles can utilize the unique requirements these capabilities can provide. These new models will promote full lifecycle health monitoring and rapid manufacturing processes that do not compromise quality. (Cross-Cutting/TTT)
- NASA will develop integrated acoustics analysis capabilities for electric Vertical Take-Off and Landing vehicles. These capabilities will enable U.S. manufacturers to design quieter urban-air mobility vehicles. (Cross-Cutting/TTT)
- NASA will demonstrate new autonomous capabilities in flight on the HQ-90 aircraft, which will provide a path forward toward certification. This testing will provide data for automation architectures with run-time assurances and other robust prioritization of safety with the intent to automate functions on aircraft. (Cross-Cutting/TTT)
- NASA will complete a feasibility assessment of a free-bonding adhesive that will enable improvements in manufacturing rates of composite airframes. The adhesive uses a joining method with mechanical fasteners, which in turn improves reliability and manufacturability in aircraft. (Cross-Cutting/CAS)
- NASA will complete a feasibility assessment of concepts to assure operators of commercial drone fleets that their vehicles are able to fly using automated inspection and digital airworthiness certificates. This concept will create an auditable system determining whether aircraft have enough reliability to perform their intended missions. (Cross-Cutting/CAS)
- NASA will conduct prototyping efforts to inform implementation of the project’s new operating model. Topics for prototyping efforts include Weather Tolerant Operations (WTO) for Urban Air Mobility and Air Mobility Data and Reasoning Fabric. The virtual prototyping efforts will engage subject matter experts from the research centers using novel methodologies provided through a Small Business Innovation Research (SBIR) Phase III contract. These activities will conduct rapid feasibility assessments of high-value, disruptive concepts and solutions with potential for transformational impacts at the aeronautics system levels. (Cross-Cutting/CAS)
- NASA will complete its first ULI activity, an effort to develop communication capabilities that improve link and network capacity, reliability, and security in support of new Air Traffic Management applications. Evaluation of several of the technologies will occur with a flight test conducted by an industry partner. (Cross-Cutting/UI)

TRANSFORMATIVE AERO CONCEPTS PROGRAM

- NASA will make additional ULI awards in response to a solicitation that included zero-emission topics. (Cross-Cutting/UI)

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- NASA will complete a Multi-disciplinary Design, Analyses, and Optimization (MDAO) activity, which develops advanced design and optimization tools. These tools are for coupled multi-disciplinary analysis with a range of fidelities to shorten the design cycle of revolutionary vehicles. This technology uses historical X-Plane ground and flight test data to validate the critical physics required to model new concept aircraft. (Cross-Cutting/TTT)
- NASA will develop and demonstrate efficient, eddy-resolving computational modeling tools that can predict the maximum lift coefficient for the take-off and landing of transport aircraft. The improved accuracy will enable a reduction in flight tests points required for aircraft certification. (Cross-Cutting/TTT)
- NASA will complete three CAS activities: Solid-state Additively manufactured Batteries for enhanced Energy, Recharging, and Safety; Sensor-based Prognostics to Avoid Runaway Reactions & Catastrophic Ignition; and Scalable Traffic Management for Emergency Response Operations. (Cross-Cutting/CAS)
- NASA will award new ULI proposals under the UI Project. Proposals will address additional technical barriers intrinsic to achieving ARMD's strategic outcomes. NASA anticipates that new awards will include investment in research for zero-emissions aviation for the future. (Cross-Cutting/UI)

Program Elements

CONVERGENT AERONAUTICS SOLUTIONS (CAS)

The CAS project performs rapid feasibility assessments of early-stage innovations that challenge existing technical approaches, create alternate paths to solutions, and enable new strategic outcomes. The project's focus is on merging traditional aeronautics disciplines, with advancements driven by the non-aeronautics world to overcome barriers and enable new capabilities in commercial aviation. Internal research teams conduct initial feasibility studies, perform experiments, try out new ideas, identify failures, and try again. When a review determines that the developed solutions met their goals and identified potential for future aviation impact, ARMD considers the most promising capabilities for continued development by other programs or by direct transfer to the aviation community.

TRANSFORMATIONAL TOOLS AND TECHNOLOGIES (TTT)

The TTT project advances state-of-the-art computational and experimental tools and technologies that are vital to aviation applications in the six strategic thrusts. These new computer-based tools, models, and associated scientific knowledge provide first-of-a-kind capabilities to analyze, understand, and predict performance for a variety of aviation concepts. Applying these tools will enable and accelerate NASA's research and enable the aviation community to introduce advanced concepts and designs. An example includes, the development and validation of new computational tools used to predict complex turbulent airflow around vehicles and within propulsion systems; ultimately leading to an improved ability to predict future vehicle performance in flight. The project also explores technologies that are critical to advancing ARMD strategic outcomes, such as understanding new types of strong and lightweight materials, innovative aircraft control techniques, and experimental methods. Such technologies will support and enable concept development and benefit assessment across multiple ARMD programs and disciplines. TTT has an Autonomous Systems sub-project to explore new capabilities to enable improved performance and safety of innovative autonomous aircraft and their operational controls.

UNIVERSITY INNOVATION (UI)

The UI project contains a portfolio of disruptive technologies, and other new concepts, to meet the goals established by the ARMD strategic thrusts, and support education of the next generation of engineers. The project utilizes NASA Research Announcement solicitations where university-led teams assess the most critical technical challenges to solve to achieve the Strategic Implementation Plan strategic outcomes; and propose independent, innovative research projects to solve those technical challenges. Universities develop their own success criteria, progress indicators, and technical approaches. Universities pursue multi-disciplinary approaches and incorporate partnerships with other universities, industry, and U.S. entities.

Program Schedule

Date	Significant Event
Mar 2021	UI – Plan to release ULI Round 5 Solicitations
Jun 2021	CAS – Close out/transition of adhesive free bonding of complex composite structures
Jun 2021	UI – Award ULI Round 4 Solicitations
Sep 2021	TTT – Complete development of computational tools that can predict lean blowout of combustion of alternative fuels, relative to Jet-A fuel
Sep 2021	TTT – Complete flight test campaign of unmanned HQ-90 air vehicle to demonstrate autonomous system capabilities
Sep 2021	CAS – Close out/transition of High-Efficiency Electrified Aircraft Thermal Research
Sep 2021	UI – ULI Round 1 Solicitation, University of South Carolina, plans to complete performance period
Mar 2022	CAS – Close out/transition of Solid-state Additively-manufactured Batteries for enhanced Energy, Recharging, and Safety
Mar 2022	UI – Plan to release ULI Round 6 Solicitations
Apr 2022	TTT – Fly second-generation deployable vortex generator system on Boeing's EcoDemonstrator
Jun 2022	UI – Awards ULI Round 5 Solicitations
Jul 2022	CAS – Close out/transition of Sensor-based Prognostics to Avoid Runaway Reactions & Catastrophic Ignition

TRANSFORMATIVE AERO CONCEPTS PROGRAM

Date	Significant Event
Jul 2022	CAS – Close out/transition of Scalable Traffic Management for Emergency Response Operations
Sep 2022	TTT – Deliver validated set of coupled, variable-fidelity, multidisciplinary design, analysis, and optimization (MDAO) tools enabling assessment of non-conventional air vehicles, including electric urban air mobility aircraft

Program Management & Commitments

Program Element	Provider
Convergent Aeronautics Solutions (CAS)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: HQ Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): PCKrause & Associates, National Institute of Aerospace, Boeing, AFRL, ESAero, Launch Point, Straight Up Imaging, DoT Volpe, Moog Inc., IDEO, Idea Couture, Tecolote Research Inc., AFRL, Universities
Transformational Tools and Technologies (TTT)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: GRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): Boeing, Pratt & Whitney, Rolls Royce, Honda, UTRC, ESI, Blue Quartz Software, General Electric, FAA, AFRL, U.S. Air Force, U.S. Army, U.S. Navy, Defense Advanced Research Projects Agency (DARPA), Distributed Engine Controls Working Group Consortium, Honeywell, BAE Systems, UTC Aerospace Systems, Ohio Aerospace Institute, U.S. small businesses and universities
University Innovation (UI)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: HQ Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): N/A

Acquisition Strategy

TACP research and technology development focuses on foundational research capabilities. The program uses of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages teaming among large companies, small businesses, and universities.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

MAJOR CONTRACTS/AWARDS

TACP awards multiple smaller contracts, which are generally less than $5 million, and widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2020	The 12-month review is a formal independent peer review. Experts from other Government agencies report on their assessment of technical and programmatic risk and/or project weaknesses.	Received expert feedback on project improvement from the Panel. Determined that the project(s) made satisfactory progress in meeting technical challenges and met all annual performance indicators.	Oct 2021

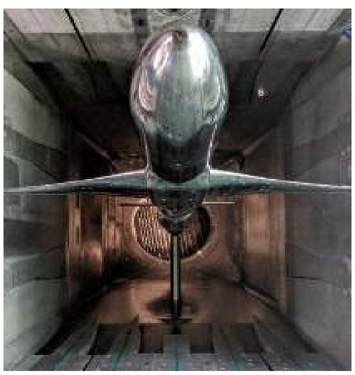
AEROSCIENCES EVALUATION AND TEST CAPABILITIES

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**117.0**	**116.9**	**117.0**	**117.0**	**117.0**	**117.0**	**117.0**
Change from FY 2021			**0.1**				
Percentage change from FY 2021			**0.1%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.



Pictured above is the Common Research Model at the Langley Research Center (LaRC) National Transonic Facility.

The Aerosciences Evaluation and Test Capabilities (AETC) Portfolio sets the strategic direction and funds operations, maintenance, and upgrades of NASA's versatile and comprehensive portfolio of aerosciences ground-test capabilities and assets. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels, propulsion test facilities, and specialty tunnels at the Ames Research Center (ARC), Glenn Research Center (GRC), and Langley Research Center (LaRC). NASA’s integrated approach to test capability planning, use, and management also considers complementary computational tools, software, and related systems to effectively acquire and process research data.

Through broad alliances outside of NASA, AETC optimizes the use of these capabilities across the Government. NASA participates in the National Partnership for Aeronautical Testing and collaborative working groups that include NASA, the Department of Defense (DoD), and other partners. Members of these working groups: (1) gain awareness of capabilities across the government, academia, and industry; (2) share best practices; (3) provide technical support; and (4) refer test programs to facilities best suited to meet test requirements.

Within NASA, AETC directly supports the testing needs of four mission directorates: Aeronautics Research Mission Directorate, Human Exploration and Operations Mission Directorate, Science Mission Directorate, and the Space Technology Mission Directorate.

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

ACHIEVEMENTS IN FY 2020

- Despite the COVID-19 pandemic, AETC wind tunnels supported testing and new capability investments, albeit at reduced levels. Approximately half of the normal annual tunnel utilizations supported various NASA mission testing needs, including those related to advanced aircraft engine concepts, future space exploration mission vehicle developments (e.g., Space Launch System [SLS], Orion), planetary entry system modeling, external customer tests, and multiple classified tests in support of national security efforts.
- AETC demonstrated reduced test section background noise by completing an acoustic characterization of the NASA GRC 9-foot x 15-foot Low-Speed Wind Tunnel. The improvements reduced tunnel background noise to enable testing of more advanced aircraft engine fan technologies.
- At the LaRC 14-foot x 22-foot Subsonic Wind Tunnel, AETC supported the SLS Liftoff/Transition Test and the Dragonfly Mission to Titan with a Rotor Propeller Test.

WORK IN PROGRESS IN FY 2021

- AETC brought back to full operations all 12 of NASA's large wind tunnels after a long duration shutdown stemming from the COVID-19 pandemic. AETC is providing wind tunnel support for various Agency mission testing needs including advanced aircraft engine concepts, future space exploration mission vehicle developments, planetary entry system modeling, external customer tests, and multiple classified tests in support of national security activities.
- AETC will fabricate and install a new Mach 6 nozzle in the LaRC 8-foot High-Temperature Tunnel. The upgraded wind tunnel will provide high-fidelity, true enthalpy, and true pressure Mach 6 test environments for durations of up to five minutes required to meet future NASA and DoD hypersonic vehicle ground test requirements.
- AETC will evaluate and report on the operational capability of the GRC Propulsion Systems Laboratory to address potential issues for future full-scale engine and component tests with controllable icing conditions.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- AETC will assess the condition and health of testing capabilities at ARC, GRC, and LaRC. The review will identify equipment with a high-risk of failure due to age or maintenance issues.
- AETC wind tunnels will support NASA's various mission testing needs including those related to advanced aircraft engine concepts, future space exploration mission vehicle developments, planetary entry system modeling, external customer tests, and multiple classified tests in support of national security requirements.
- AETC will deploy a new propulsion-aircraft/spacecraft simulation testing and calibration capability at the NASA Ames Unitary Plan Wind Tunnel. This new capability enables acquisition of next generation aerodynamic test data from aircraft and spacecraft models that integrate with propulsion simulators (e.g., air ejection nozzle or air-powered turbine propulsion simulators).
- AETC will improve integration of Computational Fluid Dynamics (CFD) and experimental testing, which will allow more efficient, optimized testing for all customers, and provide a strong basis in future capability sustainment. AETC will complete an assessment of the accuracy and efficiency of

computational analysis compared to the LaRC Unitary Plan Supersonic Wind Tunnel testing across multiple models having a wide spectrum of aerodynamic prediction challenges. NASA will use methods learned from this assessment in future wind tunnel assessments.

Program Element

AEROSCIENCES EVALUATION AND TEST CAPABILITIES (AETC)

Aerosciences ground-test capabilities (e.g., facilities, systems, workforce, and tools) that support future aircraft, space vehicles, and operations require efficient and effective investment, operations, and management. Efforts in this area preserve and enhance ground test capabilities necessary to achieve the Agency's multi-Mission requirements. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels and propulsion test facilities at Ames Research Center in Mountain View, CA, the Glenn Research Center in Cleveland, OH, and Langley Research Center in Hampton, VA. These test facilities and capabilities also serve the needs of non-NASA users. NASA's integrated approach to test capability planning, use, and management will consider the complementary computational tools, software, and related systems to effectively acquire and process research data. NASA offers research customers high-quality data that accurately reflects the simulated test environment and the interactions of test articles in those test environments. Furthermore, NASA expertise helps ensure safe and successful use of the assets and the high quality of research outcomes. The portfolio is crosscutting and supports the Aeronautics Research Mission Directorate's Strategic Thrusts, as well as other Agency efforts and those of key industry partners.

Program Schedule

Date	Significant Event
Sep 2021	AETC – Completion of capability for a full life cycle Mach 6 testing at long durations for NASA LaRC 8-foot High-Temperature Tunnel
Jan 2022	AETC – Completion of report on the evaluation of CFD for testing at high supersonic speeds at LaRC Unitary Wind Tunnel
Feb 2022	AETC – Completion of ARC Propulsion Simulator Calibration Facility

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

Program Management & Commitments

Program Element	Provider
Aerosciences Evaluation and Test Capabilities (AETC)	Provider: ARC, LaRC, GRC Lead Center: HQ Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): TBD

Acquisition Strategy

AETC uses of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions NASA strongly encourages teaming among large companies, small businesses, and universities.

MAJOR CONTRACTS/AWARDS

AETC awards multiple smaller contracts, which are generally less than $5 million, and are typically with industry, which provide systems applicable to the sustainment and operations for large-scale wind tunnel assets.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance (Annual)	Expert Review	Nov 2020	This 12-month review is a formal independent peer review. Experts from other NASA Missions report on their assessment of technical and programmatic risk and/or program weaknesses.	This was a very favorable review. The Expert Reviewers encouraged the team to continue improving its processes and communicate to customers their prioritization strategy for return-to-test.	Nov 2021

STEM ENGAGEMENT

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
NASA Space Grant	48.0	51.0	**57.0**	58.2	59.4	60.8	62.1
Established Program to Stimulate Comp Research	24.0	26.0	**26.0**	26.5	27.1	27.7	28.3
Minority University Research Education Program	36.0	38.0	**48.0**	49.0	50.1	51.2	52.3
Next Gen STEM	12.0	12.0	**16.0**	16.3	16.7	17.1	17.4
Total Budget	**120.0**	**127.0**	**147.0**	**150.0**	**153.3**	**156.7**	**160.2**
Change from FY 2021			**20.0**				
Percentage Change from FY 2021			**13.9%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

STEM ENGAGEMENT

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
NASA Space Grant	48.0	51.0	**57.0**	58.2	59.4	60.8	62.1
Established Program to Stimulate Comp Research	24.0	26.0	**26.0**	26.5	27.1	27.7	28.3
Minority University Research Education Program	36.0	38.0	**48.0**	49.0	50.1	51.2	52.3
Next Gen STEM	12.0	12.0	**16.0**	16.3	16.7	17.1	17.4
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Percentage Change from FY 2021			**13.9%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Montage of students from NASA's 2020 internships program cohort. These students participated virtually during the pandemic with exciting projects and experiences.

NASA will continue to make vital investments in Science, Technology, Engineering, and Mathematics (STEM) engagement, in direct alignment with the Administration's priority of building a future diverse STEM workforce. The Office of STEM Engagement (OSTEM) will continue to lead the Agency's STEM engagement function, providing strategic guidance and charting direction in partnership with the mission directorates. OSTEM will also continue to manage the STEM Engagement Program.

The scope of NASA STEM Engagement comprises all endeavors to attract, engage, and educate students and to support educators and educational institutions. STEM Engagement is comprised of a broad and diverse set of programs, projects, activities, and products. This encompasses student internships and fellowships; student learning opportunities (e.g., challenges and competitions, camps, and other hands-on and virtual experiences); informal education and out-of-school learning activities; educational products, tools, and platforms; educator and faculty support; competitive grants and cooperative agreements to educational institutions for research and development and institutional support; and strategic partnerships with organizations to expand reach and impact.

NASA will continue to support Federal STEM education priorities and drive strategic alignment of the Agency's STEM engagement efforts through the NASA Strategy for STEM Engagement (2020-2023) via three strategic goals:

- Create unique opportunities for a diverse set of students to contribute to NASA's work;

- Build a diverse future STEM workforce by engaging students in authentic learning experiences with NASA's people, content, and facilities; and
- Attract diverse groups of students to STEM through learning opportunities that spark interest and provide connections to NASA's mission and work.

These goals, along with their corresponding objectives and strategies, guide the Agency's STEM engagement efforts and are complemented by five design principles to guide the planning and execution of work in direct support of achieving the strategic goals: (1) mission-driven authentic STEM experiences, (2) evidence-based practices, (3) scalability, (4) outcome-driven, and (5) diversity and inclusion.

OSTEM is accountable for the management of NASA's STEM Engagement Program, comprised of four projects: National Space Grant College and Fellowship Project (Space Grant); Established Program to Stimulate Competitive Research (EPSCoR); Minority University Research and Education Project (MUREP); and Next Generation STEM Project (Next Gen STEM). These projects are outlined in detail in subsequent sections.

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Budget provides increases for Space Grant and MUREP. With the additional funding in Space Grant, NASA will look to expand opportunities to partner with mission directorates, in areas that further mission directorate priorities and align with Space Grant capabilities. NASA will focus on collaborating with Space Grant to implement student opportunities that have potential for regional or national scalability and move beyond individual state application. Additionally, NASA will have an increased focus on how Space Grant can address the persistent challenges of broadening participation in STEM and reaching those students who are underrepresented and underserved.

In MUREP, the budget increase will enable a greater reach to Minority Serving Institutions (MSIs) and underrepresented minorities in geographical areas of the country where MUREP does not have investments. Additionally, MUREP intends to focus its student engagement investments on on high school bridge programs and fellowships to encourage students to explore a future career in STEM.

WORK IN PROGRESS IN FY 2021

In FY 2021, OSTEM continues Agency-wide coordination in support of Agency and Federal priorities, to attract, engage, and educate students and toward building the next generation of STEM practitioners and explorers. OSTEM continues to implement enterprise initiatives to improve efficiency and strengthen standards and rigor in program management, fiscal accountability, and performance measurement. In FY 2021, NASA will continue to implement a mission-driven STEM Engagement program through its four projects. Details regarding project plans and activities are provided in dedicated subsequent sections.

In FY 2021, NASA's STEM Engagement enterprise is committed to implementing the following:

- Drive strategic alignment and a mission-driven programmatic model. This includes conducting a comprehensive analysis of the portfolio and building on programmatic efforts established in partnership with the mission directorates.
- Implement cross-cutting strategies toward more effective operations. OSTEM will complete development and deployment of a new STEM Gateway, replacing an outdated performance

measurement system with a single platform integrating student registration, functional management and performance measurement and analytics. OSTEM will also continue its work in significantly enhancing the digital footprint to better reach students, including improved products at https://stem.nasa.gov. In addition, NASA will drive progress on the Agency internships program, with objectives for growth and enhanced student experiences. NASA will also continue implementation of a new partnerships' strategy, cultivating new partnerships to scale reach and impact. Finally, OSTEM will continue to implement and build upon the new STEM Engagement Performance Assessment and Evaluation Learning Agenda and conduct a set of studies to inform evidence-based program changes.

- Meet students and educators where they are during the pandemic. NASA will continue translating student activities to virtual implementation and augmenting to improve learning in a virtual environment, while working with partners and collaborators to address challenges of the digital divide. Also, OSTEM will continue to work with grantees and partners to accommodate and adapt in the pandemic environment. This includes oversight of the recently awarded TEAM II Remote Opportunity Rapid Response awards to informal education institutions to develop innovative remote learning opportunities, capable of reaching a diverse set of students.
- Focus on broadening student participation. NASA has developed a new integrated action plan toward broadening student participation in STEM engagement programs and activities. OSTEM will continue to capitalize on MUREP to build effective partnerships to drive results and will utilize the evidence-based results to drive changes in programmatic efforts.
- Further an enterprise operating model and focus on building skills and capabilities.

NASA is committed to defining and implementing a portfolio of projects, activities and products directed toward achieving the Agency's Strategy for STEM Engagement goals and objectives. Ultimately, the work dedicated to this strategy will contribute to achieving NASA's STEM Engagement vision to immerse students in NASA's work, attract students to STEM, and inspire the next generation to explore.

KEY ACHIEVEMENTS PLANNED IN FY 2022

NASA will execute a new integrated action plan toward broadening student participation in STEM Engagement programs and activities. This plan has outlined discrete initiatives and identified best practices already underway under four overarching goals:

- Enhance communications and stakeholder engagement, and build networks and relationships dedicated to broadening student participation;
- Strengthen practices and systems toward broadening student participation;
- Build a solid foundation for a focus on metrics and evaluation to effectively measure progress in broadening student participation; and
- Drive a collective focus across NASA's STEM Engagement community on broadening student participation and foster a commitment to achieving more diversity, equity, and inclusion in student opportunities and programs.

This integrated action plan will include leveraging increased investments through MUREP and Space Grant, as well as pursuing partnerships to reach diverse groups of students and educators in Next Gen

STEM. Specific plans are outlined in dedicated subsequent sections for each of the four STEM Engagement projects.

Additionally, STEM Engagement will also aim to engage students by expanding the use of strategic partnerships and networks to magnify the impact of its efforts and investments. Space Grant will continue to build on its existing national network of universities with interests and capabilities in aeronautics, space, and related fields to provide hands-on learning experiences for U.S. undergraduate and graduate students. For example, increased funding will enable the Space Grant consortia to increase impact of NASA learning opportunities centered around the 2023 and 2024 Eclipses. Space Grant will also look to extend its reach through mission directorate cost-matching awards, in areas that further mission directorate priorities and align with Space Grant capabilities. Similarly, MUREP will seek to expand its investments in activities that connect with both internal NASA partners, like mission directorates, and external partners, like the National Science Foundation, which will increase research capacity of MSIs, directly contribute to mission directorate needs, and amplify efforts to reach underserved and unrepresented students. Within the Next Gen STEM project, NASA will use partnerships to enhance of NASA's continuum of K-12 student opportunities, especially those dedicated to reaching underserved student groups.

NASA SPACE GRANT

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**48.0**	**51.0**	**57.0**	**58.2**	**59.4**	**60.8**	**62.1**
Change from FY 2021			**6.0**				
Percentage change from FY 2021			**11.8%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

University of Idaho students launch a high-altitude balloon with a radiosonde during a practice launch in summer 2020.

Space Grant is a competitive grant opportunity that enables the active involvement of 52 consortia in 50 States, the District of Columbia, and the Commonwealth of Puerto Rico. Space Grant supports and enhances science and engineering education and research efforts for educators and students by leveraging the resource capabilities and technologies of over 1,000 affiliates from universities, colleges, industry, museums, science centers, and State and local agencies. Cooperative Agreements with each consortium align their work with the Nation’s science, technology, engineering, and mathematics (STEM) education priorities, NASA's missions, and the annual Agency performance goals.

Space Grant utilizes key NASA resources in order to provide students access to research and hands-on STEM learning experiences. These experiences may include working with high-altitude balloons, sounding rockets, aircraft, computer code, or small satellites. In order to maximize impact for these STEM investments, Space Grant leverages Agency resources in STEM education through strategic collaborations with NASA centers, subject matter experts, and mission directorates.

All activities conducted by the 52 consortia are in alignment with Agency goals, the Office of STEM Engagement (OSTEM) priorities, and the National Science and Technology Council's (NSTC) Committee on Science, Technology, Engineering, and Math Education (CoSTEM) priority areas. In terms of direct student support, Space Grant awards at the state level consist of scholarships, fellowships, and/or internships. The Consortia provide a broad array of projects in support of higher education, research infrastructure, as well as pre-college and informal education that directly align with NASA's mission directorates. Space Grant consortia also support flight project activities led by student teams. Some of those flight activities include:

- RockOn! Workshop
- RockSat-C

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- First Nations Launch in collaboration with Minority University Research and Education Project (MUREP)
- High Altitude Student Platform in collaboration with SMD

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Budget provides a $6 million increase to Space Grant to expand STEM opportunities for students through the Consortia's base awards and other initiatives. FY 2022 will see an increase of at least $100,000 per Consortium to increase the number of student awards and other programming within each Consortium. With the additional funding in Space Grant, NASA will look to expand opportunities to partner with mission directorates on awards that further mission directorate priorities and align with Space Grant capabilities. Additionally, NASA will have an increased focus on how Space Grant can address the persistent challenges of broadening participation in STEM and reaching underrepresented and underserved students.

ACHIEVEMENTS IN FY 2020

In FY 2020, Space Grant consortia each received a new four-year base award. These new base awards will be active until FY 2024. These base awards implemented a significant programmatic change by dissolving the old Consortium classifications of Designated, Program Grant, and Capability Enhancement and providing level funding for all 52 Consortia. For this base award period, the Consortia proposed activities that show direct alignment with NASA's four mission directorate needs and priorities. For the base award, the Consortia must apply at least 26 percent of their NASA funds toward direct student awards.

FY 2020 also saw the creation of two Independent Program-Level Evaluation efforts competitively awarded to New Mexico State University and University of Alaska, Fairbanks. Both awards will enable the Space Grant Consortia to interrogate timely and pertinent research questions about the overall efficacy of the Space Grant Program and how the States retain students in STEM. The two pilot awardees will have two years to conduct smaller regional-scale evaluations that lay a foundation for a national level evaluation to be conducted over the last two years of the base award period of performance.

Space Grant also delivered on conducting a highly anticipated Artemis Student Challenge competitive awards solicitation, with six awardees each receiving a portion of their funding from Space Grant, and other funding directly from NASA's mission directorates. This level of combined resources provides additional funding to the Consortia to conduct national-scale projects that expand the reach of the Artemis Program by focusing on three different themes. For Artemis Teaching and Resource Availability awards, the University of Alabama, Huntsville and the University of Illinois, Champaign-Urbana will provide foundational resources on specific aspects of the Artemis Program. For Artemis Core Technologies awards, the University of Colorado, Boulder and the University of Hawaii, Honolulu will provide hands-on learning activities, utilizing small satellite platforms. Lastly, for Artemis Student Challenges awards, the University of California, San Diego and University of Washington will each lead nation-wide student challenges that will develop a Lunar/Martian lander, exploration, and habitation skills.

Space Grant also provided additional opportunities for the Consortia to directly participate in other mission directorate projects or other OSTEM projects. For instance, Space Grant partnered with MUREP to expand the highly successful First Nations Launch Program, which is managed by the Wisconsin Space Grant Consortium. Space Grant partnered with STMD to provide an expanded Breakthrough, Innovative,

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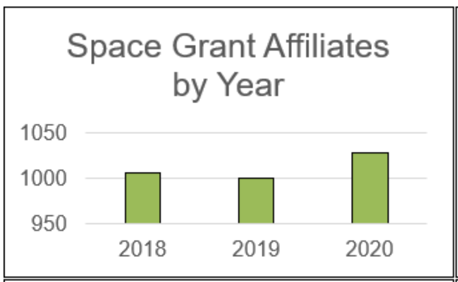
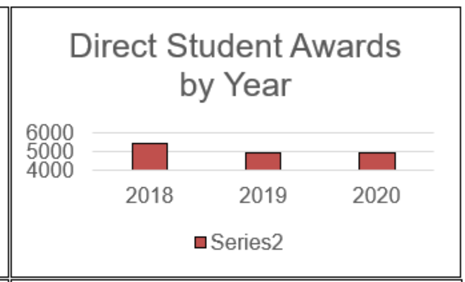
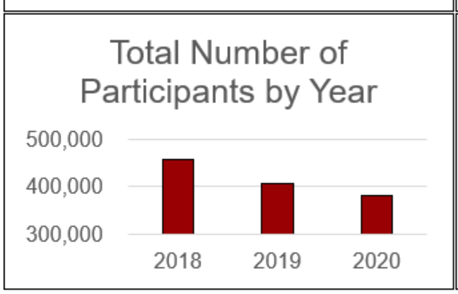
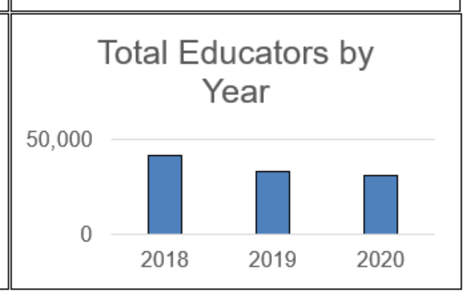
Game Changing Idea Challenge in FY 2020. The expansion allowed for larger awards to STMD selected teams from the Space Grant Consortia to design, build, and test a low-cost sample payload targeted for delivery to the lunar surface. The proposed payload should demonstrate technology systems needed for exploration and science in the Permanently Shadowed Regions (PSRs) in and near the lunar polar regions.

Space Grant Awards in FY 2020		
Award Type	**Number of Awards**	**Funding Total**
Base Awards	52	$39,795,925
Independent Evaluation Awards	2	$499,721
Space Grant Artemis Student Challenge Awards	6	$1,199,166
Special Topics	10	$678,870









COVID-19 directly impacted every state, and thus every Consortium. The Consortia had reductions in student awards attributed to a lack of opportunities for hands-on learning experiences due to university/college facility closures, which is reflected in the reduction of student awards in FY 2020. Space Grant directly supported 4,936 students through NASA Internship and Fellowship (NIF) awards. COVID-19 also impacted the Consortia's abilities to reach K-12 students and educators with face-to-face activities. Yet, the number of Consortia affiliates increased (now 1,028) in FY 2020 because of the positive track record Space Grant has established for over 30 years. Lastly, Space Grant supported over 200 publications despite COVID-19 restrictions impeding access to laboratories and facilities.

Space Grant targeted elementary and secondary students through NASA's informal education activities, Web-based activities, and other instructional and enrichment activities, reaching more than 350,000 pre-college students and more than 30,000 educators.

FY 2020 was the 30th anniversary of the founding of Space Grant. Consortia held a multitude of events to promote and highlight this significant milestone. During the Annual National Space Grant Spring

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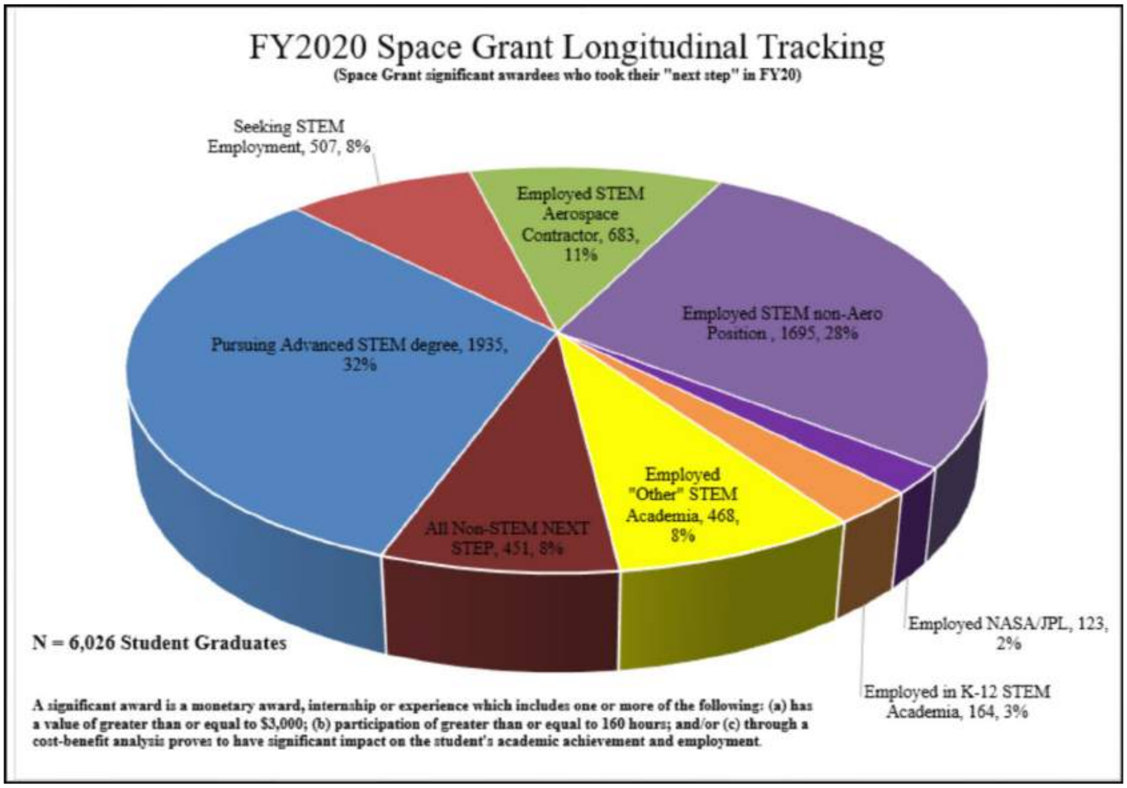
Directors Meeting, Space Grant hosted a 30th anniversary celebration in the rotunda of the Rayburn House Office Building on February 24, 2020.

The graph below represents students who participated in Space Grant Consortia programming from 2015 to 2020 and have since graduated from college in 2020.



WORK IN PROGRESS IN FY 2021

Space Grant consortia are currently implementing activities outlined in their four-year accepted proposals. In FY 2021, the Space Grant project successfully released and awarded two funding augmentations which provided the opportunity for the Consortia to propose raising their base award funding levels to $800,000. The work of the FY 2020 Independent Evaluation awards continues with each awardee providing an evaluation plan and in the beginning stages of their approved work. Lastly, the Artemis Student Challenge awardees have made significant progress despite COVID-19 impacting their ability to recruit students, to have the students conduct the necessary research, and to access to the required facilities. All teams passed their first gate checks, which provided approval to proceed to Phase 2 of their proposed milestones. The Space Grant project continues to monitor the execution of all the awards especially considering continued impacts associated with the COVID-19 pandemic.

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KEY ACHIEVEMENTS PLANNED FOR FY 2022

The budget supports base awards for the 52 consortia to do the following:

- Provide hands-on learning experiences for U.S. graduate and undergraduate students to prepare them for the future workforce and/or academic careers;
- Conduct programs and projects that align with the NASA STEM engagement and mission directorate priorities, CoSTEM priority areas, and State-specific needs to build STEM pathways in higher education, research infrastructure, pre-college and informal education;
- Promote a strong STEM education base from elementary through secondary levels while preparing teachers in these grade levels to become more effective at improving student academic outcomes;
- Build upon and maintain the existing national network of universities with interests and capabilities in aeronautics, space, and related fields; and
- Leverage the opportunities emerging from the NASA OSTEM strategy to develop high-impact, nationwide partnerships.

Additionally, in FY 2022 Space Grant will:

- Release, approve, and award base award augmentations to raise the base award funding level to at least $820,000 per Consortium;
- Provide a new competitive opportunity for multiple Consortia to propose jointly to expand the reach and impact of NASA learning opportunities and content with a focus on underserved K-12 communities;
- Down-select one awardee to complete the program-level evaluation for the remaining base award period from the two pilot awards; and
- Provide funded extension of the six Space Grant Artemis Student Challenges with new end dates in August 2022.

Project Schedule

Date	Significant Event
Q1 FY 2022	Release of K-12 Notice of Funding Opportunity (NOFO)
Q2 FY 2022	Selections of K-12 awards
Q2 and Q3 FY 2022	Release of Year 3 base award funding
Q4 FY 2022	Down select of Independent Program-Level Evaluation Award

NASA SPACE GRANT

Project Management & Commitments

The Space Grant Project Manager at NASA Headquarters provides management responsibility for day-to-day Space Grant operations. Civil servants at NASA centers actively engage with regional Space Grant Consortia, providing direction, oversight, and integration with center and mission directorate activities.

Acquisition Strategy

NASA solicits through competitive proposals from Space Grant 52 consortia in 50 States, District of Columbia, and the Commonwealth of Puerto Rico. Each Consortium program or project must align with the Administration priorities, NASA's Strategic Plan, and the NASA Strategy for STEM Engagement. All award selections undergo rigorous peer reviews by internal and external panels that evaluate technical merit, assess content, feasibility, and alignment to Agency STEM engagement, research, and technology goals. Awards are typically multi-year.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

NASA continues to use performance assessment and evaluation-driven processes to enhance the effectiveness of STEM engagement investments, executing a refined OSTEM learning agenda to understand the outcomes of its investments. Space Grant has continuously assessed its contents and activities in pursuit of continuous improvement, in the context of the OSTEM learning agenda.

Space Grant will have an independent performance assessment review in the fourth quarter of FY 2024 to assess their accomplishments and strategies.

ESTABLISHED PROGRAM TO STIMULATE COMP RESEARCH

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**24.0**	**26.0**	**26.0**	**26.5**	**27.1**	**27.7**	**28.3**
Change from FY 2021			**0.0**				
Percentage change from FY 2021			**0.0%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

NASA EPSCoR project researcher, Dr. Ellyn Enderlin, and students working on the snow pit at Lower Deer Point near Bogus Basin in Idaho. The team will also use NASA's ICESat-2 laser altimeter data and the water-penetrating nature of the ICESat-2 laser to map stream cross sections and to estimate seasonal snow and ice meltwater fluxes to the streams.

The NASA Established Program to Stimulate Competitive Research (EPSCoR) project provides cooperative agreement opportunities designed to establish partnerships between government, higher education, and industry to build stronger research and development capabilities in 28 eligible EPSCoR jurisdictions (States or regions). The project strives to improve a jurisdiction's research infrastructure to a level such that its research and development programs contribute to its economic development. EPSCoR supports competitively funded awards and provides research and technology development opportunities for research teams. NASA actively seeks to integrate the research conducted by EPSCoR jurisdictions with the scientific and technical priorities pursued by the Agency. EPSCoR has established a series of individual components to facilitate this work.

EPSCoR Research Infrastructure Development (RID) Cooperative Agreement enables States to build and strengthen relationships with NASA researchers. Beginning in FY 2022, the RID will have a five-year base period of performance with awards up to $200,000 per year, for a total of $1 million.

EPSCoR Research Cooperative Agreement addresses topic-specific, high-priority NASA research and technology development needs. Awards are up to $750,000 for a three-year performance period with all funding provided at the beginning of the award.

EPSCoR International Space Station (ISS) Flight Opportunity Cooperative Agreement utilizes the ISS as a microgravity platform or test bed for a space flight demonstration of the basic ground research.

ESTABLISHED PROGRAM TO STIMULATE COMP RESEARCH

EPSCoR Suborbital Flight Opportunity Cooperative Agreement Pilot (new in 2021) utilizes the STMD Suborbital Flight capability as a short-term microgravity platform or test bed for a suborbital flight demonstration (reusable rockets, balloons, or parabolic flight) of the basic ground research.

EPSCoR Rapid Response Research (R3) Cooperative Agreement is a collaborative effort between EPSCoR and the NASA Science Mission Directorate, centers, commercial partners, and others, to provide a streamlined method to address high priority research issues important to NASA.

EPSCoR uses the latest National Science Foundation (NSF) eligibility table to determine overall jurisdiction eligibility for NASA EPSCoR. The NSF eligibility table is available at: https://www.nsf.gov/od/oia/programs/epscor/Eligibility_Tables/FY2021_Eligibility.pdf

EXPLANATION OF MAJOR CHANGES IN FY 2022

The EPSCoR program will partner with the Science Mission Directorate and Space Technology Mission Directorate to extend the NASA Suborbital Flight Opportunities (SFO) program to EPSCoR jurisdictions. The SFO facilitates rapid demonstration of promising technologies for space exploration, discovery, and the expansion of space commerce through suborbital testing with industry flight providers. EPSCoR awards researchers $200,000 to work with NASA for a three-year performance period with funding provided up front and no cost-sharing requirement.

NASA/NSF Fellows Advancing in Science and Technology (FAST) Pilot is a joint pilot effort of NSF EPSCoR and NASA EPSCoR specifically focusing on Institutions of Higher Education (IHE), primarily serving underrepresented minorities, students with disabilities, women's colleges and Primarily Undergraduate Institutions (PUI). NSF and NASA aim to recognize efforts to build research capacity and transform the career trajectories of early career investigators at these institutions and to further develop their individual research potential through extended collaborative research at selected NASA centers and at their home institutions.

ACHIEVEMENTS IN FY 2020

In FY 2020, NASA EPSCoR invested a total of $18,936,769 through awards via the aforementioned components. Below are the amounts allocated to each component.

EPSCoR Awards in FY 2020 (Component Award Values)		
Element	**Awards**	**Total Amount**
EPSCoR Research Infrastructure Development (RID) continuation	28	$4,200,000
Research	15	$11,249,804
ISS Flight Opportunity	7	$699,556
Rapid Response Research (R3)	28	$2,787,409
Total	**78**	**$18,936,769**

NASA EPSCoR funded academic research has provided benefits and has increased competitive research capacity within targeted jurisdictions. The EPSCoR Stimuli document highlights EPSCoR-funded

ESTABLISHED PROGRAM TO STIMULATE COMP RESEARCH

research accomplishments within the eligible jurisdictions, and is available here for 2017-2020: https://www.nasa.gov/stem/epscor/home/EPSCoR_Stimuli.html

The NASA EPSCoR project has grown over the years from one research solicitation per year and an infrastructure award every three years. The project has developed collaborative opportunities with the mission directorates to award Suborbital Flight Opportunities to conduct research and partnered with NSF in a pilot program titled the NASA/NSF Fellows Advancing in Science and Technology (FAST).

WORK IN PROGRESS IN FY 2021

EPSCoR will make new Research, R3, ISS, Suborbital, and FAST awards. Each funded proposal will establish research activities with the potential to make significant contributions to NASA's strategic research and technology development priorities while at the same time contributing to the overall research infrastructure, science and technology capabilities of higher education, and economic development within the EPSCoR jurisdiction.

Additionally, EPSCoR uses its collaboration with the nine NASA centers and JPL to provide workshops aimed at increasing the jurisdiction's knowledge of NASA's unique and innovative capabilities, resources, and facilities. An example of this is two 2021 Proposal Writing workshops for the jurisdictions provided by JPL and SMD.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

NASA EPSCoR will utilize NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) to issue a call for 28 formula RID awards, 5-10 ISS Flight Opportunity awards, 5-8 Suborbital Flight Opportunity awards, 30-35 R3 awards, 15-18 Research Cooperative Agreement Notice (CAN) awards, support Technical Interchange Meetings (TIMs), and support Science Mission Directorate/EPSCoR provided workshops. NASA EPSCoR research priorities are defined by the Mission Directorates (Aeronautics Research, Human Exploration and Operations, Science, and Space Technology), and NASA's centers and Jet Propulsion Laboratory (JPL). Each funded NASA EPSCoR proposal establishes research activities that will make significant contributions to the strategic research and technology development priorities of one or more of the mission directorate programs.

For additional information on NASA research via NSPIRES solicitations, please visit: http://nspires.nasaprs.com (select "Solicitations" and then "Open Solicitations" and type in keyword "EPSCoR"). Appendix A of the Research CAN provides a summary of the Research priorities for each of the mission directorates and centers. This Appendix is provided in advance to the jurisdictions so the jurisdictions can plan their proposals.

ESTABLISHED PROGRAM TO STIMULATE COMP RESEARCH

Project Plan

Date	Significant Event
Q1 and Q2 FY 2021	Release of Solicitations: *Research Cooperative Agreement* *Research Infrastructure Development (RID)* *EPSCoR Rapid Response Research (R3)* *ISS Flight Opportunity* *NASA/NSF Fellows Advancing in Science and Technology (FAST)* *Suborbital Flight Opportunities (SFO)*
Q1 and Q2 FY 2021	Proposals Due and Review Process
Q3 and Q4 FY 2021	Selection and Awards: *Research Cooperative Agreement* *Research Infrastructure Development (RID)* *EPSCoR Rapid Response Research (R3)* *ISS Flight Opportunity* *NASA/NSF Fellows Advancing in Science and Technology (FAST)* *Suborbital Flight Opportunities (SFO)*

Project Management & Commitments

The NASA EPSCoR project manager is responsible for overall administrative duties of this national project. The project manager is located at Kennedy Space Center (KSC) and the new deputy project manager is located at Stennis Space Center (SSC). Management responsibility for day-to-day operations is provided by these two key positions. Contractor staff and representatives from each NASA mission directorate work closely with EPSCoR project management to ensure that current and future research requirements are in EPSCoR solicitations. The mission directorate representatives serve as the proposal selection committee, further ensuring that the selected work contributes to NASA priorities. Technical monitors from the NASA centers and Headquarters monitor and assess the progress of each award. They provide scientific guidance and technical advice as required throughout the year regarding the overall progress of the proposed effort and review all progress reports. Additional involvement may occur depending upon the nature of the collaboration already established or desired. This includes integrating the EPSCoR research into ongoing activities or research efforts and increasing the principal investigating team's awareness of other related or relevant research within NASA. Additionally, NASA is a member of the Federal EPSCoR Interagency Coordinating Committee (EICC), chaired by the NSF. The committee works to improve the leveraging of Federal EPSCoR investments. NASA EPSCoR continues to develop strategies to adhere to the guidance within the America COMPETES Act. The America COMPETES Act authorizes Federal investments in science and early-stage technology research and development (R&D). The original law was signed in 2007 and the latest reauthorization was signed on January 6, 2017 as Public Law 114-329. Among other provisions, the law affirms the merit review process of EPSCoR research proposals and changes the name of EPSCoR to Established (instead of Experimental) Program to Stimulate Competitive Research.

ESTABLISHED PROGRAM TO STIMULATE COMP RESEARCH

Acquisition Strategy

NASA solicits and awards EPSCoR Cooperative Agreements through a competition among institutions from designated EPSCoR States. Each jurisdiction's proposal must align with the Administration's priorities and NASA's Strategic Plan. All award selections undergo rigorous peer reviews by internal and external panels that assess technical merit, content, feasibility, and alignment to Agency research and technology goals. Awards are typically multi-year.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

NASA continues to use performance assessment and evaluation-driven processes to enhance the effectiveness of STEM engagement investments, executing a refined Office of STEM Engagement (OSTEM) learning agenda to understand the outcomes of its investments. EPSCoR has continuously assessed its contents and activities in pursuit of continuous improvement, in the context of the OSTEM learning agenda.

MINORITY UNIVERSITY RESEARCH EDUCATION PROGRAM

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**36.0**	**38.0**	**48.0**	**49.0**	**50.1**	**51.2**	**52.3**
Change from FY 2021			**10.0**				
Percentage change from FY 2021			**26.3%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

PR-SPRInT Principal Investigator, Dr. Eduardo Nicolau, works on an experiment with Perla Cruz-Tato (former NASA ASTAR Fellow). University of Puerto Rico, Rio Piedras astronauts' immune systems in space.

MUREP provides financial assistance (grants and cooperative agreements) to the Nation's Historically Black Colleges and Universities, Hispanic Serving Institutions, Asian American and Native American Pacific Islander-Serving Institutions (AANAPISI), Tribal Colleges Universities, Alaska Native and Native Hawaiian Institutions (ANNH), Predominantly Black Institutions (PBI), and eligible community colleges. These minority-serving institutions (MSIs) play a vital role in educating students who may be underrepresented and underserved in STEM, including women and girls, veterans, and persons with disabilities. MUREP's investments in these MSIs are a part of a comprehensive approach toward advancing equity for all, including people of color and others who have been historically underserved, marginalized, and underrepresented in STEM fields.

Participation in NASA projects and research has the potential benefit of both increasing numbers of students in STEM at all education levels and encouraging them to earn degrees in STEM fields that are critical to NASA and the nation.

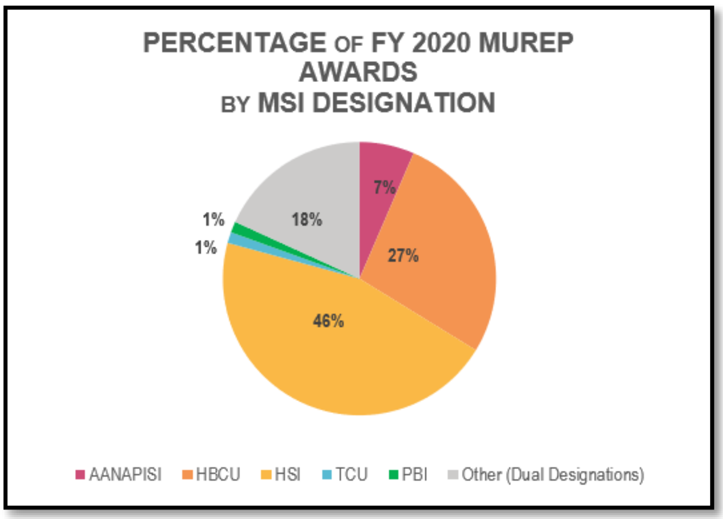
NASA's MUREP investments enhance the research, academic, and technology capabilities of MSIs through competitive, multi-year awards. Awards assist faculty and students in research and provide authentic STEM engagement related to NASA missions. These funded opportunities provide NASA-specific knowledge and skills to historically underrepresented and underserved students in STEM. MUREP investments also assist NASA in meeting the goal of a diverse future workforce through student participation in internships and fellowships at NASA centers and the Jet Propulsion Laboratory (JPL).

MINORITY UNIVERSITY RESEARCH EDUCATION PROGRAM

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Budget provides a $10 million increase to MUREP to expand reach to MSIs and underrepresented minorities (URMs) in geographical areas of the country where MUREP does not have investments; execute a focused strategy to partner with Space Grant Consortia; shift student engagement efforts away from K-8 to make inroads into high school to undergraduate bridge programs; and increase fellowship opportunities and avenues to pursue advanced STEM degrees related to NASA missions and areas of interest.

ACHIEVEMENTS IN FY 2020



Strengthening Minority Serving Institutions (MSI):

In FY 2020, MUREP provided engagement and oversight of 100+ active cooperative agreement awards at MSIs across 28 states and territories.

Student Engagement:

MUREP awarded more than 800 internships and fellowship opportunities to MSI students across all institutional categories and levels in FY 2020. These significant awards provided a total of $7.7 million in direct financial support to higher education students at MSIs.

Innovations to Reach Target Populations during the COVID-19 Pandemic:

MUREP efforts shifted from in-person to virtual programming to support continued engagement of students, faculty, and strategic partners. A collaboration between the University of Texas at El Paso, a MUREP Aerospace Academy (MAA) awardee, and Gadsden Independent School District in New Mexico demonstrates an innovative approach to virtual engagement of underserved and underrepresented communities during the pandemic. The plan to retrofit vehicles to host internet access points allowed STEM engagement opportunities for surrounding remote communities. Initiatives such as this highlight the importance of partnerships within a within a STEM ecosystem that expand the reach of engagement opportunities with students, educators, and families.

MINORITY UNIVERSITY RESEARCH EDUCATION PROGRAM

Leveraging Technology to Drive Participation:

The Minority Serving Institutions (MSI) Exchange is a searchable database that helps those looking for diverse academic collaborators. The MSI Exchange is a curated collection of MSI profiles that include the institution's STEM offerings and capabilities. As an online matchmaking tool, the MSI Exchange aids Federal researchers, industry, and principal investigators seeking diverse partners for mission-focused research through Cooperative Agreements, Space Acts Agreements, grants, and other Federal contracts. The MSI Exchange was piloted in FY 2019 for use through a technology enterprise team at NASA HQ and launched in FY 2020. Since then it has scaled to become a resource for internal and external stakeholders through the addition of digital badges, professional development that promotes MSI competitiveness, and by providing an official NASA MSI List (see: https://www.nasa.gov/sites/default/files/atoms/files/2020-nasa-list-of-minority-serving-institutions.pdf), the only reference the Agency will use to verify an institution's MSI status to determine eligibility for NASA solicitations. Future opportunities to scale the MSI Exchange offerings include rolling out a strategy that identifies the requirements of each mission directorate and matches them with the capabilities of MSIs. For more information, go to: https://msiexchange.larc.nasa.gov/

The MUREP Institutional Research Opportunity (MIRO) aims to promote literacy in STEM at MSIs and to enhance the sustainable capabilities of institutions to perform research and education aligned to NASA's mission. Twenty of these research awards were under cooperative agreement management going into FY 2020 and resulted in over 200 research publications and papers written, more than 275 Research Presentations given, seven patents granted, and the creation of 14 new or revised Courses.

MUREP has instituted the use of planning grants as a method to attract and prepare MSIs who desire to compete for larger funding opportunities. The planning grants have allowed MUREP to better understand the research capabilities of those MSIs who have traditionally not submitted proposals and to leverage relationships to build a more robust MSI pipeline. These planning grants yielded 32 new awards to 24 MSIs.

WORK IN PROGRESS IN FY 2021

MUREP will support multiple award selections to MSIs under the newly released FY 2021 Engagement Opportunities in NASA STEM (EONS) solicitation. By continuing to align much of its funding opportunities to mission directorate research focus areas, MUREP not only adds value to accomplishing the Agency's mission, but through its collaboration and partner relationships with other Federal Agencies, academic and industry leaders, it also develops deeper connections and engagement with Minority Serving Institutions.

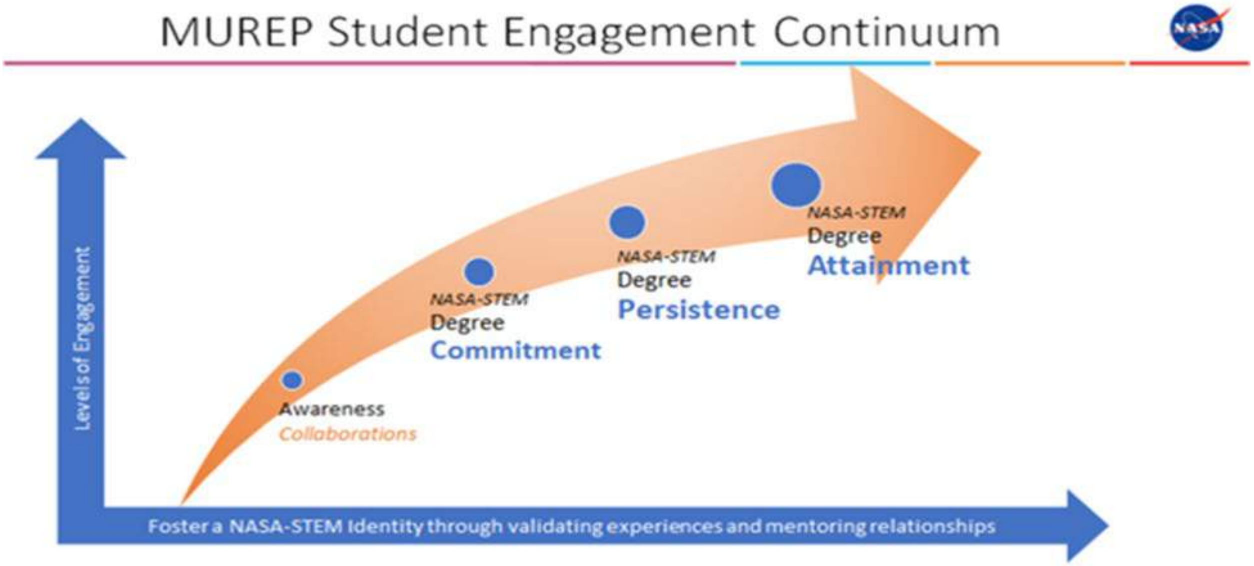
Specific funding efforts will be in support of NASA's ocean-focused research in collaboration with the Science Mission Directorate's Earth Science Division. In addition, MUREP solidified a Memo of Understanding with the National Science Foundation (NSF) to fund implementation awards that promote coalitions aimed to broaden participation in engineering. FY 2021 will also see MUREP encouraging competitiveness by building upon planning grants that foster MSI engagement with the Space Technology Mission Directorate.

MUREP's American Indian and Alaska Native STEM Engagement (MAIANSE) seeks to increase American Indian and Alaska Native engagement in science, technology, engineering, and mathematics (STEM) through authentic and unique NASA experiences. By collaborating with multiple indigenous affinity groups, like the American Indian Science and Engineering Society (AISES) and the American Indian Higher Education Consortium (AIHEC), and creating student engagement options with the

MINORITY UNIVERSITY RESEARCH EDUCATION PROGRAM

Choctaw Nation of Oklahoma via NASA Astro Camp, Tribal Colleges and Universities are able to learn diverse ways to honor traditional customs and practices while actively participating in OSTEM challenges, competitions, and research offerings.

MUREP will also focus on developing a Student Engagement Strategy that balances a portfolio of activities with a diversity of student participants and MSI types toward enhancing STEM degree attainment for underrepresented and underserved students in NASA-related STEM majors by providing opportunities to engage in mission-driven research and technology development efforts.



Due to COVID-19 restrictions, the expansion of virtual offerings for STEM Engagement efforts as well as center-based research experience was necessary to meet the needs of MSI students and faculty.

MUREP plans to provide over 225 new internship and more than 25 new fellowship opportunities so that students can connect with mentors and other interns to grow in their knowledge of pivotal NASA missions during the sessions. MUREP Innovative Technology Transfer Idea Challenge (MITTIC) and NASA Community College Aerospace Scholars (NCAS) both made excellent transitions of their team-based competitions to fully virtual execution and still found creative avenues to broaden student participation, expand reach in recruitment, and provide incentives to sustain the engagement throughout the lifecycle of the activities. Over 35 states were represented in the student competitions.

MUREP has leveraged key partnerships to drive its strategic priorities and increase long-term competitiveness at MSIs including: 1) supporting relationships through its collaboration with the Aeronautics Research Mission Directorate on the MUREP High Volume Manufacturing activity; 2) formalizing internal NASA relationships via the NASA Technology Infusion Road Tour events in partnership with the Offices of Small Business Programs, Procurement and SBIR/STTR (over 100 MSIs participated in these events collectively); and 3) leveraging external partnerships like the work in broadening participation in engineering with the NSF through a formal MOU and solicitation.

MINORITY UNIVERSITY RESEARCH EDUCATION PROGRAM

KEY ACHIEVEMENTS PLANNED FOR FY 2022

Building upon work co-created by MAIANSE and other indigenous collaborators, there will be a dedicated effort to select and award funding to ANNH serving Institutions, Tribal Colleges and Universities, and other higher education institutions to foster the connections of scientific research and the integration of indigenous practices.

The formation of a HBCU-focused sub project would be specifically designed to address deficits in STEM research, faculty development and student success and degree attainment at these institutions. Funding will be provided to initiate, advance, implement and broaden efforts developed by the Nation's HBCUs. The overall aim will be to support competitiveness and sustainability post awards.

Further expansion of MIRO that fund MSIs with necessary resources are critical to not only build capacity but also develop Centers of Excellence that transcend the original awards provided by NASA. These interdisciplinary efforts are cross-cutting and align directly with mission directorate priorities at the Agency.

Project Schedule

EONS is an omnibus announcement that includes a range of NASA STEM Engagement opportunities for basic and applied science and technology research and education. In response to feedback from the MSI community, several improvements to EONS were made in FY 2021, including: 1) establishing November as the set month of release for each updated version of EONS; 2) releasing an annual schedule of NRAs projected to be released under EONS; and 3) proposal writing webinars and workshops to aid MSIs in preparing successful proposals.

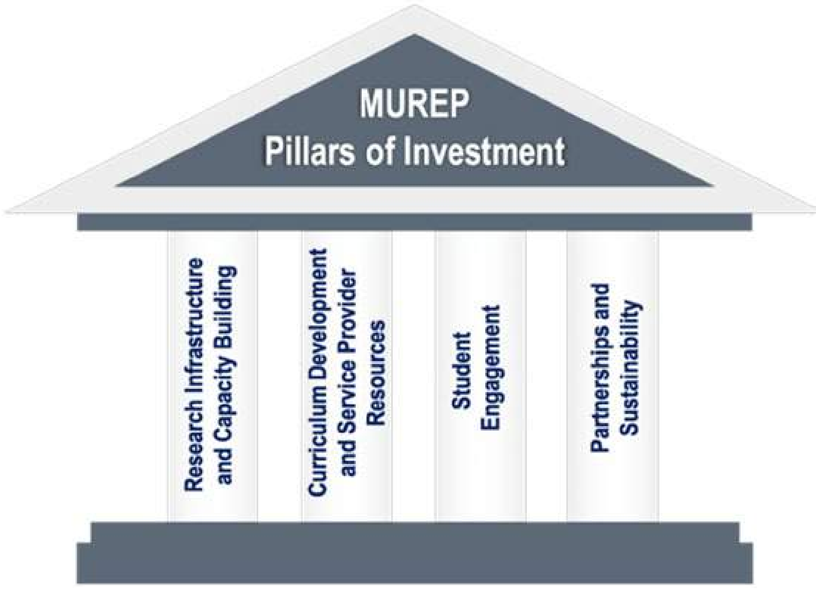
The table below includes significant milestones in FY 2021 and FY 2022.

Date	Significant Event
Q1 FY 2021	Open EONS Omnibus Solicitation; Release OCEAN appendix
Q2 FY 2021	MUREP INCLUDES, M-STAR Solicitation Release
Q3 FY 2021	MUREP STTR Solicitation Release; OCEAN, INCLUDES and M-STAR Selection and Awards
Q4 FY 2021	STTR Selection and Awards; MUREP High Volume Solicitation Release

Project Management & Commitments

The MUREP project manager is located at NASA Headquarters and provides management and oversight for overall activity operations. NASA centers manage significant investments in project activity elements. MUREP Activities map strategically to four investment pillars:

MINORITY UNIVERSITY RESEARCH EDUCATION PROGRAM



MUREP has four pillars that include capacity building, curriculum development and resources, student engagement, and partnerships and sustainability.

Acquisition Strategy

NASA MUREP awards cooperative agreements, grants, and contracts, if applicable, through full and open competition.

MAJOR CONTRACTS/AWARDS

None.

Independent Reviews or Evaluation

All MUREP activities document performance through either external evaluations or internal reviews.

In FY 2020-2021 MUREP commissioned a two-phased study of the portfolio. In Phase 1, a critical examination of the projects and activities was done to develop a more evidence-based understanding of: 1) the efficiency and effectiveness of management operations; 2) alignment to OSTEM and MUREP priorities, goals and objectives; 3) identify promising practices; and 4) to evaluate partnerships and sustainability efforts. The next facet of evaluation will begin in mid FY 2021 - Phase II efforts will be more concentrated in the Student Engagement & Partnership pillars. Emphasis will be given to the overall solicitation process, attracting and recruiting of URMs for activities, events, challenges, competitions, and to what extent MUREP's activities increase the overall competitiveness of its Awardees.

NEXT GEN STEM

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**12.0**	**12.0**	**16.0**	**16.3**	**16.7**	**17.1**	**17.4**
Change from FY 2021			**4.0**				
Percentage change from FY 2021			**33.3%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Elementary aged students engage in hands-on standards-based activities from the Next Gen STEM Moon to Mars activity.

In 2018, the STEM Education and Accountability Project (SEAP) created a pilot to develop STEM Engagement content and experiences tied to the work of NASA's mission directorates and emphasizing current Agency priorities. Since then, the three pilot focus areas (Aeronautics, Human Exploration of the Moon and Mars, and the Commercial Crew Program) have grown, matured and been combined with other successful award and non-award elements of SEAP to become an integrated, comprehensive portfolio of initiatives called the Next Gen STEM project. This name change was reflected in the FY 2019 NASA Initial Operating Plan and in the FY 2021 Congressional Justification.

Next Gen STEM focuses on the goal of building a future STEM workforce with an emphasis on learning opportunities for students in grades K-12 by infusing the excitement of NASA missions and programs into an integrated portfolio of educational products, experiences, challenges, and competitive awards. Next Gen STEM reaches students where they are: in school, in after school programs, in informal education institutions (e.g., museums and science centers), and at home. Next Gen STEM seeks to broaden student participation in STEM by ensuring the greatest accessibility to NASA STEM opportunities, challenges, experiences, and educator support to effectively contribute to building a diverse and inclusive STEM workforce for the future of the Nation.

Next Gen STEM includes a comprehensive program in support of Informal Education Institutions (IEIs) through both its Museum and Informal Education (MIE) Alliance (formerly Museum Alliance) community of practice and its competitive awards program, Teams Engaging Affiliated Museums and Informal Institutions (TEAM II). TEAM II provides a competitive awards program for science centers, museums, planetariums, NASA visitor centers, and other IEIs.

NEXT GEN STEM

EXPLANATION OF MAJOR CHANGES IN FY 2022

The Budget provides a $4 million increase for Next Gen STEM to lower the barriers to participation often experienced by students and educators, especially those in communities historically underserved or underrepresented in STEM. For example, Next Gen STEM is reexamining and revamping its student challenge construct to provide more impactful interactive experiences with NASA STEM professionals. These innovations will ensure that all project initiatives will be more accessible and impactful and will employ the latest in national education standards, pedagogy, and culturally relevant engagement methodologies.

In FY 2022, increased project funding will allow increased awards to IEIs through TEAM II. This will include additional awards in the $750,000 - $1,000,000 range and the establishment of a second tier called Community Anchor awards. These awards will provide financial support of $25,000 to institutions seeking to establish themselves as new or emerging local NASA STEM informal education community resources. This funding will help these institutions reach into communities underserved and underrepresented in STEM with the most current and authentic NASA content and experiences. Being a Community Anchor awardee makes these institutions part of a cohort of similar institutions and larger, more established institutions. This cohort of institutions can share unique perspectives and strategies for effective STEM engagement Community Anchor awardees for larger funding opportunities in the future.

ACHIEVEMENTS IN FY 2020

In FY 2020, Next Gen STEM transitioned the following original mission-driven pilots to formal activities, which became the four core divisions of the project: Moon to Mars, Commercial Crew Program, STEM on Station, and Aeronaut-X. These mission focus areas delivered over 20 evidence-based products and opportunities engaging students in authentic STEM experiences. In addition to executing planned activities, Next Gen STEM quickly pivoted, in the face of the global pandemic, to providing substantial new activities, and newly-curated collections of activities and experiences for virtual audiences. A few examples of FY 2020 achievements include:

- STEM on Station held 18 educational downlinks, live events where groups of students ask questions of an astronaut working on the ISS, as part of a larger educational experience for the participants. Nearly 13,000 students were involved in these events along with over 36,000 community members and 1,600 educators.
- STEM on Station also kicked off a newly curated set of virtual resources and events for school year 2020-2021, celebrating 20 years of scientific research on the ISS and tying those advancements to monthly themes of academic content.
- TEAM II selected four proposals totaling $3.5 million from their 2019 solicitation that were awarded in January 2020. In June 2020, a rapid response solicitation was released seeking projects that addressed the pandemic-induced virtual learning environment.

NEXT GEN STEM

NASA STEM Stars is a virtual engagement series where students can meet and ask questions of a variety of NASA professionals to learn about their roles at NASA and their personal journeys. Students are inspired to see themselves in future STEM professions. Available weekly (live and on demand afterward) with one session per month conducted in Spanish.

- A new initiative, NASA STEM Stars, was created in response to address the need for virtual engagement of students. These live virtual events allow students to meet and ask questions of a variety of NASA STEM professionals from diverse backgrounds, whose personal stories and current work spark student interest in STEM careers and help imagine what may have previously seemed impossible. Between April and September 2020, 25 episodes were conducted, with over 20,000 views to-date.
- The Next Gen STEM Commercial Crew Program mission focus team created launch and mission "tool kits" full of educational content aligned to the Launch America Space-X flights, Demonstration-2, and Crew 1. Live virtual events with teachers and students added to the excitement and learning. The collective reach of the CCP educational content, kits and events positively impacted hundreds of thousands of students and educators across the nation.

A student from Florida participating in of the "STEM on Station" Events.

- Educational Downlinks were quickly redesigned to work for students in virtual learning environments. Next Gen STEM ("STEM on Station") personnel worked with schools and other Downlink customers to collect pre-recorded videos of students asking their questions of Space Station astronauts. The events remained live NASA TV broadcasts that students could watch with their classmates, remotely.

NEXT GEN STEM

WORK IN PROGRESS IN FY 2021

Middle school students immersed in the wonder of STEM learning through Next Gen STEM standards-aligned classroom activities tied to NASA mission content.

In FY 2021, Next Gen STEM is continuing to execute all the initiatives from FY 2020, focusing on virtual events and student STEM engagement experiences due to the continuing pandemic and limitations on in-person gathering. The Next Gen STEM FY 2021 project plan also includes significant planning and development to restructure elements and design innovations to be employed in FY 2022. Some notable efforts currently in progress are:

Exciting mission-inspired student challenges such as the Human Exploration Rover Challenge and the App Development Challenge are giving 89 high school and middle school teams authentic, immersive experiences that allowed hands-on participation and problem solving relevant to NASA missions. Over 600 students are involved.

The excitement of the Artemis Program is being leveraged to create engaging content for wide dissemination in virtual and in person summer camps in 2021. The Artemis Moon Pod essay contest that garnered over 14,000 student submissions has selected 155 semi-finalists and will eventually name nine finalists and three best essays across three age groups.

The 2020-2021 school year celebrated 20 years of Space Station scientific achievements with curated content and special events for students and educators. In FY 2021, "STEMonstrations," STEM concept demonstration videos created by astronauts onboard Space Station, surpassed 1 million downloads.

The Next Gen STEM "Moon to Mars" and "Aeronaut-X" focus areas are finalizing a new slate of educator guides and individual student learning activities inspired by NASA's work on the Artemis human landing system, deep space communications, physical challenges for humans on deep space exploration missions, and furthering safe urban air mobility and unmanned aerial systems.

The Moon to Mars team, in conjunction with NASA JPL, has created a Mars 2020 educational content mission kit and classroom challenge opportunity that is engaging students in the excitement of the Mars Perseverance Rover and Ingenuity Helicopter missions.

The success of NASA STEM Stars in FY 2020 has continued into FY 2021, with 23 weekly episodes engaging over 21,000 viewers.

An additional three selections were made from the FY 2019 TEAM II solicitation and seven awards were made from the FY 2020 TEAM II remote opportunity rapid response (RORR) solicitation, for a total of $4.15 million awarded to IEIs in FY 2021. The FY 2021 Solicitation was released on April 19, 2021 for awards to be made in FY 2022.

NEXT GEN STEM

Team RORR Awardees	Project
Abrams Planetarium Michigan State University East Lansing, Michigan	World Building on Mars, an Educational Program for Middle School Students
Boys & Girls Club Pueblo, Colorado	Indoor Farming Innovation Zone Remote Learning Program
Museum of Science Boston, Massachusetts	EVOLVE (Expanding Versatile Offerings for Learning in Virtual Environments)
Virginia Living Museum Newport News, Virginia	Understanding the Invisible: Studying Ozone through Bioindicator Gardens Under NASA's TEMPO Mission
Fairchild Tropical Botanic Garden Coral Gables, Florida	Growing Beyond Earth: Distance Learning for Underserved Communities
Sharespace Foundation Los Angeles, California	Project Ianos: Inspirational Space Education, Past, Present, and Future
Nevada State Library and Archives Carson City, Nevada	NASA HOLA: STEM Hands-On Learning Activities to Inspire a Diverse Population

KEY ACHIEVEMENTS PLANNED FOR FY 2022

In FY 2022, Next Gen STEM will reorganize to align project elements with four new mission focus areas: Aeronaut-X (centered on aeronautics efforts), Earth, Moon, and Solar System and Beyond. These four mission-driven focus areas will support content development and delivery, student experiences and educator support within their exploration area and will seamlessly support multiple NASA mission directorates while integrating with each other to ensure consistency. External beneficiaries will find navigating cContent from these four focus areas intuitive since the educational content will closely align to the Agency's public communication themes.

Another major milestone for FY 2022 will be an increased number of TEAM II awards, both standard and Community Anchors, from the solicitation that was released in FY 2021.

In FY 2022, Next Gen STEM will pilot a new student challenge construct that will provide opportunities for multiple depth-of-knowledge levels and science and engineering subject themes, specifically designed to reach more students, especially in populations not currently engaged in NASA STEM engagement experiences.

In addition to extending current partnerships, Next Gen STEM will also form new external partnerships that are mutually beneficial through Space Act Agreements and other appropriate means to further the reach and impact of the Next Gen STEM budget and initiatives.

Next Gen STEM will create a STEM subject matter expert recruitment training and support effort that will ensure that students have access to effective role models from NASA's workforce that look like them and that are trained to deliver grade-appropriate and culturally-appropriate engagements for K-12 students across the nation. Direct interaction with NASA experts will significantly increase student STEM interest, learning, and identity.

Additionally, to complement the MIE Alliance, Next Gen STEM will launch a new, highly interactive virtual community of practice focusing on formal educators to allow educators to effectively engage with NASA and with each other. The longer-term goal is to merge the communities of practice, employing an advanced virtual platform with separate tracks for formal and informal educators, but with the capability for educators to interact across the tracks.

Project Schedule

As described in previous sections, FY 2022 will be a pivotal year, with many new and improved products and offerings for K-12 students, informal and formal educators, and for IEIs.

Date	Significant Event
Q1 FY 2022	Selection of TEAM II Standard and Community Anchor Awards
Q1 FY 2022	Launch of Science and Engineering Expo student challenge for school year 2021-2022 and Launch of newly redefined mission focus areas.
Q1 FY 2022	Launch Community of Practice for Formal Educators
Q2 FY 2022	Complete release of TEAM II awards
Q2 FY 2022	Launch STEM Subject Matter Expert Training Program for effective student engagement
Q3 FY 2022	Conclude student challenges with culminating events
Q3 FY 2022	Release summer camp content and plans for 2022-2023 school year
Q4 FY 2022	Kick off 2022-2023 school year challenges and other initiatives

Project Management & Commitments

The Next Gen STEM project manager is physically located at NASA Marshall Space Flight Center and reports to NASA Headquarters. The TEAM II/MIE Alliance activity manager is located at NASA Headquarters. The remainder of the Next Gen STEM activity leads and all supporting personnel for project efforts are located at various NASA field centers. The current Next Gen STEM elements are as follows:

- Mission Focus Areas
- STEM on Station
- Moon to Mars
- Commercial Crew
- Aeronautics
- Competitive Awards - TEAM II
- Museum and Informal Education Alliance (community of practice)

NEXT GEN STEM

Acquisition Strategy

Consistent with existing NASA practices, NASA uses cooperative agreements, grants, and contracts through full and open competitions. All Next Gen STEM award selections undergo rigorous peer reviews by internal/external experts, usually including panel reviews, that evaluate proposals technical merit, feasibility and alignment to Agency STEM Engagement goals and objectives.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

NASA continues to use performance assessment and evaluation-driven processes to enhance the effectiveness of STEM engagement investments, executing a refined Office of STEM Engagement (OSTEM) learning agenda to understand the outcomes of its investments. Since its inception in 2018, Next Gen STEM has continuously assessed its contents and activities in pursuit of continuous improvement, in the context of the OSTEM learning agenda.

In FY 2020, a study was conducted to examine the Sparking STEM Interest Expert Review Panel recommendations about sparking and sustaining student interest in STEM. The panel was convened in response to the NASA Advisory Council's recommendation that "The Office of STEM Engagement should create a deep and comprehensive document that describes what we know about sparking student interest, STEM engagement, and motivation."

The Sparking STEM Interest Study recommended strategies for Next Gen STEM to effectively partner with external organization to create networks that maximize reach and impact of STEM engagement opportunities and for Next Gen STEM to deliver evidence-based transdisciplinary learning opportunities. The study was informed by convening focus groups of educators and institutional representatives and by conducting a literature review and benchmarking study. The findings and recommendations from this study were used to support the design of the ongoing FY 2021 Next Gen STEM outcome evaluation which will assess the project's implementation against intended outcomes. This FY 2021 study will also assess how NASA can develop data collection, analysis and reporting mechanisms to better assess the extent to which Next Gen STEM activities spark student interest in STEM.

SAFETY, SECURITY, AND MISSION SERVICES

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Mission Services & Capabilities	1,849.7	1,918.3	**2,028.8**	2,070.8	2,113.7	2,157.6	2,202.4
Engineering, Safety, & Operations	1,063.6	1,018.2	**1,020.4**	1,041.5	1,066.8	1,093.2	1,120.6
Total Budget	**2,913.3**	**2,936.5**	**3,049.2**	**3,112.3**	**3,180.5**	**3,250.8**	**3,323.0**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2020 reflects actual budget authority that has been re-cast into the new SSMS budget structure.

SAFETY, SECURITY, AND MISSION SERVICES

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Mission Services & Capabilities	1,849.7	1,918.3	**2,028.8**	2,070.8	2,113.7	2,157.6	2,202.4
Engineering, Safety, & Operations	1,063.6	1,018.2	**1,020.4**	1,041.5	1,066.8	1,093.2	1,120.6
Total Budget	**2,913.3**	**2,936.5**	**3,049.2**	**3,112.3**	**3,180.5**	**3,250.8**	**3,323.0**
Change from FY 2021			**112.7**				
Percentage change from FY 2021			**3.8%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2020 reflects actual budget authority that has been re-cast into the new SSMS budget structure.

SpaceX's Demo-2 launch from Kennedy Space Center (KSC) on May 30, 2020 (shown here) marks an historic milestone in the commercialization of space, requiring new and cutting-edge support services.

Safety, Security, and Mission Services (SSMS) enable NASA's missions by providing foundational support capabilities. SSMS is an enterprise resource capable of responding to NASA's evolving mission requirements with efficiency and effectiveness.

SSMS provides strategic direction and integration of essential business and technical functions across 9 NASA centers and Headquarters (HQ). NASA manages operations with independent oversight to ensure the health and safety of NASA employees and the public. SSMS provides services and capabilities that ensure NASA has the technical skills, physical assets, financial resources, and top talent to be successful, safe, and reliable.

Mission Support Priorities

Goal 4 of the NASA Strategic Plan 2018 directs mission support to optimize its capabilities and operations to enable the Agency’s missions in six key areas: (1) partnership strategies, (2) space access and services, (3) safety and mission assurance, (4) human capital management, (5) protection and cybersecurity, and (6) infrastructure and asset management. Together, functions and capabilities that align to these six priorities comprise the foundational business that support NASA activities, including the other three goals of Agency strategy. Industry and academic partnerships, modernized labs and equipment, a highly talented workforce, and IT assets are paramount to expanding scientific discoveries (Goal 1). Launch and testing facilities, mission assurance and safety oversight, Center infrastructure, protective services and an empowered engineering workforce enables the extension of human presence deeper into space (Goal 2). Communicating NASA's discoveries and data, forming legal and strategic bonds with industry and international space partners, securing national assets, and providing technical guidance for safety and health help to catalyze sector growth. To achieve this level of service, SSMS must prioritize critical support, optimize operations, and mature enterprise capabilities.

These mission enabling capabilities and related processes provide support needed to successfully and safely implement and complete requisite missions. The following are several examples of services funded under the SSMS account:

- Coordination of test facilities, laboratories, chambers, and other capabilities required to conduct research, development, and engineering for Agency mission objectives;
- Development of engineering, systems engineering, and safety and mission assurance capabilities that support technical activities;
- Governance of information technology (IT), sustainment of IT infrastructure, and sustainment of security capabilities to support the productivity of NASA scientists and engineers.
- Human capital, financial management, procurement, legal counsel, small business programs, occupational health and safety, and equal employment opportunity and diversity services providing strategic and operational planning and management to ensure resources are available when needed; and
- Administration of international and interagency relations, legislative and intergovernmental affairs, and strategic communications to facilitate communications with a broad range of internal and external communities.

SSMS evaluates funding needs based on six mission support priorities:

- Health, Wellness, & Safety: provide technical expertise, project oversight, and essential services to protect the health and wellness of NASA employees and the public. This includes services related to mission safety, environmental compliance, public health, and employee wellness.
- Workforce Investment: invest in a diverse workforce of top talent and high-performance to maintain NASA's leadership as a pioneer in exploration, science, and technology. This includes management of human capital, workforce planning, training and development, and employee awards.
- Infrastructure: maintain physical assets that are critical to NASA's evolving missions and invest in emerging capabilities that enable missions to meet future requirements. This includes the maintenance of facilities, utility systems (e.g., roads, water, electrical), and information technology (IT) infrastructure (e.g., hardware, software).
- Agency Outreach: promote innovation and discovery through engagement with NASA stakeholders and customers with the success of and provide a rich and continuous sharing of data, technological advancement, and inspiration to the public. This includes communications content through media, partnerships with international, intergovernmental, and industry partners, and advocacy for national goals set forth for science, technology and space exploration.
- Research and Engineering: ensure research spaces (e.g., laboratories, testing facilities) have the technical capacity and thought leadership to attract the highly skilled workforce to complete mission work, while investing in capabilities that ensure NASA's leadership and American preeminence in

space, avionics, science, and technology. This includes supporting technical authorities to forecast requirements and strategize investments in scientific, technologic, digital, and human capabilities across NASA's mission portfolio.

- Support Viability: ensure foundational business processes continue to deliver high-quality services that ensure mission success, now and in the future. This includes innovating business to reach effectiveness and efficiency goals, enhancing the risk management process to protect life and assets, and evolving our enterprise delivery model to better partner with industry and harmonize business practices across centers.

Balancing SSMS and CECR

NASA's mission support portfolio is divided between two accounts: Safety, Security, and Mission Services (SSMS) and Construction and Environmental Compliance and Restoration (CECR). The Mission Support Directorate (MSD) utilizes both accounts to maintain NASA's critical infrastructure. MSD must balance spending on the maintenance of assets and infrastructure, repairs and renewal of failing assets, and the replacement and demolition of unneeded assets. Maintenance activities drive SSMS spending decisions, while repairs, renewals (including new construction), and associated demolition drive CECR spending.

Much of NASA's infrastructure dates back to Apollo-era space exploration. Maintenance activities funded by SSMS are necessary to prevent costly delays to missions and risks to health and safety. Meanwhile, failures require immediate repairs and account for an increasing share of the maintenance budget. These activities do not directly enhance NASA's technical capabilities, but they are vital to support evolving mission requirements. MSD takes an Agency-wide approach to make difficult trade-off decisions that ensure critical capabilities and assets are mission-ready, while also investing in the long-term asset health, sustainability, and footprint reductions that ensure NASA's future mission success.

EXPLANATION OF MAJOR CHANGES IN FY 2022

To align with NASA's priorities, SSMS services and content will be increased in the following areas:

Diversity, Equity, and Inclusion (DEI)

NASA is committed to implementing data analytics, workforce training, and leadership development and other services that will increase the inclusivity of the NASA workforce, science community, and space partners. In FY 2020, "inclusion" was added to NASA’s core values in order to ensure NASA workplaces are emphasizing these Administration priorities, while also encouraging diversity, equity, and inclusion principles are clearly communicated to NASA’s partners in aerospace, technology, and science.

Business Innovation

NASA will invest in Agency-wide business innovation that creates strategic cohesion, service resilience, new efficiencies, and cutting-edge capability for mission success. The focus of this investment is technology, enhancing the Agency's foundational business with data, process transformation, culture, workforce, and advanced technology capabilities like artificial intelligence (AI), machine learning (ML), and model-based everything (MBx).

Cybersecurity

The FY 2022 discretionary request identified a cyber reserve of $750 million. The FY 2022 President's Budget allocates these resources to nine agencies that were significantly impacted by the SolarWinds incident, one of which is NASA. The purpose of the funding is to address immediate response needs and does not focus on wholesale replacement of IT systems at this time. The funding request targets vital cybersecurity needs at these nine agencies which prioritizes basic cybersecurity enhancements, including: cloud security, Security Operations Center (SOC) enhancements, encryption, Multi-Factor Authentication (MFA), increased logging functions, and enhanced monitoring tools. Each agency's maturation levels were reviewed in these areas to determine the most critical gaps that require additional funding.

The FY 2022 President's Budget requests $53.1 million to address the impacts of the SolarWinds incident at NASA.

Electric Vehicles

In support of the President's goal of transitioning to a fully Zero Emission Vehicle (ZEV) Federal fleet, the NASA's budget includes $5 million for zero emission vehicle (ZEV - battery electric, plug-in electric hybrid, and hydrogen fuel cell vehicles) acquisitions and deploying necessary vehicle charging and refueling infrastructure. These acquisitions are a significant step towards eliminating tailpipe emissions of greenhouse gases (GHG) from the NASA fleet and aligning fleet operations with the goal of achieving a fully ZEV Federal fleet. This action is important because tailpipe emissions are currently the leading source of GHG emissions that threaten the planet and harm U.S. communities.

NASA's ZEV acquisitions may include vehicles for both its Agency-owned and General Services Administration (GSA)-leased segments of its vehicle fleet, including incremental costs of leased vehicles and lease payments to GSA for conversion of Agency-owned vehicles to GSA's leased fleet where appropriate. To ensure effective and efficient deployment of ZEVs, NASA will prepare and plan for arriving ZEVs at its facilities, properly prioritize transition to ZEVs where it is simplest, and allow time for additional planning where mission demands pose a challenge to transitioning based on current technologies. Integral to this preparation is growth in the number of Agency-accessible re-fueling points (vehicle charging stations). In installing this infrastructure on-site to support acquired ZEVs, NASA will take the long-term view to ensure efficiencies and thereby ensure wise infrastructure decisions that limit total expenditures. Using its experienced personnel and lessons learned in the fleet arena, NASA will undertake a process that relies on a cross-functional team of staff from fleets, operations, facilities, finance, and acquisition departments with executive leadership support. The collaboration will not stop with initial deployment, as the NASA fleet and facility managers will work closely and employ existing training and tools to control utility costs by managing the overall charging load and thereby ensuring a seamless operation that now will involve building systems and vehicles together. Further, NASA will ensure proper training of personnel to address any initial shortcomings in terms of any necessary ZEV knowledge and operations as the advanced vehicle technologies roll into the NASA fleet.

The Agency is coordinating all of these efforts to meet or exceed the ZEV-related goals set forth in the comprehensive plan developed pursuant to E.O. 14008, Section 205(a). Funds for the NASA ZEV activities are part of a $600 million request in the President's Budget for ZEVs and charging infrastructure that is contained within the individual budgets of 18 Federal agencies, including ZEV Federal fleet dedicated funds at GSA. This investment will be complemented by Department of Energy funding to provide technical assistance to agencies through the Federal Energy Management Program as NASA builds and grows its ZEV infrastructure. This investment serves as a down payment to support a multiyear, whole-of-government transformation to convert the Federal motor vehicle fleet to ZEVs and thereby reduce carbon emissions.

SAFETY, SECURITY, AND MISSION SERVICES

Orbital Debris

A primary focus for NASA is the safe and secure exploration of space and the protection of national assets. As more commercial and international entities become spacefaring, and the amount of debris in orbit grows, the need to understand the debris environment and mitigate the orbital debris hazard increases. NASA's efforts will support the protection of NASA, other government, and commercial assets, while laying the groundwork for addressing this growing environmental problem.

ACHIEVEMENTS IN FY 2020

The following achievements are major milestones and highlights. More robust lists of accomplishments are available in the program sections.

- Continued to provide leading-edge services to support mission success:
    - Negotiated the Artemis Accords
    - Launched the NASA Unity Campaign to enhance inclusion, diversity, equity, and access
    - Exceeded NASA's goal of 15.4 percent small business participation by reaching 17.5 percent
    - Supported the historic SpaceX DM-2 and Mars Perseverance Rover launches with Agency outreach, media engagement, and security for government officials and public visitors
    - Catalyzed industry growth with a legal framework, procurement pathway, and numerous collaborative agreements in commercial space industries
    - Named "Best Place to Work in the Federal Government" for the eighth consecutive year

- Enhanced the technical capabilities across the Agency and delivered high-quality leadership and services that ensure mission success, health and safety, and stewardship of resources, including the environment:
    - Provided independent testing and simulation capabilities for all mission programs
    - Provided Agency-wide technical assessment and independent evaluation of critical and high-risk mission systems through the NASA Engineering and Safety Center (NESC)
    - Enhanced key laboratories, facilities, and other physical assets in response to evolving mission requirements

- Continued to evolve the mission support enterprise to optimize effectiveness and efficiency:
    - Initiated transformation to an enterprise model for five mission support organizations
    - Modified human capital management with enterprise management of Agency awards and consolidation of staffing and hiring processes
    - Renegotiated partnerships and land-use agreements at numerous centers

- Rapidly responded to unprecedented challenges and evolving mission requirements with minimal loss or risk to Agency priorities:
    - Adapted to COVID-19 conditions with negligible impacts to missions

WORK IN PROGRESS IN FY 2021

- Continue to transform operations and technology to increase effectiveness, optimize efficiencies, and mature the enterprise model for a more agile and responsive support services:
    - Finalize the transition to an enterprise service model for remaining organizations
    - Implement enterprise technologies, including virtual tools, to optimize work

- Deepen the technical capabilities and expertise that support mission-critical work across NASA:
    - Enhance NASA workplaces with investments in laboratory equipment, enterprise platform technologies, and other physical and IT improvements
    - Continue to provide independent assessments, audits, and activities that support mission work, particularly those related to systems integration, health, and safety
    - Refine NASA's Learning Agenda in accordance with The Foundations for Evidence-Based Policymaking Act of 2018

- Improve training and create an agile and responsive diverse workforce:
    - Enhance NASA's ability to recruit top-talent and improve responsiveness to mission requirements by implementing new talent acquisitions systems (USAStaffing/USAHire)
    - Enhance employee opportunities for growth and development with NASA's Talent Marketplace, which empowers internal hiring for rapid response to mission needs

- Continue building a viability support foundation capable of ensuring exploration, science, technological advancement, and leadership:
    - Increase Agency outreach to broadcast coverage for NASA's historic mission accomplishments, including Commercial Crew launches, the launch and landing of the Mars Perseverance Rover, the flight of the Mars Ingenuity Helicopter, OSIRIS-REx, and International Space Station activities
    - Improve the security architecture to protect human health and safety

- Advance work in support of 2021 Executive Orders:
    - Implement requirements for NASA grant recipients to report on harassment
    - Develop a new NASA Diversity, Equity, and Inclusion (DEI) strategic plan
    - Inculcate equity principles throughout NASA business practices and establish outcome assessment tools

- Address aging, Apollo-era infrastructure challenges to be mission-ready for Artemis-era spaceflight, exploration, and scientific missions:
    - Improve maintenance activities with sensors and real-time monitoring capabilities
    - Finalize the technical approach for the first Agency Master Plan for facilities and
    - infrastructure

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- Provide novel, innovative, and high-quality services and solutions to enable NASA's missions:
    - Expand DEI support services and data analytic capabilities, to ensure diversity and inclusion at NASA and with its partners
    - Outreach to underserved communities and enhance the equity of the administration of grants to external research institutions, including academia and private industry
    - Implement four evaluations under the Agency's Annual Evaluation Plan (AEP)
    - Conduct Agency-level, labor management activities with national representatives from NASA's labor unions to share information and ensure they have a voice in the workplace
    - Ensure NASA's acquisition strategies secure the Agency's supply chain by maximizing the purchase of American-made goods

- Improve IT management, data access, security, reliability, and service delivery for information technology platforms, software, and physical infrastructure:
    - Improve the security of NASA's internal and external network with controls, detection tools, monitoring, firewalls, and other enhancements
    - Modernize core capabilities to meet increased data needs, including log aggregation, malware analysis, incident management, email security, virtual hosting, and storage
    - Develop end-to-end enterprise IT architecture and inventory services
    - Establish a streamlined enterprise IT acquisition capability
    - Implement integrated enterprise cybersecurity logging and assessment services

- Transform physical asset management with technologies, enterprise process, and data to be more efficient, effective, and environmentally protective:
    - Enhance NASA's physical assets with environmentally sustainable acquisitions and improvements, including zero-emission vehicles and "green" infrastructure
    - Address routine and backlogged maintenance with a tiered maintenance strategy
    - Continue installing key technologies for Condition Based Maintenance (CBM)

- Ensure the safety and reliability of mission critical assets by conducting routine testing and maintaining or upgrading safety and monitoring systems:
    - Continue Arc Jet Complex modernization at Ames Research Center (ARC as part of Space Environmental Test Management Office (SETMO) activitiesTest wear and erosion for the Advanced Electric Propulsion System (AEPS) thruster
    - Continue to enhance and provide health and medical expertise to NASA's priority missions
    - Support the development and integration of products and plans, including medical operations concepts, flight rules, ground-support procedures, and more

- Ensure technical excellence and safety for all NASA missions through policies, guidance, and oversight:
    - Enhance orbital debris modeling and tracking
    - Provide independent testing and evaluation for NASA missions
    - Provide engineering guidance, oversight, and review through the NESC

- Support center investments, research, and delegated technical authority to ensure safety and mission assurance for all NASA missions:
    - Solicit Internal Research and Development (IRAD) Program submissions and invest in new ideas and technologies
    - Maintain occupational safety oversight for all centers
    - Manage hazardous conditions and materials to avoid exposure and injury
    - Continue the multiyear pressure systems program to certify vital pressure vessels
    - Continue strategic analysis to assess investment and divestment opportunities across centers based on mission relevance and use this analysis to conduct master planning of facilities and capabilities

SAFETY, SECURITY, AND MISSION SERVICES

Themes

MISSION SERVICES AND CAPABILITIES

Mission Services and Capabilities (MSaC) provides enterprise solutions under three programs: Information Technology, Mission Enabling Services, and Infrastructure and Technical Capabilities. Strategically, these programs meet workforce, infrastructure, information technology, and business operations requirements necessary to enable NASA's mission. MSaC ensures that critical Agency operations are effective, efficient, safe, and meet statutory, regulatory, and fiduciary responsibilities. These mission enabling services, capabilities, and related processes provide efficient and effective administration across all NASA centers.

ENGINEERING SAFETY AND OPERATIONS

Engineering, Safety, and Operations (ESO) provides for the ongoing management and operations of NASA Headquarters, nine centers, and component facilities under two programs: (1) Agency Technical Authority and (2) Center Engineering, Safety, and Operations. The programs support scientific and engineering activities. They contribute to the reduction of program risks by ensuring that: technical skills and assets are ready and available to meet program and project milestones; mission and research endeavors are technically and scientifically sound; and center practices are safe and reliable, including the highly skilled staff and specialized infrastructure at the centers that facilitate NASA missions.

MISSION SERVICES & CAPABILITIES

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Information Technology (IT)	475.0	548.6	**612.2**	624.9	637.8	651.0	664.6
Mission Enabling Services	697.0	702.5	**731.5**	746.5	761.9	777.6	793.7
Infrastructure & Technical Capabilities	677.8	667.2	**685.1**	699.4	714.0	728.9	744.1
Total Budget	**1,849.7**	**1,918.3**	**2,028.8**	**2,070.8**	**2,113.7**	**2,157.6**	**2,202.4**
Change from FY 2021			**110.5**				
Percentage change from FY 2021			**5.8%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2020 reflects actual budget authority that has been re-cast into the new SSMS budget structure.

Testing of the Artemis Thermal Enclosure is shown here at the Glenn Research Center (GRC) Space Environments Complex (SEC).

Mission Services and Capabilities (MSaC) provides foundational business service and enterprise solutions to all of NASA. While mission requirements evolve with Agency priorities and external conditions, MSaC is focused on the permanent and critical essentials that enable all NASA activity.

MSaC offers a range of foundational services, including, but not limited to, human capital, financial management, physical asset management, software and hardware services, communications, diversity and inclusion programs, legal services, small business program, procurement services, and safety/protective services. MSaC is broken up into three programs: Information Technology (IT), Mission Enabling Services (MES), and Infrastructure and Technical Capabilities (I&TC) (see Program Elements below for a description of each).

MSaC Priorities

MSaC provides foundational business services, which remain a permanent requirement as missions and conditions evolve. Permanence, however, does not mean static. MSaC is focused on business innovation and transformation that ensure agility, efficiency, and effectiveness as mission requirements evolve.

MISSION SERVICES & CAPABILITIES

NASA's long-term success will depend on a foundation of reliable support services that are responsive to mission requirements in real time and streamlined to minimize cost while maximizing impact.

MSaC is focused on providing reliable, essential services and capabilities to missions in response to evolving requirements, while improving the mission support enterprise. While maintaining the foundational business of NASA, MSaC is innovating business to support more effective and efficient work, a more agile and empowered workforce, and workplaces that support automation, collaboration, and thought-leadership.

EXPLANATION OF MAJOR CHANGES IN FY 2022

MSaC will increase services and content in four categories to improve mission capability and support NASA's priorities:

Diversity, Equity, and Inclusion (DEI)

NASA is committed to implementing data analytics, workforce training, and leadership development and other services that will increase the inclusivity of the NASA workforce, science community, and space partners. In FY 2020, "inclusion" was made a NASA core value in order to make NASA workplaces more diverse and empowering, while also encouraging diversity in aerospace, technology, and science. SSMS is responding to this priority with increases to key programs that empower leaders with data, workforce training, and other enhancements for DEI across NASA and in education, science, engineering, and industry partners.

Business Innovation

NASA will invest in Agency-wide business innovation that creates strategic cohesion, service resilience, new efficiencies, and cutting-edge capability for mission success. The focus of this investment is technology, enhancing the Agency's foundational business with data, process transformation, culture, workforce, and advanced technology capabilities like artificial intelligence (AI), machine learning (ML), and model-based everything (MBx).

Cybersecurity

The FY 2022 discretionary request identified a cyber reserve of $750 million. The FY 2022 President’s Budget allocates these resources to nine agencies that were significantly impacted by the SolarWinds incident, one of which is NASA. The purpose of the funding is to address immediate response needs and does not focus on wholesale replacement of IT systems at this time. The funding request targets vital cybersecurity needs at these nine agencies which prioritizes basic cybersecurity enhancements, including: cloud security, Security Operations Center (SOC) enhancements, encryption, Multi-Factor Authentication (MFA), increased logging functions, and enhanced monitoring tools. Each agency’s maturation levels were reviewed in these areas to determine the most critical gaps that require additional funding.

The FY 2022 President’s Budget requests $53.1 million to address the impacts of the SolarWinds incident at NASA.

Electric Vehicles

In support of the President’s goal of transitioning to a fully Zero Emission Vehicle (ZEV) Federal fleet, the NASA’s budget includes $5 million for zero emission vehicle (ZEV - battery electric, plug-in electric hybrid, and hydrogen fuel cell vehicles) acquisitions and deploying necessary vehicle charging and refueling infrastructure. These acquisitions are a significant step towards eliminating tailpipe emissions of greenhouse gases (GHG) from the NASA fleet and aligning fleet operations with the goal of achieving a fully ZEV Federal fleet. This action is important because tailpipe emissions are currently the leading source of GHG emissions that threaten the planet and harm U.S. communities.

NASA's ZEV acquisitions may include vehicles for both its Agency-owned and GSA-leased segments of its vehicle fleet, including incremental costs of leased vehicles and lease payments to GSA for conversion of Agency-owned vehicles to GSA's leased fleet where appropriate. To ensure effective and efficient deployment of ZEVs, NASA will prepare and plan for arriving ZEVs at its facilities, properly prioritize transition to ZEVs where it is simplest, and allow time for additional planning where mission demands pose a challenge to transitioning based on current technologies. Integral to this preparation is growth in the number of Agency-accessible re-fueling points (vehicle charging stations). In installing this infrastructure on-site to support acquired ZEVs, NASA will take the long-term view to ensure efficiencies and thereby ensure wise infrastructure decisions that limit total expenditures. Using its experienced personnel and lessons learned in the fleet arena, NASA will undertake a process that relies on a cross-functional team of staff from fleets, operations, facilities, finance, and acquisition departments with executive leadership support. The collaboration will not stop with initial deployment, as the NASA fleet and facility managers will work closely and employ existing training and tools to control utility costs by managing the overall charging load and thereby ensuring a seamless operation that now will involve building systems and vehicles together. Further, NASA will ensure proper training of personnel to address any initial shortcomings in terms of any necessary ZEV knowledge and operations as the advanced vehicle technologies roll into the NASA fleet.

The Agency is coordinating all of these efforts to meet or exceed the ZEV-related goals set forth in the comprehensive plan developed pursuant to E.O. 14008, Section 205(a). Funds for the NASA ZEV activities are part of a $600 million request in the President's Budget for ZEVs and charging infrastructure that is contained within the individual budgets of 18 Federal agencies, including ZEV Federal fleet dedicated funds at the General Services Administration. This investment will be complemented by Department of Energy funding to provide technical assistance to agencies through the Federal Energy Management Program as NASA builds and grows its ZEV infrastructure. This investment serves as a down payment to support a multiyear, whole-of-government transformation to convert the Federal motor vehicle fleet to ZEVs and thereby reduce carbon emissions.

ACHIEVEMENTS IN FY 2020

- Provided essential and exceptional support services to enable NASA missions:
  - See the MES program section for a full list of accomplishments
  - Negotiated the Artemis Accords
  - Created a dedicated procurement service for IT
  - Provided comprehensive coverage of NASA's major mission successes

- Provided foundational information technology (IT) services that enable all NASA missions:
  - See the IT program section for a full list of accomplishments
  - Exceeded enforcement goals for network access, dramatically increasing cybersecurity
  - Developed a single enterprise service for Robotic Process Automation (RPA)
  - Enabled over 36 mission-critical events with technology and support services

- Managed NASA's facilities, infrastructure, and asset portfolio with a commitment to environmental stewardship and the goal of avoiding costs by reducing the Agency's footprint:

MISSION SERVICES & CAPABILITIES

- See the I&TC Program section for a full list of accomplishments
- Completed future development concepts for two Centers as part of the Agency's commitment to reduce operating costs by 25 percent by 2038
- Received "Best 100 Fleets in the Americas" by General Services Administration (GSA)
- Disposed approximately 36,000 items and re-utilized approximately $88 million of property

- Continued to transform NASA's foundational business to reach greater efficiency and effectiveness by maturing enterprise management and service delivery and leveraging technology:
  - A more robust list of transformational achievements is available in each program section.
  - Transitioned four mission support offices to an enterprise service model
  - Consolidated human capital management for staffing, training, classification, and awards.
  - Implemented Condition Based Maintenance (CBM) at all centers
  - Reduced duplicative contracts by developing enterprise procurements services

- Provided rigorous testing and supported unique technical capabilities that ensure safe and reliable mission progress:
  - See the I&TC Program section for a full list of accomplishments
  - Tested laser-induced fluorescents for the Advanced Electric Propulsion System (AEPS)
  - Supported the development of the Vertical Motion System at Ames Research Center
  - Built the shipping container to transport the James Webb Space Telescope to launch site

- Transitioned approximately 90 percent of the workforce to work-from-home within a week of the Federal response to the COVID-19 pandemic, while providing essential services to minimize mission impacts:
  - See the program sections for a more robust list of COVID-19 response accomplishments
  - Provided on-site, 24/7 communications support during the pandemic
  - Adapted IT services to empower employees working from home
  - Distributed $1.4 million of personal protective equipment (PPE)

WORK IN PROGRESS IN FY 2021

- Provide foundational business services that support NASA's unique and evolving missions:
  - See the MES Program for a full list of current work
  - MES Program for a full list of current work
  - Conduct the Technology Infusion Road Tour Initiative with Historically Black Colleges and Universities/Minority Serving Institutions (HBCU/MSIs)
  - Ensure proper and equitable enterprise distribution of Agency awards and training with a focus on retaining top talent.
  - Develop a new NASA DEI strategic plan
  - Expand outreach to contractors and vendors and integrate equity principles into procurement strategies
  - Engage in collective bargaining activities with NASA's exclusive union partner to address and revise agreement provisions

- Continue to transform business by leveraging technology, maturing the enterprise management and service delivery mode, and focusing on customer experience:
  - See program sections for a full list of transformational current work

MISSION SERVICES & CAPABILITIES

- Implement cloud infrastructure to better use artificial intelligence and machine learning
- Establish a roadmap for consolidation to the enterprise contract
- Reduce vulnerabilities with greater cybersecurity for building systems
- Launched HireNow to improve hiring and onboarding pipeline

- Deliver secure and reliable technology and data access solutions to enable NASA's mission goals:
    - See the IT Program for a full list of current work
    - Implement the Gateway Data Storage project to meet the needs of NASA's missions
    - Migrate the local data center model to a cloud-managed service model
    - Eliminate cybersecurity vulnerabilities and leakage of NASA's data
    - Identify efficiencies and consolidate investments in cybersecurity services

- Manage NASA's infrastructure, facilities, and asset portfolio to ensure mission success while reducing NASA's footprint and protecting the environment:
    - See the I&TC Program for a full list of current work
    - Complete NASA's first Agency Master Plan (AMP) to align to evolving mission needs
    - Continue investment in Condition Based Maintenance (CBM) measures across centers
    - Sustain deteriorating or failed physical assets
    - Implement early and life-cycle environmental planning processes

- Conduct routine tests and provide enhanced testing facilities to ensure mission success and maintain NASA's high standard of health and safety:
    - See the I&TC Program for a full list of current work
    - Refurbish Vacuum Chambers A and B at JSC
    - Test the Advanced NASA Evolutionary Xenon Thruster (NEXT) electronic propulsion thruster at GRC
    - Conduct vertical motion simulations for Advanced Air Mobility (AAM) flight tests

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- Provide novel, innovative, and high-quality services and solutions to enable NASA's missions:
    - See program sections for a full list of planned achievements
    - Expand DEI support services and data analytic capabilities, to ensure diversity and inclusion at NASA and with its partners.
    - Outreach to underserved communities and enhance the equity of the administration of grants to external research institutions, including academia and private industry.
    - Continue to deliver cloud-based, IT solutions across the Agency
    - Provide safety, security, and communications coverage for all NASA mission launches
    - Share information with NASA’s labor unions to ensure their voice in the workplace
    - Draft program and procurement guidance to deliberately support members of underserved communities to advance equity

- Improve IT management, data access, and cybersecurity:
    - See the IT Program section for a full list of planned achievements
    - Enable greater cybersecurity features with improved Microsoft O365 licensing, firewall modernization, new detection tools, network upgrades, and other improvements
    - Modernize NASA's internal and external network controls for increased cybersecurity

MISSION SERVICES & CAPABILITIES

- Enhance data mining with artificial intelligence and natural language processing
- Develop end-to-end enterprise IT architecture and inventory services
- Streamline enterprise IT acquisition capability

- Transform physical asset management with technologies, enterprise process, and data to be more efficient, effective, and environmentally protective:
  - See the I&TC Program section for a full list of planned achievements
  - Enhance NASA's physical assets with zero emission vehicles and "green" infrastructure
  - Update Center Master Plans to align with Agency Master Plan and mission requirements
  - Address routine and backlogged maintenance with a tiered maintenance strategy
  - Continue installing key technologies for condition-based maintenance (CBM)

- Ensure the safety and reliability of mission critical assets by conducting routine testing and maintaining or upgrading safety and monitoring systems:
  - See the I&TC Program section for a full list of planned achievements
  - Refurbish JSC's Vacuum Chambers A and B to support Exploration Extravehicular Mobility Unit Design Verification Test activities
  - Continue Arc Jet Complex modernization at ARC as part of Space Environmental Test Management Office (SETMO) activities
  - Test wear and erosion for the Advanced Electric Propulsion System (AEPS) thruster
  - Support Advance Air Mobility (AAM) development with vertical motion simulations

Program Elements

INFORMATION TECHNOLOGY

The Information Technology (IT) Program provides the information services needed to fulfill NASA’s multifaceted missions and operations. NASA's Information Technology Program helps improve Agency outcomes by, accelerating results through tools that increase productivity, share NASA’s data and discoveries, and increase the quality, resiliency, and cost-effectiveness of its information systems. Reliable, adaptable, and secure cloud-based IT is increasingly important to NASA's mission portfolio because it is a key enabler for advances in science, technology, aeronautics, space exploration.

MISSION ENABLING SERVICES

The Mission Enabling Services (MES) Program provides an enterprise approach to managing NASA's business operations and mission support activities. Missions rely on these institutional services to provide the business services and skilled staff required to accomplish their objectives. Enterprise management of these areas ensures that critical Agency operations are effective, efficient, and meet statutory, regulatory, and fiduciary responsibilities. Business services include financial management, human capital management, procurement, small business, legislative affairs, equal opportunity and diversity management, legal, communications, international and interagency relations, and protective services.

MISSION SERVICES & CAPABILITIES

INFRASTRUCTURE AND TECHNICAL CAPABILITIES

The Infrastructure and Technical Capabilities (I&TC) Program provides sustainment, operations, and maintenance for facilities and technical capabilities. The program also provides effective oversight and management of real property, environmental program activities, aircraft operations, and logistics functions. These capabilities enable NASA to meet its statutory and regulatory responsibilities and ensures that the right infrastructure is available to meet mission requirements. This mission is accomplished through effective management of assets and capabilities, proactive coordination with NASA mission directorates, institutional planning, proactive deployment of sustainable practices, ongoing regulatory compliance, and reducing current and future infrastructure-related risks.

INFORMATION TECHNOLOGY (IT)

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**475.0**	**548.6**	**612.2**	**624.9**	**637.8**	**651.0**	**664.6**
Change from FY 2021			**63.6**				
Percentage change from FY 2021			**11.6%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2020 reflects actual budget authority that has been re-cast into the new SSMS budget structure.

Communications capabilities at NASA HQ Space Operations Center (SOC) July 2020. SOC provides support ISS/Exploration real-time planned and contingency operations.

NASA's Information Technology (IT) program provides secure connectivity and data access for the NASA workforce and its partners, deploying over 100,000 continuous diagnostics and mitigation (CDM) tools across the corporate and mission networks and achieving Personal Identity Verification (PIV) access for 90 percent of unprivileged and 100 percent of privileged users. The program provides NASA end-users with cloud-based email inboxes and collaboration capabilities. The IT program supports over 250 applications that empower scientific research, mission support, and the processing of approximately 4.3 million inquiries per year about NASA's Scientific and Technical Information (STI), providing the scientific community the information needed to achieve new discoveries.

IT Priorities

NASA's inspiring missions are evolving as scientific discovery and human presence extends to the Moon and beyond. Existential conditions, like commercial partners, global competitors, expanding data capacity requirements, disruptive conditions (i.e. climate change, natural disasters, pandemics, etc.) and fast-evolving mission requirements challenge NASA's traditional IT support approach. Technology, data, and collaboration across organization and geographic boundaries is imperative to NASA's immediate mission goals and long-term organizational health. In addition to providing a foundation of service that empowers NASA with technology solutions, equipment, software, and support services, the IT program is focused on the following areas of work to enhance NASA's technical capacity, resilience, agility, and mission-effectiveness:

INFORMATION TECHNOLOGY (IT)

- Continue to mature the enterprise model by supporting the development of integrated technologies, software applications, and management processes
- Eliminate legacy and duplicative systems to drive down costs and enhance efficiency
- Utilize technology, data, artificial intelligence (AI), machine learning (ML) and automation to enhance workforce capabilities; and
- Invest in cyber-physical workspaces that enhance work, promote data access, and eliminate geographic constraints and organizational boundaries.

EXPLANATION OF MAJOR CHANGES IN FY 2022

NASA's IT program continues to implement its transformational activities, thereby refining content and redistributing budgets as appropriate. In addition, business innovation is a critical investment for immediate and long-term mission success.

Business Innovation

NASA will invest in Agency-wide business innovation that creates strategic cohesion, service resilience, new efficiencies, and cutting-edge capabilities for mission success. The focus of this investment is technology, enhancing the Agency's foundational business with data, process transformation, culture, workforce, and advanced technology capabilities like artificial intelligence (AI), machine learning (ML), and model-based everything (MBx).

Cybersecurity

In response to the recent SolarWinds incident and increasing global competition in space, $53.1 million in cybersecurity investments will better protect U.S. assets and data against malicious or accidental attacks. NASA will invest in key improvements and upgrades to enhance network security, monitoring and detection systems, authentication, encryption, software patches, and more.

ACHIEVEMENTS IN FY 2020

- Provided foundational IT support services for all NASA missions:
  - Operated over 200 enterprise applications and 3,000 websites and supported over 36 mission-critical events with telecommunications
  - Expanded the Mission Communications Program (CP) NASA Communications (NASCOM) Mission Backbone (NMB), a mission-critical telecommunications hardware network that now extends to DoD, commercial and other Federal partners
  - Continued to grow the IT program and staffed a 24/7 NASA SOC Continuity of Operations capability to maintain critical cybersecurity service operations

- Enhanced IT capabilities, including cybersecurity posture, data storage and access, and connectivity:
  - Modernized NASA’s in-memory database platform for vendor transactions, enhancing NASA’s financial system, contract writing system, and business intelligence platform
  - Established a single enterprise robotic process automation (RPA) service to facilitate robotic operations against enterprise and/or center-level applications or tools
  - Following the NASA Strategy to Improve Network Security (NSINS), the Network Access Control (NAC) initiative exceeded the Agency's 2020 enforcement goals to monitor and close network access for increased cybersecurity

  - Accelerated the adoption of cross-cutting collaboration and user experience tools, like Microsoft Teams and ServiceNow, in response to COVID conditions, but with permanent enhancement of NASA's enterprise capabilities
  - Created metadata tags using artificial intelligence for NASA websites
  - Used business application of Tableau/Power Business Intelligence (BI) software for data integration, intelligent automation of business processes, and Internet of Management Things
  - Architected a cloud-based platform for next generation Scientific and Technical Information (STI)/NASA Technical Reports Server (STI/NTRS) System

- Responded to COVID-19-induced telework conditions, with minimal disruption to the support provided to mission work:
  - Responded to the dramatic increase in use of the Agency's Virtual Private Network (VPN) in response to COVID-19 telework conditions, with no delays to mission
  - Provided on-site, 24/7 communications support during the COVID pandemic, ensuring world-wide, real-time, mission-critical support for the Agency spacecraft operations
  - Partnered with the Office of the Chief Health and Medical Officer (OCHMO) to provide accelerated cybersecurity engineering and authorization to operate support for multiple COVID-19 response efforts.

WORK IN PROGRESS IN FY 2021

- Implement IT innovations that improve data access:
  - Full implementation of a data governance platform
  - Implement the Gateway Data Storage project to meet the intensive data storage needs of the Artemis Program by moving to a common cloud platform
  - Implement business application of Tableau/Power BI software for data integration, intelligent automation of business processes, and the Internet of Management Things
  - Migrate local data storage services to Agency-provided tools to reduce local infrastructure cost and consolidate IT contracts
  - Migrate the local data center model to a cloud-managed service model
  - Enhance the Agency's financial systems to improve functionality in budget execution and reporting

- Enhance management for all physical assets, including IT and non-IT infrastructure, workforce equipment, and enterprise software:
  - Enable higher shared bandwidth and flexible software by aggregating NASA's existing individual network connections to major, commercial cloud providers
  - Assess applications development and sustainment contracts across the Agency to establish a roadmap for consolidation to the enterprise contract
  - Migrate the Agency Financial Management System to the new cloud platform
  - Implement a Configuration Management Database (CMDB) to better manage NASA assets on an enterprise-level
  - Revise the Capital Planning and Investment Control process (CPIC) to strengthen IT portfolio management and strategic oversight of IT investments

- Ensure the reliability and security of NASA IT assets and capabilities:

INFORMATION TECHNOLOGY (IT)

  - Continue Network Access Control (NAC) enforcement activities, which are on track to exceed the Agency's 80 percent target goal by June 2021
  - Eliminate cybersecurity vulnerabilities and leakage of NASA's data with compliance enforcement for unauthorized software
  - Implement Application Control (AC) security policies on all center and data center firewalls to enhance application visibility and security controls
  - Identify efficiencies and consolidate investments in cybersecurity services and investments across all of NASA to mitigate IT risk, reduce duplication, and de-scope investments for affordability

- Partner with NASA missions on novel technology requirements that are unique to NASA missions:
  - Provide an isolated testing environment and internet access with analytics at Johnson Space Center (JSC)
  - Complete the design and installation of the NASCOM Mission Next Generation Voice (MNGV) system at Goddard Space Flight Center (GSFC)
  - Collaborate with spaceflight projects and Near-Earth Network (NEN) to identify and test architecture solutions to support utilization of cloud computing services

- Enhance customer and employee experience:
  - Implement cloud infrastructure components to improve the use of AI and ML across the Agency
  - Capitalize upon the new, centralized support functions implemented in FY 2020 with the enterprise IT operating model to eliminate redundancies, increase efficiencies, and address obsolete technology

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- Implement IT innovations that improve data access:
  - Implement and leverage micro-segmentation and multi-site capability in NASA's major on-premises data centers
  - Implement cloud-based platforms for data access, processing, and distribution, which will be used to support two key flight missions that will begin to produce the first of several hundred petabytes of Earth Science information
  - Mature NASA's Internal Data Inventory and Digital Assets to effectively create a "Yellow Pages" of NASA Information

- Enhance management for all physical assets, including IT and non-IT infrastructure, workforce equipment, and enterprise software:
  - Reduce application redundancy and implement low-code application platforms to speed application development
  - Develop end-to-end enterprise IT architecture and inventory services to form a pipeline that performs data-related application development and analysis
  - Develop IT working capital fund to support IT modernization
  - Partner with the Office of Procurement to establish a streamlined enterprise IT acquisition capability
  - Shift services from local IT contracts to enterprise IT contracts (when appropriate) while optimizing unique, local services

INFORMATION TECHNOLOGY (IT)

- Partner with NASA missions on novel technology requirements that are unique to NASA missions:
    - Continue to provide voice, video, and network services to NASA centers and missions, requests for which are expected to accelerate with growing missions work.
    - Finalize and implement architecture and roles for NASCOM connectivity between space flight projects and NASA space communications and tracking resources

- Enhance the reliability and security of NASA IT assets and capabilities:
    - Shift workloads between NASA's data centers to optimize resource utilization
    - Enable NASA's ability to isolate applications across the network to improve security
    - Greatly increased levels of commercial cloud utilization across NASA.
    - Continue to create a more secure environment through enhanced patch management
    - Fully implement the Controlled Unclassified Information (CUI) Program, including user-training and ensuring physical and technical safeguarding of CUI data.
    - Implement integrated enterprise cybersecurity logging and assessment services to provide increased insight and visibility into network threats across NASA
    - Consolidate disparate cybersecurity services into an enterprise-wide contract to improve cost-effectiveness while strengthening cybersecurity

- Further enhance cybersecurity with $53.1 million of additional investment in response to the SolarWinds incident:
    - Enable greater cybersecurity features with improved Microsoft O365 licensing to ensure a secure, "work from home" IT environment
    - Improve NASA's identity and authentication infrastructure
    - Modernize firewalls at the external border of NASA's network
    - Modernize NASA's internal network, including analysis upgrades and monitoring tools
    - Replace outdated and insufficient intrusion detection and prevention capabilities
    - Implement tools to monitor, log, and analyze cloud platforms used by NASA
    - Modernize core capabilities to meet increased data needs, including log aggregation, malware analysis, incident management, email security, virtual hosting, and storage.
    - Move to a single enterprise cybersecurity forensics technology solution
    - Modernize and expand NASA's cybersecurity measures, including continuous monitoring (CDM) infrastructure and threat detection tools

- Enhance customer and employee experience:
    - Continue to deliver cloud-based solutions, including expanding/enhancing Office 365 offerings to include all NASA mission and mission support requirements
    - Continue Agency-wide intranet deployment and implement customer experience (CX) strategies in collaboration with NASA's Mission Support Directorate (MSD) and Business Innovation Office (BIO)

INFORMATION TECHNOLOGY (IT)

Program Elements

ENTERPRISE IT

The Enterprise IT program is multifaceted and includes several project elements, each with unique functions and focuses of work:

- Applications: anticipates and aligns customer requirements with solutions that best meet Agency needs by delivering secure, sustainable applications quickly and cost effectively, establishing a platform-centric architecture that empowers mission support, enhanced software management to reduce software license costs, and continuous portfolio rationalization
- Communications: NASA's enterprise service provider for fully managed network and communications services supporting institutions, programs and projects located at the NASA centers. Communications is also responsible for maintaining, operating, and continually evolving services to improve delivery capabilities, strengthen NASA's cybersecurity posture, and reduce costs
- Computing Services: brokers commercial cloud computing services for the NASA community and provides oversight of NASA's compliance with the Federal Data Center Optimization Initiative. Cloud computing services extends to all NASA missions, mission support, and to external partners
- End User Services (EUS): provides high-quality, reliable, cost-effective service desk, end-user computing services, collaboration, content management systems and services in support of all NASA Federal and contractor employees, including support for laptops, desktops, mobile devices, printing, email, messaging, help desk services, software patching, distribution, and more
- Information Management (IM): provides NASA with framework, guidelines, and services to ensure secure and efficient access, use, analysis, and preservation of the Agency's information resources. The program ensures NASA's compliance with Federal statutes relating to data access and integrity
- Transformation and Data: engages the brightest minds across the Agency to guide NASA's data strategy, technology infusion, and strategic investment decisions, and identifies emerging information technologies to most effectively support NASA's needs in a rapidly changing world

SAFEGUARDING DATA AND IT ASSETS

NASA OCIO is responsible for Agency cybersecurity policy and the implementation and management of enterprise cybersecurity and privacy services. The budget is aligned to the National Institute of Standards and Technology (NIST) Cybersecurity Framework to evaluate cybersecurity gaps and investments against the NIST cybersecurity functions: Identify, Detect, Protect, Respond, and Recover. This alignment allows the Agency to make strategic investments to develop, modernize, and enhance Agency cybersecurity capabilities to address the greatest areas of risk to the Agency, its missions, and supporting functions.

INFORMATION TECHNOLOGY (IT)

IT GOVERNANCE AND OVERSIGHT

NASA OCIO provides Agency-level capabilities for intentionally managing IT and meeting Agency and Federal requirements. IT Governance & Oversight efforts involve collaborating with stakeholders across the Agency to formulate plans and manage budgetary data to meet legal mandates, OMB requirements and guidance, Executive Orders, and regulations. These efforts also include the E-Government activities and Federal CIO Council Committees in which NASA participates.

MISSION ENABLING SERVICES

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**697.0**	**702.5**	**731.5**	**746.5**	**761.9**	**777.6**	**793.7**
Change from FY 2021			**29.0**				
Percentage change from FY 2021			**4.1%**				

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Beginning in FY 2021, SSMS has a revised budget account structure. FY 2020 reflects actual budget authority that has been re-cast into the new SSMS budget structure.

NASA establishes "inclusion" as its fifth, core value (shown here), which is supported by workforce training, data analytics for increased diversity, and leadership development from MES programs.

Mission Enabling Services (MES) ensure NASA mission success with foundational support services, using enterprise service delivery to enhance problem solving and agile responses to evolving requirements. Using an enterprise approach, the MES program eliminates duplicative capabilities, provides opportunities for employees to collaborate across geographic boundaries, and remains agile to shifting demands and surge requirements. Missions rely on MES's institutional capabilities to accomplish their objectives. Enterprise management ensures that critical Agency operations are strategic, mission-focused, agile, and streamlined.

Approximately 82 percent of the MES budget supports labor costs associated with nearly 2,000 civil servants and 1,500 support contractors who provide critical services to the Agency. Recruiting, hiring, and maintaining the right mix of high-performing talent remains a critical focus for the MES program.

MES provides NASA with a bedrock of business functionality in human capital and financial management; procurement and protective services; small business, diversity, and equal opportunity programs; legislative affairs; communications; and international and interagency relations (For a full breakdown of the offices responsible for MES content, see the Program Elements section below).

MES Priorities

MES comprise business support that spans the Agency. The Mission Support Directorate (MSD) priority areas and Agency demand drive the level and scope of MES activity and that includes the following :

MISSION ENABLING SERVICES

- Ensure the health, wellness, and safety of NASA employees and the public;
- Manage NASA's physical assets, including infrastructure and facilities, to be mission-ready, sustainable, and supportive of the Agency's goal of environmental stewardship;
- Manage NASA's physical assets, including infrastructure and facilities, to be mission-ready, sustainable, and supportive of the Agency's goal of environmental stewardship;
- Provide business services that support the unique research and engineering capabilities across centers;
- Maintain the Agency's outreach to the public, industry, and both Federal and international partners; and
- Ensure capabilities, facilities, and infrastructure are ready to enable NASA's missions, now and in the future.

EXPLANATION OF MAJOR CHANGES IN FY 2022

MES will enhance services and content to address NASA's core value of "inclusion".

Diversity, Equity, and Inclusion (DEI)

NASA is committed to implementing data analytics, workforce training, leadership development, and other services that will increase the inclusivity of the Agency workforce, science community, and space partners. In FY 2020, "inclusion" was made a NASA core value in order to make NASA workplaces more diverse and empowering, while also encouraging diversity in aerospace, technology, and science. SSMS has budgeted funding increases for key programs that will provide leaders with data, workforce training, and other enhancements to support the priority DEI across NASA and among education, science, engineering, and industry partners.

ACHIEVEMENTS IN FY 2020

- MES ensured the success of Agency priority goals with key support services and milestones:
    - Worked in partnership with Department of State to develop and negotiate the Artemis Accords, signed by 9 initial countries including the United States, to encourage the safe, peaceful, and responsible exploration of space with global partners
    - Concluded agreements with Canada, Europe, and Japan for critical contributions to the Gateway including habitation space and capabilities, life support systems, external robotics, and science capabilities
    - Created a dedicated procurement service for IT to more effectively acquire the approximately $1.5 billion worth of IT hardware and software purchased annually
    - Exceeded the Agency's small business participation goal (15.4 percent) by achieving 17.5 percent and scored an "A" grade for FY 2019 by the Small Business Administration (SBA)
    - Operated the new Uncrewed Aircraft Systems (UAS) detection system to detect and investigate potential drone threats to NASA launches and assets
    - Worked with the Office of the Director of National Intelligence (ODNI) to implement the Continuous Evaluation (CE) Program
    - Launched the NASA Unity Campaign to enhance inclusion, diversity, equity, and access to improve organizational performance and employee engagement

MISSION ENABLING SERVICES

- Provided comprehensive, high-quality coverage of NASA's major mission successes, including the first all-female spacewalk, the first launch of astronauts from American soil since 2011 Demo-2 (DM-2), and the Mars Perseverance Rover launch
- Bolstered NASA's social media presence with an approximate 20 percent increase in followers and subscribers across all platforms
- Supported Artemis Program activities and the development of a low-Earth orbit commercial market by providing legal support for procurements and collaborative agreements across the Agency
- Enabled acquisitions and agreement activities with legal support for NASA's highest-priority missions, including Artemis, Gateway, Commercial Lunar Payload Services, and others
- Resolved a complex bid protest at the Government Accountability Office (GAO), enabling the Lucy mission and its unique launch service to remain on schedule to meet its limited launch window

- MES enhanced service efficiency, improved reliability, and reduced risk across mission support:
    - Gained Small Business Administration (SBA) approval for the Mentor Protégé program
    - Reduced duplicative contracts by developing enterprise procurements services that centralized and regionalized contracts
    - Improved the complaint process for Final Agency Actions (FAA), reducing the average processing time from 353 days to 92 days for complaints that requested a hearing and from 468 days to 144 days for complaints that did not request a hearing
    - Worked with a cross-Agency team to exclude a company from the aluminum supply chain due to their falsified certifications and material tests, protecting vital NASA resources and successfully recovering approximately $24.6 million in restitution
    - Developed public-private partnerships and land use agreements that generated approximately $9 million in Enhanced Use Lease (EUL) revenue and approximately $15.5 million in National Historic Preservation Act (NHPA) revenue for NASA's infrastructure needs
- MES continued to realign support services to an enterprise delivery model:
    - Four mission support offices initiated their transition to an enterprise model, including the Offices of Communications (OCOMM), Protective Services (OPS), Chief Information Officer (OCIO), and Strategic Infrastructure (OSI)
    - Consolidated human capital management into an enterprise service for staffing, training, classification, and Agency awards
- MES responded to the COVID-19 pandemic with no significant delays to mission or disruptions of service, while simultaneously enhancing service options for the future of work permanently:
    - Implemented a virtual Personal Identity Verification (PIV) badge renewal process to support telework conditions with minimal interactions
    - Delivered remote, monthly training for employee emergency preparedness and safety

MISSION ENABLING SERVICES

WORK IN PROGRESS IN FY 2021

- MES will enhance mission support agility and responsiveness to evolving mission requirements by deepening the functionality and optimizing enterprise service delivery:
    - Implement the G-invoicing process and system requirements to consolidate financial services and contracts to achieve cost efficiencies and increased buying power
    - Continue to promote Talent Marketplace as an Agency tool to meet internal hiring needs
    - Launch HireNow, a ServiceNow function, to improve hiring and the onboarding pipeline and enhance NASA's unique Astronaut Selection tool
    - Update NASA's Enterprise Physical Access Control System (EPACS) infrastructure to reduce the costs of licensing and operations, while ensuring safety across centers
    - Finalize Lawnet and Legal Files (LEOS), which enables the NASA legal community to collaborate across legal offices, improves efficiency in organization and archiving, and optimizes information and knowledge transfer
    - MES will establish leading-edge business services to ensure NASA success now and in the future:
    - Achieve an SBA Scorecard Grade of "A" for FY 2020 small business engagement
    - Implement NASA's new term and condition for grantees that requires reporting on findings of sexual and other forms of harassment
    - Engage in collective bargaining activities with NASA's exclusive union partner to address and revise agreement provisions.
    - Initiate Agency-level labor management activities with national representatives from NASA's labor unions in order to share information and ensure they have a voice in the workplace.
    - Develop a new NASA Diversity, Equity, & Inclusion (DEI) strategic plan, including a new policy on D&I, Equal Employment Opportunity (EEO), and Anti-Harassment for issuance by the NASA Administrator

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- MES will enhance mission support agility and responsiveness to evolving mission requirements by deepening the functionality and optimizing enterprise service delivery:
    - Implement four evaluations under the Agency's Annual Evaluation Plan (AEP).
    - Consolidate contracts for physical security and emergency management with the award of a regional contract that streamlines services and reduces costs
    - Standup the due diligence capability to determine NASA contractor's ability to deliver on contractual obligations
    - Drive increased efficiencies with a new enterprise governance model for legal services and knowledge management
    - Implement empirical data analytics, based on key performance indicators, to validate the effectiveness and efficiency in procurement methods

MISSION ENABLING SERVICES

- Provide leading-edge business services that will ensure NASA success now and in the future
- Implement the DEI strategic plan, which will include a Balanced Scorecard.
- Support targeted recruiting initiatives and track DEI Executive Orders to support more diversity and equity in job candidate pools and applicable, Federal programs
- Develop Workforce Diversity Dashboards for NASA centers and major HQ offices

- Provide foundational business, communications, safety, and security services to ensure full support for key missions including Artemis, Commercial Crew, James Webb Telescope, and other NASA mission launches:
    - Continue executing the Agency's Strategic Workforce Plan to consolidate contracts while ensuring the right mix of civil servant and contractor support to enable the missions
    - Enhance Agency broadcasting with Spanish language translation to improve equity and reach
    - Support growing mission activity with more coverage of climate science, crewed flights, scientific efforts, and new technologies
    - Change NASA TV to NASA+ (Plus) on-demand video service to keep pace with media and broadcasting trends
    - Complete the SBA assessment to receive an SBA Scorecard Grade of "A" and establish the Agency's small business goals based on current and anticipated conditions
    - Negotiate with the SBA to establish the Agency's small business goals for FY 2022 based on current and anticipated requirements
    - Continue to engage NASA's exclusive union partners in collective bargaining to address and revise agreement provisions
    - Conduct Agency-level labor management activities with national representatives from NASA's labor unions in order to share information and ensure they have a voice in the workplace
    - Collaborate with the mission directorates to address priorities, resources, and collaboration with commercial partners to share the FY 2022 mission success stories and ensure they are told at the level of inclusion and innovation expected of NASA
    - Ensure NASA's acquisition strategies secure the Agency's supply chain by maximizing the purchase of American-made goods
    - Draft program and procurement guidance to deliberately support members of underserved communities to advance equity
    - Implement sustained, strategic engagement with international and interagency partners in support of growing partnership requirements for NASA programs
    - Support overseas travel and international engagement for the NASA Administrator and senior NASA officials to advance cooperative and international partnerships
    - Maintain NASA's commitment to export-import controls and Federal compliance through policies and regulations to ensure maximum benefit to the Agency

MISSION ENABLING SERVICES

Program Elements

OFFICE OF THE CHIEF FINANCIAL OFFICER

The Office of the Chief Financial Officer (OCFO) provides leadership for the performance reporting, budget analysis, justification, control, and reporting of all Agency fiscal resources; provides co-leadership for the strategic planning of all Agency fiscal resources; directly supports the development of the Agency's overarching strategic plan and associated annual performance reports; leads the Agency's planning, programming, budgeting, and execution process; oversees all financial management activities relating to the programs and operations of the Agency; and monitors and reports the financial execution of the Agency budget. Through supporting and fostering an agile workforce and enhancing robotic process automation, the OCFO continuously develops and matures modern toolsets, services, and processes for tracking, analyzing, and reporting mission and Agency financial information. The OCFO manages the Agency's budget and financial operations, directs the preparation and submission of annual financial and budgetary reports, and coordinates Agency financial management activities with other Federal agencies.

OFFICE OF CHIEF HUMAN CAPITAL OFFICER

The Office of the Chief Human Capital Officer (OCHCO) provides services and innovative solutions to ensure it meets the needs of our mission today and tomorrow. From creating a learning culture to implementing technology that supports work/life balance, OCHCO supports and strengthens the human foundation of NASA. Game-changing programs help Agency leaders understand workforce investments, anticipate workforce needs, and easily acquire talent for the task. Game-changing programs include streamlining and modernization of the Human Capital Information Technology (HCIT), simplification of position description (PD) classification, centralized training administration, implementing a flexible and agile workforce approach through the Strategic Workforce Plan (SWP), and replacing our aging talent acquisition system. NASA's talent needs are always evolving with mission activities that test the limits of human capability. Leaning forward to be a global leader in human capital excellence, OCHCO enables the people of NASA to push the boundaries of achievement by supporting NASA's mission first and its people always.

OFFICE OF LEGISLATIVE AND INTERGOVERNMENTAL AFFAIRS

The Office of Legislative and Intergovernmental Affairs (OLIA) provides executive leadership, direction, and coordination of all communications and relationships, both legislative and non-legislative, between NASA and the U.S. Congress as well as state and local governments.

OFFICE OF PROCUREMENT

The Office of Procurement (OP) explores and executes innovative, effective, and efficient acquisition business solutions to optimize capabilities and operations that enable NASA's mission. NASA spends approximately 85 percent of its budget on acquiring goods and services through approximately 750 procurement and small business professionals across the Agency. In FY 2019, Agency spend was $19.7 billion via approximately 28,000 procurement actions (e.g., awards, modifications) while managing more than 23,000 instruments (e.g., contracts, purchase orders, task orders, and delivery orders). OP's

MISSION ENABLING SERVICES

transformed workforce, optimized capabilities, and continuous training opportunities keep it poised to deliver effective and efficient procurement services that ensure mission agility, resilience, and success.

OFFICE OF SMALL BUSINESS PROGRAMS

The Office of Small Business Programs (OSBP) promotes and integrates small businesses into NASA's industry base of competitive contractors that pioneer the future of space exploration, scientific discovery, and aeronautics research. OSBP provides integration, policy, initiatives, and oversight needed to ensure compliance with law and regulation to increase the Agency's small business industry base while offering the best technical solutions and value to support the Agency's mission. OSBP conducts, sponsors, and participates in small business outreach activities which assist small businesses, including small disadvantaged, women-owned, Historically Underutilized Business Zones (HUBZone), veteran-owned, service-disabled veteran-owned, and Historical Black Colleges and Universities (HBCU) / Minority Serving Institutions (MSI) in supporting the NASA mission.

OFFICE OF PROTECTIVE SERVICES

The Office of Protective Services (OPS) provides security services at all NASA facilities to ensure the protection of life and property across the Agency. OPS resources include a large contractor workforce in addition to its civil servant workforce. OPS provides secure access to intelligence and information essential to mission success, fire services, and emergency management at all NASA facilities and is the focal point for policy formulation, oversight, coordination, and management of Agency physical security, intelligence, counterintelligence, counterterrorism, emergency management, continuity of operations, fire services, national security, communications security (COMSEC), classified information security, personnel security, identity and credential management, electronic physical access management, insider threat, and protective services training programs. OPS provides services to ensure the safety and security of people, property, and information at 20 locations across the country.

OFFICE OF DIVERSITY AND EQUAL OPPORTUNITY

The Office of Diversity and Equal Opportunity (ODEO) leads diversity and civil rights policies, programs, and services, which enables the universe of available talent to contribute inclusively and equitably, propelling NASA organizations and people to work together more effectively to accomplish Agency missions. ODEO offers the best approaches to recruit, hire, engage, empower, and retain a highly talented workforce across a diverse landscape. ODEO programs empower and advance NASA as a leader and model Agency for diversity, equity, inclusion, and access, as well as promote external civil rights compliance in NASA-funded science, technology, engineering, mathematics, and other related programs.

OFFICE OF COMMUNICATIONS

The Office of Communications (OCOMM) delivers NASA's incredible work to billions of people around the world with compelling storytelling on a variety of platforms. NASA communicates via various methods including news and media engagement, digital services and products (e.g., web, multimedia, social media), non-technical publications, exhibits, as well as speaking and public engagement activities and events, to promote effective and consistent NASA communications by ensuring strategic alignment and working collaboratively with other Agency organizations. OCOMM continues to manage NASA's

MISSION ENABLING SERVICES

astronaut appearances, guest operations, speakers' bureaus, exhibits, and artifacts. With NASA's new era in human spaceflight, OCOMM's work is critical to ensure NASA's advances in exploration, science, and discovery are shared with all communities.

OFFICE OF INTERNATIONAL AND INTERAGENCY RELATIONS

The Office of International and Interagency Relations (OIIR) provides executive leadership and coordination for all NASA international and interagency activities and partnerships, and for policy interactions between NASA and other U.S. Executive Branch offices and agencies. OIIR manages the Agency's Export Control Program and Overseas Representation (France, Japan, and Russia), including compliance with Federally-mandated requirements and all NASA and U.S. export and import laws, policies and regulations, to maximize the benefits of the Agency's international efforts. OIIR provides Agency leadership for NASA overseas representatives who work with U.S. Embassies and senior foreign government officials in support of NASA's activities. OIIR travel resources are required to support the international travel of the NASA Administrator, Deputy Administrator, and other senior NASA officials in the cooperation of more than 700 active international agreements in over 125 countries as well as the NASA Advisory committees.

OFFICE OF THE GENERAL COUNSEL

The Office of the General Counsel (OGC) provides legal services Agency-wide, including establishing and disseminating legal policy and interpreting new statutes and cases to enable diverse and cutting-edge Agency activities, thus ensuring NASA remains in compliance with all statutory and regulatory requirements. Additionally, OGC is responsible for developing the ethics and patent program requirements, establishing metrics, and developing quality standards. As a functional office, OGC serves in an advisory capacity to the Administrator, Enterprise Associate Administrators, and Center Directors across nearly 20 core legal disciplines. OGC provides litigation expertise to the Agency and acts as the Agency representative before the U.S. Patent and Trademark Office and other administrative forums. NASA attorneys also function as leaders and trusted advisors on matters of policy and legal risk, upholding NASA values and enabling the NASA mission.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**677.8**	**667.2**	**685.1**	**699.4**	**714.0**	**728.9**	**744.1**
Change from FY 2021			**17.9**				
Percentage change from FY 2021			**2.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2020 reflects actual budget authority that has been re-cast into the new SSMS budget structure.

Engineers (shown here) adjust the Advanced Electric Propulsion System thruster in GRC's Vacuum Facility 5 to conduct 4,500-hour wear/erosion testing for new propulsion systems.

The NASA Infrastructure and Technical Capabilities (I&TC) program addresses Agency-wide operating requirements for physical assets considered institutional, and not fully funded by a single NASA mission directorate. The program maintains facilities, utilities, structures, and technical capabilities. It also provides oversight and management of real property assets, environmental program activities, aircraft operations, and logistics functions. Critical to supporting NASA's missions is the underlying infrastructure and skilled workforce that keep the centers and facilities operating effectively and efficiently.

I&TC Priorities

The I&TC program balances asset management with improvement projects (including tradeoffs between facility maintenance in the Safety, Security, and Mission Services account with construction projects in the Construction and Environmental Compliance and Restoration account). I&TC must also ensure NASA facilities have the research and engineering capabilities to sufficiently support mission activities. I&TC must divide its allocation between failure prevention, in the form of routine preventative maintenance and predictive testing, and inspection and other forward-looking investments in capabilities to support NASA's future missions.

The following priorities outline how funding is allocated within I&TC to ensure mission success and long-term support viability:

INFRASTRUCTURE & TECHNICAL CAPABILITIES

- Address critical assets based upon criticality and NASA's mission priority:
    - Address risks that threaten health, safety, and mission success, including preparedness for unpredictable conditions
    - Address critical infrastructure maintenance and repair requirements to enable mission timelines and ensure safety, including horizontal infrastructure (utilities, roads, etc.)
    - Ensure NASA missions have the facilities, laboratories, and essential utilities to be successful
    - Enhance the Aircraft Safety Program for key NASA mission safety and success
    - Implement innovative business solutions that improve asset management for cost reduction and mission-readiness

- Enhance asset management forecasting and management with real-time data and joint planning across the Agency, including condition-based and tiered maintenance strategies
    - Invest in workplaces to ensure technical capabilities, respond to changing work conditions, and support an optimally efficient and effective workforce
    - Support good stewardship of the environment with footprint reduction and enforcement of compliance standards
    - Conduct Agency-wide strategic planning to better prioritize maintenance, repair, and construction activities and optimize the integration of technical capabilities

EXPLANATION OF MAJOR CHANGES IN FY 2022

I&TC will increase support and content to meet NASA's commitment to environmental stewardship.

Electric Vehicles

NASA will support the government’s goal of transitioning to a Zero Emission Vehicle (ZEV) fleet by installing the necessary recharging infrastructure and establishing acquisition criteria to begin replacing fuel-powered vehicles with electrical vehicles. NASA’s fleet is comprised of 2,609 vehicles assigned to a combination workforce of civil servants and contractors. The commitment to transition to a ZEV fleet constitutes a substantial impact, as the currently fleet contains only ~15 percent hybrid and electric vehicles. NASA’s strategy includes both Agency-owned and GSA-leased elements of its fleet. The Agency will provide for associated training, including the ZEV acquisition strategy, and operation and maintenance of the ZEV fleet. NASA regards these enhancements as paramount to its leadership in climate science and environmental stewardship, as it reflects a commitment to addressing the human impact on climate change by reducing harmful greenhouse gasses (GHG)

ACHIEVEMENTS IN FY 2020

- Improved asset management capabilities to increase efficiency and effectiveness for business operations, including NASA's goal of footprint reduction:
    - Completed a future development concept at two NASA centers to reduce center operating costs by 25 percent by 2038, while ensuring critical facilities are mission-ready
    - Created a strategic framework to reduce Agency energy and water costs and consumption
    - Disposed of approximately 36,000 items and reutilized approximately $88 million of property
    - Recycled approximately 22,000 electronic items and generated approximately $71,000 in proceeds to support NASA environmental programs
    - Generated approximately $1.8 million of exchange sale value to offset the cost of new property

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  - Disposed approximately 50,000 cubic feet of aircraft parts and materials, including the trade of four aging helicopters to offset the purchase of three new helicopters

- Maintained NASA's commitment to environmental stewardship, compliance, and utility efficiency:
  - Established sustainability priorities, such as energy conservation measures, that provide an annual cost avoidance of $1 million to NASA
  - Completed installation of 4.3-megawatt solar photovoltaic system through an Energy Savings Performance Contract (ESPC) at Wallops Flight Facility
  - Completed Title V air compliance testing of 14 high pressure industrial water diesel engines at Stennis Space Center (SSC) to ensure no impact to critical Green Run stage test activities for the Space Launch System for Artemis

- Reduced risks of failure and damage to health or property ensuring NASA’s critical ground testing capabilities are available as needed to enable NASA missions:
  - Refurbished Vacuum Chamber B at Johnson Space Center (JSC), a critical facility for the safe development of the next generation spacesuit
  - Completed risk reduction testing in direct support of NASA’s SpaceX Crew 1 Mission
  - Completed qualification testing to enable the collection and use of Thermal Protection System performance data for Orion and other mission programs
  - Tested laser-induced fluorescents for the Advanced Electric Propulsion System (AEPS) thruster in Vacuum Facility 5 chamber at Glenn Research Center (GRC)

- Delivered, developed, and/or supported technical capabilities that enable NASA's unique missions:
  - Supported the development of the Vertical Motion System at Ames Research Center (ARC), a test environment for electric vertical take-off and landing certification criteria for the Federal Aviation Administration (FAA)
  - Partnered with GSA and over 100 organizations (e.g., states, museums, schools, universities, libraries, and planetariums) to ensure over 3,485 space-unique artifact items were available for future generations

- Responded to the COVID-19 pandemic by adapting facilities and logistics management to support work-from-home with minimal disruption to NASA missions:
  - Distributed $1.4 million of personal protective equipment (PPE) and signage to support the safe continuation of mission-critical, on-site work
  - Executed the contingency operations plan (COOP) related to logistics support

WORK IN PROGRESS IN FY 2021

- Finalize the transition to an enterprise service delivery model and mature the enterprise to make physical management assets more streamlined and effective for NASA's missions:
  - Provide NEPA coverage for all centers to streamline the decision-making process, reduce costs, and schedule impacts to future projects
  - Complete NASA's first Agency Master Plan to align the future development of center facilities with evolving mission needs

- Invest in technologies that will enhance NASA's physical asset management and reduce costs:

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- Continue investment in condition-based maintenance (CBM) measures across all centers to include pressure, vibration, and temperature sensors on critical equipment to predict potential critical equipment failures before they break
- Continue replacement of over aged electrical controls and address identified safety risks of arc flash events

- Support NASA mission success with safe and reliable facilities, infrastructure, and logistical management:
  - Sustain deteriorating or failed physical assets, including chillers, air handlers, fire alarm panels, boilers, exhaust fans, roofs, roads, and various infrastructure system repairs
  - Develop pre-emptive mitigation measures to reduce project cost and schedule impacts due to regulatory compliance activities
  - Completed the first work package as part of a multi-year program to restore and modernize the ARC Arc Jet Complex

- Protect the Earth and maintain NASA's commitment to environmental stewardship:
  - Work to reduce petroleum products usage and increased Alternative Fuel usage to 17 percent, meeting executive order metrics, and receive OMB Green rating
  - Develop an Agency Climate Action Plan in accordance with Executive Order 14008, Tackling the Climate Crisis at Home and Abroad to integrates NASA's climate change adaptation and climate resilience across Agency programs

- Provide and enable critical ground testing capabilities to ensure mission success and maintain NASA's high standard of health and safety:
  - Test the unique Vertical Motion Simulator at ARC to support Human Landing System (HLS) commercial partners and reduce landing risks as the vehicle design matures
  - Refurbish JSC Vacuum Chambers A and B, including safety measures and fire suppression systems, which ensure human safety for Artemis lunar missions
  - Test erosion and wear in the GRC Vacuum Facility 5 to understanding long-duration performance and limitations of the Advanced Electric Propulsion System (AEPS) thruster for future large-scale, science missions and the transportation of cargo
  - Conduct vertical motion simulations to develop scenarios and test cards in preparation for real, Advanced Air Mobility (AAM) flight tests with commercial partners

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- Transform physical asset management to be more efficient and effective, including leveraging technologies, developing enterprise processes, and using data in decision-making:
  - Update Center Master Plans to align with Agency Master Plan and mission requirements
  - Continue transformation to improve strategic coordination, resource allocation, and agile management of NASA's physical asset portfolio, including real-property and facilities
  - Address routine and backlogged maintenance with a tiered maintenance strategy that evaluates risk to mission-critical assets based on available funding and mission priorities
  - Install key technologies for condition-based maintenance on critical equipment and facilities to prevent failures and reduce operational maintenance costs
  - Improve sustainability practices, such as the Energy and Water Program Management Strategic Plan, to drive efficiency and cost savings across the Agency

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- Implement Agency maintenance program use of the enterprise-level, computerized maintenance management system/enterprise asset management software system

- Support mission critical activities by providing unique, leading-edge technical facilities and capabilities, including unique and crucial testing:
  - Reduce arc flash and layered pressure vessel system risk through ongoing mitigation and testing
  - Refurbish JSC's Vacuum Chambers A and B with upgrades for safety, data collection, and unique capabilities to support Exploration Extravehicular Mobility Unit Design Verification Test (xEMU DVT) activities
  - Continue modernization of ARC's Arc Jet Complex, a critical Agency ground testing capability used for flight qualified thermal protection systems for atmospheric entry
  - Test wear and erosion for the Advanced Electric Propulsion System (AEPS) thruster in the GRC Vacuum Facility 5 for future, large-scale, science missions and cargo transportation
  - Support Advance Air Mobility (AAM) industry development with vertical motion simulations to develop scenarios and test cards in preparation for real flight test

- Ensure safety, health, and environmental stewardship across all NASA facilities and properties:
  - Implement an Environmental Management Enterprise Strategic Plan to align center environmental resources, providing efficiencies and standardize practices
  - Reduce risk to mission and support NASA's commitment to the environment with comprehensive environmental compliance programing, including proactive agreements and permitting with state regulators and removal of potential compliance issues

Program Elements

AIRCRAFT MANAGEMENT

The Aircraft Management Program provides capability leadership, oversight, and coordination of NASA’s aviation assets, including Uncrewed Aircraft Systems to enable NASA’s missions in science, technology, aeronautics, and space exploration. NASA policy sets the highest standards and best practices of aviation safety. Program-Independent Flight Operations Offices provide oversight of center aircraft flight operations and ensure aircraft operations can meet unique missions worldwide in a safe manner. These offices include a Chief of Flight Operations, an Aviation Safety Officer, a Chief of Maintenance, and a Chief of Quality Assurance to ensure oversight of qualified personnel operating aircraft that are airworthy and mission ready.

ENVIRONMENTAL MANAGEMENT

The Environmental Management Program encompasses the development, implementation, and oversight of Agency policies for environmental planning, compliance, restoration, pollution prevention, energy and water conservation, and sustainability while preserving natural, cultural, and historic resources in balance with enabling the NASA missions. The program enables compliance with applicable Federal, state, and local environmental laws and regulations, as well as NASA policy in day-to-day operations and mission support. Specifically, Environmental Management covers NASA's programs for local environmental

INFRASTRUCTURE & TECHNICAL CAPABILITIES

policy development, Environmental Management System (EMS) implementation, environmental permitting and compliance, recycling, sustainable acquisition, hazardous materials and waste management, pollution prevention, energy and water management systems and reporting, renewable energy, natural resources, historic properties, and National Environmental Policy Act (NEPA) program support.

FACILITIES SERVICES

The Facilities Services program encompasses the institutional facilities support activities throughout the Agency. The budget supports utilities, operations and maintenance, real estate, and facilities engineering to include civil construction designers, engineers and project managers. I&TC funds the civil servants and procurements that operate and manage NASA's institutional infrastructure. NASA recently deployed a cost model that forecasts the funding requirements to sustain its inventory of facilities at the current condition. NASA manages a portfolio of assets with over $2.66 billion in deferred maintenance. The I&TC budget supports a strategy to reduce the growth of backlogged maintenance and systematically improve the reliability of NASA institutional infrastructure from transformers and substations to buildings, horizontal infrastructure, and test capabilities.

LOGISTICS MANAGEMENT

The Logistics Management program encompasses the development, implementation, and management of Agency-wide logistics policies, processes, services, system innovation, and facilitates the implementation of government and industry best practices for NASA's centers and facilities. Logistics Management provides functional management, oversight, and coordination over the Agency's personal property equipment, supply and material, warehouse and receiving operations, property disposal, and artifact property disposition. The program also provides oversight for contractor-held property management, mail and freight management, transportation management, life cycle logistics and supply chain management, policy compliance and logistics contracts, and Agency library management. Logistics Management ensures the readiness of material and equipment for NASA's scientific, aeronautics, and space exploration mission requirements at 10 NASA centers and three component facilities. The program includes receiving and inspecting supplies/materials as well as issuing and moving those materials so that products critical to NASA's space exploration mission arrive at the desired locations in an efficient manner.

TECHNICAL CAPABILITIES MANAGEMENT

The Technical Capabilities Management program provides the centralized and strategic management of a portfolio of specific capabilities to enable NASA's missions in science, technology, aeronautics, and space exploration. Examples of these capabilities are provided below:

- The high-enthalpy test capability at ARC's Arc Jet Complex provides simulated high-temperature, high-velocity environments and supports the design, development, test, and evaluation of Thermal Protection Surface (TPS) materials, vehicle structures, aerothermodynamics, and hypersonic aerodynamics experienced by a vehicle during atmospheric entry.
- Flight simulators are of critical importance to NASA's research in fundamental aeronautics and aviation safety. These capabilities provide scientists and engineers with tools to explore, define, and resolve issues in vehicle design and mission operations. The capabilities include the motion

INFRASTRUCTURE & TECHNICAL CAPABILITIES

simulators and development laboratories used in the research and development of flight and crewed operations at the ARC Vertical Motion Simulator and the Langley Research Center (LaRC) Flight Simulation Facility.

- Space environments test capabilities and facilities whose primary use is related to spacecraft and instrument development and qualification, space technology development, human-rated space environments, and launch environments. Capability components include: vacuum, thermal/vacuum, and thermal chambers; vibration tables; acoustic labs; cleanrooms; and electromagnetic interference and electromagnetic compatibility, magnetic, optical, X-ray, solar spectrum, and ionizing radiation facilities. Located at most NASA centers, testing performed with these capabilities ensures the equipment, sub-systems, and assembled spacecraft will survive the harsh noise and vibrations experienced during launch and the ultra-low pressure and ultra-low or ultra-high temperatures experienced in space environments.
- The external radiation testing capability procures the necessary time and facility support at non-NASA facilities to meet the requirements of Agency programs and projects. The test facilities provide controlled sources of electrons, heavy ions, neutrons, protons, and other relevant types of high-energy radiation that NASA uses to simulate the impact of the natural space radiation environment on a wide range of electronic and material systems. National laboratories, private companies, and universities at both domestic and foreign locations operate these highly specialized facilities. Test activities support a wide range of assessment, development, and flight activities.

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FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Agency Technical Authority	184.0	182.8	**186.8**	190.6	194.6	198.6	202.8
Center Engineering, Safety, & Operations	879.6	835.4	**833.7**	850.9	872.2	894.6	917.8
Total Budget	**1,063.6**	**1,018.2**	**1,020.4**	**1,041.5**	**1,066.8**	**1,093.2**	**1,120.6**
Change from FY 2021			**2.2**				
Percentage change from FY 2021			**0.2%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2020 reflects actual budget authority that has been re-cast into the new SSMS budget structure.

To protect human life and ensure mission success, the Office of Safety and Mission Assurance (OSMA) issues technical guidance that is operationalized at each center through CESO funding to ensure the testing and validation of vital pressure systems and vessels.

Engineering, Safety, and Operations (ESO) supports NASA's high standard of safety and mission assurance, while maintaining center flexibilities that promote innovation and mission success. ESO is divided between two, distinct programs: Agency Technical Authority (ATA) and Center Engineering, Safety, and Operations (CESO).

ATA protects the overall health and safety of NASA's workforce and programs by providing technical oversight for safety, health, quality, and engineer. The independence of ATA offices is a vital part of NASA's checks and balances to ensure safety, quality, and engineering concerns are always vetted, analyzed, and mitigated. ATA offices develop policies, guidance, and conduct reviews at a corporate level, which are implemented at the center-level through CESO programs.

CESO provides funding for a number of center-level activities, including the operations and management at nine centers and component facilities, in addition to corporate leadership at NASA Headquarters (HQ), the execution of delegated technical authority at the centers, and center investments to ensure mission success, innovation, and technical excellence. CESO allows centers the flexibility to address mission-critical requirements, such as acquiring specialized scientific and engineering equipment. CESO funds center-level implementation of ATA policies and guidelines and preserves the checks and balances at

ENGINEERING, SAFETY, & OPERATIONS

each center that ensure the highest standards of health, safety, and mission assurance. It also supports NASA's competitive bid and proposal process, which maintains NASA's innovative and technical leadership in exploration, science, and engineering. CESO includes center institutional operations that are not included in the requirements of NASA's enterprise functional offices. CESO encompasses a diverse set of ongoing activities and unique projects in support of center operations and infrastructure, while enabling safe and effective mission support.

ESO Priorities

ESO is focused on management, health, safety, mission assurance, and technical excellence, which aligns to mission support's overall goals in workforce and public wellness, infrastructure, research and engineering, and overall support viability. ESO provides the critical funding that aligns center activities to corporate standards and mission priorities, while providing centers the agility and adaptability to support innovation and mission work. ESO priorities outline these essential areas of support and investment:

- Provide independent review and technical oversight for health, safety, and mission assurance, including medical and engineering evaluations
- Provide policy, guidance, and oversight to ensure optimal outcomes for health, safety, bioethics in research
- Evaluate risks of potential loss of life, engineering issues, health impacts, and mission failure.
- Provide policy, oversight, and validation of highly technical equipment, facilities, and laboratories to meet NASA's standards for quality, reliability, and safety
- Sustain NASA’s engineering and research capabilities with support services, like analysis, testing, and fabrication, as well as independent research, development projects, and equipment purchases
- Support corporate leadership at NASA HQ, the operationalization of Agency policies, business innovation, and effective and efficient mission work

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

- Provided vital health and medical expertise across the Agency, including reviews, independent evaluations, policy development, and general guidance:
  - See the ATA program section for a full list of achievements
  - Conducted rapid reviews of astronaut medical cases
  - Provided direct health and medical technical support for all human-rated spacecraft

- Provided technical oversight, independent reviews, and evaluations of mission work:
  - See the ATA program section for a full list of achievements
  - Supported the successful Crew Dragon Demo-2 mission and Mars 2020 launch

- Provided technical review and expertise of engineering specifications and activities across the Agency:
  - See the ATA program section for a full list of achievements
  - Improved orbital debris modeling
  - Provided independent technical insights and assessments for all missions

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- Supported the unique scientific and engineering capabilities at each center by funding specialized equipment, services, and other costs associated with laboratories and facilities:
  - See the CESO program section for a full list of achievements
  - Piloted a novel system for analyzing fluid dynamics
  - Fulfilled approximately 2,400 service requests in the Metrology and Calibration Laboratory (MCL)

- Invested in partnerships, research, key infrastructure, and NASA's competitive bidding process to ensure centers are innovative and capable of supporting missions, today and in the future:
  - See the CESO program section for a full list of achievements
  - Funded Independent Research and Development Projects (IRAD)
  - Supported wastewater and watershed studies to improve usage of natural resources

- Ensured operational safety across NASA centers:
  - See the CESO program section for a full list of achievements
  - Ensured safety instruments and sensitive equipment operated at full capacity
  - Managed all occupational health and institutional safety programs across centers

- Supported the independent, technical authority at the center-level:
  - See the CESO program section for a full list of achievements
  - Conducted reviews and provided program oversight for all mission activities
  - Certified over 340 pressure systems and approximately 970 pressure vessels

- Supported institutional administration and center administration:
  - See the CESO program section for a full list of achievements

WORK IN PROGRESS IN FY 2021

- Continue to enhance and provide health and medical expertise to NASA's priority missions:
  - See the ATA program section for a full list of current work
  - Provide technical requirements for human spaceflight standards
  - Support mission activities with Human Systems Integration (HSI)

- Support the ongoing safety and mission assurance activities that prevent loss of life and failures:
  - See the ATA program section for a full list of current work
  - Update standards and oversight processes for nuclear safety and planetary protection
  - Provide independent verification and validation of critical mission programs

- Provide and enhance critical engineering expertise, guidance, and oversight for mission activities:
  - See the ATA program section for a full list of current work
  - Conduct independent assessments of NASA’s highest risk challenges
  - Provide analysis in collaboration with the U.S. Navy and U.S. Air Force to reduce the effects of hypoxia to protect pilot health and limit lost aircraft

- Support the unique scientific and engineering capabilities at each center:
  - See the CESO program section for a full list of current work

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  - Purchase additional life support equipment to meet increasing Spaceport demand
  - Support Agency-wide calibrations, function tests, and adjustments through the MCL

- Invest in partnerships, research, key infrastructure, and NASA's competitive bidding process:
  - See the CESO program section for a full list of current work
  - Leverage Space Act Agreements to allow industry partners to utilize unique testing capabilities that support development of new systems

- Ensure operational safety across all NASA centers:
  - See the CESO program section for a full list of current work
  - Improve the electrical systems that protect NASA's astromaterial sample collections
  - Conduct independent studies to assess risk management for new NASA work

- Support the independent, technical authority at the center-level:
  - See the CESO program section for a full list of current work
  - Support the engineering validation and technical oversight of ARC's Arc Jet Complex and Vertical Motion Simulator

- Support institutional administration and center administration:
  - See the CESO program section for a full list of current work
  - Support Agency-wide configuration and data managed and hardware operational logistics

- Support the development of Agency-wide policies, strategies, and guidelines at HQ:
  - See the CESO program section for a full list of current work
  - Support the administration and employee programs in response to COVID-19
  - Conduct assessments and strategy planning associated with the future of work

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- Continue to enhance and provide health and medical expertise to NASA's priority missions:
  - See the ATA program section for a full list of planned achievements
  - Optimize the review process through the Agency Independent Review Board (IRB)
  - Support the development and integration of products and plans related to missions

- Support the ongoing safety and mission assurance activities that prevent loss of life and mission failures through independent evaluations and deep technical expertise:
  - See the ATA program section for a full list of planned achievements
  - Provide independent testing and evaluation for NASA missions, including simulations, studies, verification, and validation

- Provide and enhance critical engineering expertise, guidance, and oversight for mission activities:
  - See the ATA program section for a full list of planned achievements
  - Ensure employees and reviewers are able to voice concerns regarding safety
  - Provide engineering guidance, oversight, and review through the NASA Engineering and Safety Center (NESC)

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- Support the unique scientific and engineering capabilities at each center by funding specialized equipment, services, and other costs associated with laboratories and facilities:
  - See the CESO program section for a full list of planned achievements
  - Support Agency-wide calibrations, function tests, and adjustments through the MCL

- Invest in partnerships, research, key infrastructure, and NASA's competitive bidding process to ensure centers are innovative and capable of supporting missions, today and in the future:
  - See the CESO program section for a full list of planned achievements
  - Open IRAD Program solicitations and investing in ideas that address, technology development gaps, innovative opportunities, lunar and Mars missions, and risk reduction
  - Utilize astromaterials facilities for samples from asteroids, the Moon, and Phobos

- Ensure operational safety through the maintenance, repair, or replacement of equipment and facilities, or the management of hazardous or potentially hazardous conditions and materials:
  - See the CESO program section for a full list of planned achievements
  - Manage hazardous conditions and materials to avoid exposure and injury

- Support the independent, technical authority at the center-level that ensures NASA's high standard for health and safety, engineering excellence, and mission assurance:
  - See the CESO program section for a full list of planned achievements
  - Continue the multiyear Pressure Systems program to inspect and certify pressure vessels
  - Conduct routine, institutional safety programs

- Support institutional administration and center administration, which includes leadership priorities and business innovations through process improvement and technologies:
  - See the CESO program section for a full list of planned achievements
  - Continue strategic analysis and master planning of facilities and capabilities

Programs

AGENCY TECHNICAL AUTHORITY (ATA)

ATA work is managed by the Offices of the Chief Health and Medical Officer (OCHMO), Safety and Mission Assurance (OSMA), and the Chief Engineer (OCE), and includes vital programs like the NASA Safety Center (NSC), the Independent Verification and Validation (IV&V), and the NASA Engineering and Safety Center (NESC). These activities provide the foundation for NASA’s system of checks and balances, defined in NASA’s Strategic Management and Governance Handbook, by providing for the technical authority over health, safety, and engineering, independent of the missions. Through independent analysis and deep subject matter expertise, ATA develops policy, designs procedural requirements, and provides recommendations to NASA's Administrator, mission directorates, center directors, and program managers, who are ultimately responsible for the safety and mission success of all NASA activities.

ATA provides training and maintains a competent technical workforce with expertise in system engineering, system safety, reliability, quality, and space medicine. Subject matter experts analyze risks and risk acceptability through an established process of independent reviews and assessments. The

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information and advice from these experts provide critical data required to develop authoritative decisions related to the application of requirements on programs and projects

CENTER ENGINEERING, SAFETY, AND OPERATIONS (CESO)

NASA's Center Engineering, Safety, and Operations (CESO) is a multifaceted program that ensures Agency leadership is implemented at the center-level, while centers have the flexibility and support to ensure mission success and uphold NASA's high standard of safety and engineering excellence.

CESO ensures NASA's unique, technical, and innovative capabilities are mission-ready by supporting center-level institutional and technical capabilities through independent research, development projects, and maintenance of facilities, laboratories, and other mission-critical assets. The technical skill and specialized assets or services that support analyses, design, research, testing, laboratories, and fabrication enable the efficient and effective implementation of mission work at the centers, now and in the future. CESO funds are used by centers to ensure the technical skills and capabilities are available and mission-ready based on mission requirements and timelines.

CESO is a key component of NASA's overall approach to risk management by providing center-level independent technical authority. By funding center-level oversight and reporting activities that uphold the strategy and guidance from Agency Technical Authorities (ATAs), checks on safety, engineering, and mission assurance remain separate from mission directorates.

CESO funds NASA Headquarters (HQ) operations, as well as center management, across the Agency. Support for institutional administration and operational safety are vital to allow centers the flexibility to address and manage conditions unique and specialized to their center CESO also ensures that Agency policies and guidance are operationalized across centers with consistency and efficiency.

AGENCY TECHNICAL AUTHORITY

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**184.0**	**182.8**	**186.8**	**190.6**	**194.6**	**198.6**	**202.8**
Change from FY 2021			**4.0**				
Percentage change from FY 2021			**2.2%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Beginning in FY 2021, SSMS has a revised budget account structure. FY 2020 reflects actual budget authority that has been re-cast into the new SSMS budget structure.

The NASA Engineering and Safety Center (NESC) continues to investigate pilot breathing issues that have occurred when flying high-performance U.S. Navy and U.S. Air Force fighter aircraft.

Agency Technical Authority (ATA) programs protect the health and safety of the NASA workforce by evaluating programs, projects, and operations to ensure safe and successful completion. ATA capabilities provide expert technical excellence, mission assurance, and technical authority Agency-wide.

ATA work is managed by the Offices of the Chief Health and Medical Officer (OCHMO), Safety and Mission Assurance (OSMA), and Chief Engineer (OCE), and includes vital programs like the NASA Safety Center (NSC), the Independent Verification and Validation (IV&V), and the NASA Engineering and Safety Center (NESC). These activities provide the foundation for NASA’s system of checks and balances, defined in NASA’s Strategic Management and Governance Handbook. Through independent analysis and deep subject matter expertise, ATA develops policy, designs procedural requirements, and provides recommendations to NASA's Administrator, mission directorates, center directors, and program managers, who are ultimately responsible for the safety and mission success of all NASA activities.

ATA provides training and maintains a competent technical workforce with expertise in system engineering, system safety, reliability, quality, and space medicine. Subject matter experts analyze risks and risk acceptability through an established process of independent reviews and assessments. The information and advice from these experts provide critical data required to develop authoritative decisions related to the application of requirements on programs and projects.

AGENCY TECHNICAL AUTHORITY

Activities conducted through the IV&V program are funded through a combination of ATA and mission directorate resources. The following table shows the funds provided by the Safety, Security, and Mission Services (SSMS), Science, Deep Space Exploration, and Space Operations accounts:

	Estimated IV&V Funding ($M)		
Mission Account	**FY 2020**	**FY 2021**	**FY 2022***
Safety, Security, and Mission Services	$39.1	$39.1	$39.4
Science	$2.4	$3.6	$3.5
Deep Space Exploration	$5.1	$7.0	$6.8
Space Operations	$1.7	$3.5	$3.3
Total	**$48.3**	**$53.2**	**$53.0**

(Note: FY 2022 estimates are subject to change depending on mission schedules and Agency risk analysis.)

ATA Priorities

ATA is vital to ensure the safe and healthy advancement of space exploration, technological advancement, and scientific discoveries. All ATA activities support mission support's primary goal of health and safety for both the NASA workforce and the public. Within that primary goal, ATA is focused on critical objectives that support mission safety, heath, and ethics:

- Provide independent review and deep technical knowledge on health and safety, including medical and engineering evaluations, across all mission activities
- Ensure ethical conduct in NASA's research and experimentation activities
- Evaluate risks to mission, including the potential loss of life, engineering failures, health impacts, and mission failure
- Provide policy and technical guidance to ensure optimal mission health, safety, and success

EXPLANATION OF MAJOR CHANGES IN FY 2022

To align with NASA's priorities, ATA will increase content and service in one key area:

Orbital Debris

A primary focus for NASA is the safe and secure exploration of space and the protection of national assets. As more commercial and international entities become spacefaring, and the amount of debris in orbit grows, the need to understand the debris environment and mitigate the orbital debris hazard increases. NASA's efforts will support the protection of NASA, other government, and commercial assets, while laying the groundwork for addressing this growing environmental problem.

ACHIEVEMENTS IN FY 2020

- Provided vital health and medical expertise across the Agency, including reviews, independent evaluations, policy development, and general guidance:
    - Conducted rapid reviews of astronaut medical cases to validate crewmember certifications for Commercial Crew and any other human spaceflight mission

AGENCY TECHNICAL AUTHORITY

  - Provided direct health and medical technical support, insight, and oversight for all Human-Rated Spacecraft and X-Plane requirements
  - Coordinated NASA's response to the COVID-19 and collaborated with other Federal agencies to determine the best approaches to protect Americans from the virus
  - Institutionalized NASA's authority under 51 U.S.C. 20149, issued 14 CFR 1241 (To Research, Evaluate, Assess, and Treat [TREAT] Astronauts) that authorizes medical monitoring, diagnosis and treatment of former U.S. Government astronauts and payload specialists for conditions associated with spaceflight

- Provided technical oversight, independent reviews, and evaluations of mission work to ensure safety and success:
  - Supported the successful Crew Dragon Demo-2 mission and Mars 2020 launch
  - Conducted an Organizational Safety Assessment with SpaceX prior to launches
  - Provided evaluation and verification for program activities for numerous NASA mission areas, including Artemis, Commercial Crew, and the International Space Station (ISS)
  - Identified 39 Severity 1 and 2 software issues which, if manifested in operations, have the potential to result in the loss of mission or the loss of an essential mission capability

- Provided technical review and expertise of engineering specifications and activities across the Agency:
  - Provided independent technical insights and assessments of programs, including, but not limited to: X-57, X-59, ISS, Commercial Crew, SpaceX Demo and Crew flights, the Space Launch System (SLS), and the James Webb Space Telescope
  - Provided independent technical insights and assessments of NASA technical capabilities and facilities, including environmental testing and assembly
  - Initiated the 1,000th independent technical assessment through the NESC of NASA's highest risk programs
  - Conducted an unprecedented 84 new technical assessments in 2020, well above the historical average of 50 per year
  - Assessed the compatibility between high-pressure propellants and titanium materials commonly used in the new spacecraft being developed by or for NASA
  - Assessed the health of the U.S. industrial base of critical spacecraft propulsion system valves
  - Improved orbital debris modeling
  - Conducted a maturity analysis of nuclear thermal/electric propulsion for a potential Mars 2035 mission

WORK IN PROGRESS IN FY 2021

- Continue to enhance and provide health and medical expertise to NASA's priority missions:
  - Provide technical requirements for human spaceflight standards to ensure safety while minimizing cost and schedule growth
  - Support mission activities with Human Systems Integration (HSI) across spaceflight architecture
  - Prepare for the implementation of the new clinic model for health services, which will result in cost savings across the Agency by consolidating occupational health contracts
  - Continue the rapid review of astronaut medical cases to control and better understand medical risks while ensuring crewmember certifications remain valid

AGENCY TECHNICAL AUTHORITY

    - Develop and disseminate technical briefs on human spaceflight standards to train the Source Evaluation Panel of the Human Landing System (HLS) program which will enable vendors to better implement program requirements

- Support the ongoing safety and mission assurance activities that prevent loss of life and mission failures through independent evaluations and deep technical expertise:
    - Conduct Agency-wide arc flash analysis to protect human life
    - Expand the Cybersecurity Assessment Team (CAT) to find IT vulnerabilities in NASA's orbital assets
    - Examine layered pressure vessels to confirm capability and ensure safety
    - Integrate center and Agency activities performed to assess the health of institutional safety, including Agency audits, self-evaluations, center assessments, and identification of systemic safety risks
    - Update NASA standards and oversight processes for nuclear safety and planetary protection
    - Provide independent verification and validation of critical mission software

- Provide and enhance critical engineering expertise, guidance, and oversight for mission activities:
    - Ensure independent technical insight of key NASA mission work.
    - Conduct over 50 independent assessments of NASA’s highest risk challenges for NASA's priority mission work
    - Develop a Launch Vehicle Aerodynamic Buffet Flight Test to reduce uncertainties in SLS launch vehicle design loads
    - Establish a partnership with the United States Agency for International Development (USAID) to develop a medical-grade oxygen generator to help combat COVID-19 in developing countries

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- Continue to enhance and provide health and medical expertise to NASA's priority missions:
    - Optimize the review process through the consolidated Agency Institutional Review Board (IRB) to improve the efficiency of operations and cost-savings
    - Work with the national academies to conduct a radiation study to evaluate health and medical risks associated with spaceflight activities, including long-term missions
    - Support the development and integration of products and plans related to NASA's priority missions, including the development of medical operations concepts, flight rules, ground-support procedures, and Agency responses to contingency medical events

- Support the ongoing safety and mission assurance activities that prevent loss of life and mission failures through independent evaluations and deep technical expertise:
    - Provide baseline policy, oversight, training, and support functions, along with anticipated policy updates related to mission safety and assurance
    - Enhance independent program assessments related to NASA priority missions by leveraging technologies, improved processes, and business innovations.
    - Provide independent testing and evaluation for NASA missions, including simulations, studies, verification, and validation

- Provide and enhance critical engineering expertise, guidance, and oversight for mission activities:

  - Collaborate with other ATAs to enhance the Agency's ability to provide technical reviews, guidance, support, and training to missions
  - Develop employee resources to provide technical guidance and policy for consistence application of Engineering Technical Authority (ETA) services across centers
  - Ensure employees and reviewers can voice dissenting opinions or raise concerns regarding safety concerns
  - Support of upgrades of the Space Communications and Navigation (SCaN) network
  - Provide engineering guidance, oversight, and review through the NESC to all NASA missions, with priority focus on astronaut spaceflight (commercial and otherwise), ISS maintenance, space exploration activities, and science missions

- Invest in capabilities and invest in research and development related to orbital debris mitigation:
  - Develop, maintain, and update orbital debris environment models, tools, and algorithms to improve orbit predictions, understand spacecraft anomalies, and better interpret sensor data
  - Invest in space, airborne, and ground-based sensors to better detect and characterize space objects with increased perceptivity, better resolution, and reduced uncertainty.
  - Lead the development of orbital debris mitigation standards, measures, and policies with the U.S., partnering with DoD and other agencies, and internationally through forums and committees.
  - Work with interagency partners and private industry to share best practices for coordinating in-orbit activity to ensure a safe and sustainable orbital environment

Program Elements

OFFICE OF THE CHIEF HEALTH AND MEDICAL OFFICER (OCHMO)

OCHMO promulgates Agency health and medical policies and standards to support the medical technical capabilities of NASA. As a functional area, OCHMO provides independent oversight and advances expert health and medical capabilities from development through de-commissioning. It assures the physical and mental health and well-being of the NASA workforce.

OCHMO also ensures that bioethics principles and NASA's policies and practices related to the use of human and animal subjects in research are in accordance with all relevant Federal regulations and guidelines. The program oversees NASA's processes for reviewing the use of human and animal subjects in research.

OCHMO administers the Human Medical Technical Authority (HMTA), which engages in all crewed programs. The HMTA provides guidance, insight, and oversight, while translating health and medical standards into tailored technical requirements for all Human-Rated programs across the Agency. HMTA ensures that integrated spaceflight systems reflect the most current knowledge on health and medical impacts related to flight, life support, and environmental systems.

OFFICE OF SAFETY AND MISSION ASSURANCE (OSMA)

OSMA assures the safety and enhances the success of all NASA activities through the development, implementation, and oversight of Agency-wide safety, reliability, maintainability, and quality assurance policies and procedures. OSMA establishes and maintains an acceptable level of technical excellence and competence in safety, reliability, maintainability, and quality engineering areas. The program assesses and communicates risk associated with noncompliance and/or compliance with safety requirements to appropriate decision makers.

OSMA conducts a schedule of reviews and assessments that focuses on the life cycle decision milestones for crucial NASA programs and projects, safety, reliability, and quality processes. Embodied in this program is a structured development of methodology and investigation into system attributes that improve the probability of mission success.

OSMA includes the Mission Support Division, Safety and Assurance Requirements Division, and NASA Safety Center, as well as the Independent Verification and Validation Facility (IV&V).

The NSC, an OSMA component, consolidates safety and mission assurance activities for affordable and consistent service across the Agency. It supports general technical excellence, knowledge management, audits and assessments, and mishap investigation support. NSC helps protect the safety of people, equipment, and property by verifying compliance with OSMA policies and works proactively to prevent mishaps and failures.

The IV&V program ensures that mission critical systems and software will operate reliably, safely, and securely. It provides independent oversight and technical knowledge across NASA missions. IV&V is funded through the SSMS account with additional support from mission directorates.

OFFICE OF THE CHIEF ENGINEER (OCE)

OCE ensures that NASA's development efforts and mission operations are planned and conducted with sound engineering practices, proper controls, and management of technical risks. The program provides independent engineering oversight and guidance to ensure that decisions have the benefit of different points of view and are not made in isolation.

OCE ensures that NASA's development efforts and mission operations are planned and conducted on sound engineering principles with proper controls and management of technical risks. Further, OCE establishes and maintains program/project management and engineering policy and technical standards. Additionally, OCE creates the foundation for excellence of program/project management and engineering workforce, system-engineering methodology, and system of engineering standards throughout the Agency.

OCE also sponsors the Academy of Program/Project and Engineering Leadership (APPEL) to develop program and project management and systems engineering skills. APPEL provides a formal professional development curriculum designed to address four career levels from recent college graduate to executive. APPEL enables technical collaboration and information sharing through the NASA Engineering Network.

OCE manages the NESC, which enables rapid, cross-Agency responses to mission critical engineering and safety issues at NASA and improves the state of practice in critical engineering disciplines. Established in FY 2003 in response to the recommendations of the Space Shuttle Columbia Accident Investigation Board, the NESC performs independent testing, analysis, and assessments of NASA’s high risk projects to ensure safety and mission success. As an Agency-wide resource with a reporting path that is independent of the mission directorates and directly funded from OCE, the NESC helps the Agency ensure mission safety and obtain objective technical results.

AGENCY TECHNICAL AUTHORITY

OCE provides manages and implements policy for the Engineering Technical Authority (ETA), which is deployed across the Agency at the centers. OCE maintains consistent, high-quality guidance for all ETA activities. This enables mission success and demonstrates NASA's high commitment to safety and reliability.

CENTER ENGINEERING, SAFETY, & OPERATIONS

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**879.6**	**835.4**	**833.7**	**850.9**	**872.2**	**894.6**	**917.8**
Change from FY 2021			**-1.7**				
Percentage change from FY 2021			**-0.2%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

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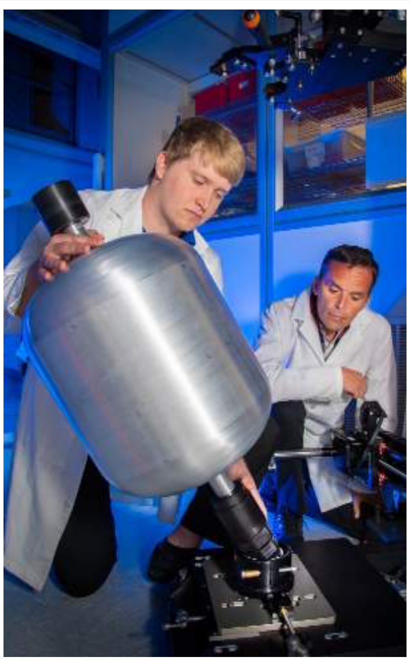


Engineers at White Sands Test Facility conduct a nondestructive inspection of a metallic liner using a pressure vessel scanner.

NASA's Center Engineering, Safety, and Operations (CESO) program provides strategic management and crucial policy direction at the Agency- and center-level in addition to center-level technical authority and capabilities that ensure mission success.

CESO maintains test capabilities, laboratories, and other mission critical assets so they are available and mission-ready based on mission requirements and timelines. The technical skill and specialized assets or services that support analyses, design, research, testing, laboratories, and fabrication enable the efficient and effective implementation of mission work at the centers.

CESO programs contribute to NASA's overall approach to risk management by providing center-level independent technical authority. By funding center-level oversight and reporting activities that uphold the strategy and guidance from Agency Technical Authorities (ATAs), checks on safety, engineering, and mission assurance remain separate from mission directorates.

CESO funds Headquarters (HQ) operations, as well as center management across the Agency. This institutional support for center operations and infrastructure allows the centers to focus on managing conditions unique to their center. CESO also ensures that Agency policies and guidance are operationalized across the centers with consistency and efficiency.

CENTER ENGINEERING, SAFETY, & OPERATIONS

CESO Priorities

CESO activities maintain the necessary technical skills and capabilities at each center, driven by mission requirements, while ensuring alignment and implementation of Agency-level policies and standards. CESO funds critical activities that maintain NASA standards for safety and engineering excellence and catalyzes technical innovation and unique capabilities. CESO priorities support the Agency and centers in their responsibility to meet mission requirements:

- Ensure laboratories, critical capabilities, and associated specialized equipment are mission-ready and meet NASA's standards for quality, reliability, and safety
- Sustain the engineering and research capabilities in analytical support, test services, lab services, and fabrication capabilities that are unique and specific to each center
- Apply delegated technical authorities to ensure the highest standards of quality and safety in engineering and mission assurance
- Fund independent research and development projects that ensure centers have mission-ready technical capabilities and capacity to support NASA's missions (now and in the future)
- Support management activities at the center-level, including the operationalization of Agency policies and guidance across institutional and functional areas
- Support Agency-level operations at NASA Headquarters (HQ) to ensure the development and implementation of Agency-wide policies, standards, and processes are effective and efficient

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2020

- Supported the unique scientific and engineering capabilities at each center by funding specialized equipment, services, and other costs associated with laboratories and facilities:
    - Acquired laboratory equipment used to develop and support cross-cutting technologies for a range of mission-critical work, including flight software systems, materials analysis equipment, propulsion testing equipment, and simulation capabilities
    - Maintained the integrity of research and development at NASA by ensuring regulatory and procedural compliance through the Metrology and Calibration Program
    - Developed a collaborative software infrastructure, Sensor Integrated Environmental Remote Research Aircraft (SIERRA) Cloud, to enable flight software development with NASA's external partners
    - Piloted a novel system for analyzing fluid dynamics using high-speed cameras that would greatly reduce the need for flight tests for aircraft certification
    - Evaluated the purity of cryogens and gases across Marshall Space Flight Center (MSFC), including clean rooms, through the Environmental Gas Lab (EGL)
    - Designed, fabricated, and installed avionics interfaces and accommodations for researchers as part of Baseline Research System in the Gulfstream III aircraft

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Invested in partnerships, research, key infrastructure, and NASA's competitive bidding process to ensure centers are innovative and capable of supporting missions, today and in the future:
    - Funded Independent Research and Development Projects (IRAD) across NASA, which covered a range of focus areas that align to NASA mission requirements, including 3D Printing Heat Shields and sterilization protocol for N95 masks
    - Supported effective stewardship of the environment with multiple wastewater and watershed studies at KSC that will significantly improve usage of natural resources
    - Updated center laboratory capabilities that directly support mission analysis activities, including analyzers to better measure radio frequency signals and electromagnetics
    - Measured and validated all types of wind tunnel test hardware including metal and ceramic models to support Mach 6 and Mach 10 Aerothermodynamics research
    - Established the New Opportunities Center, which standardizes and enhances the quality of mission and research proposals
    - Supported events to foster relationships with private industry and academia, including the Experimental Aircraft Association (EAA) Air Venture and Association for Unmanned Vehicle Systems International expo
    - Managed the Engineering Design Studio for specialized proposal development for detailed space missions, remote sensing instruments, or technology application designs

- Ensured operational safety through the maintenance, repair, or replacement of equipment and facilities, or the management of hazardous or potentially hazardous conditions and materials:
    - Ensured safety instruments and sensitive equipment operated at full capacity through routine testing, maintenance, and use of contractor support
    - Managed all occupational health and institutional safety programs across centers
    - Repaired employee wellness facilities for continued use at select centers
    - Continued the Pressure Systems 15-Year Recertification Plan to reduce risk to personnel safety, protect facility infrastructure, and ensure reliability for critical pressure systems
    - Developed new capabilities rapidly to address cleaning and sanitation requirements in response to COVID-19 (e.g., atomic oxygen to clean PPE and use ultraviolet light for sanitization)

- Supported the independent, technical authority at the center-level that ensures NASA's high standard for health and safety, engineering excellence, and mission assurance:
    - Conducted reviews and provided program oversight to mission activities at all centers in accordance with delegated authorities and NASA's safety and quality standards
    - Certified over 340 pressure systems and approximately 970 pressure vessels, including over 3,300 relief devices and 2,000 flex hoses
    - Conducted risk management and anomaly analyses for Multi-Purpose Crew Vehicle (MPCV)/Orion and Exploration Systems Development

- Supported institutional administration and center administration, which includes leadership priorities and business innovations through process improvement and technologies:
    - Expanded Cloud-Based Data Analytics with artificial intelligence (AI) and machine learning (ML) to support complex projects
    - Developed an intelligent data interface that applies ML and natural language processing (NLP) to search knowledge repositories and scholarly articles for enhanced research

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Updated the Quality Management Standard (QMS) policy and procedures to align with new standards, including a self-assessment and compliance process
- Implemented the Agency's COVID-19 response strategy consistently across all centers

WORK IN PROGRESS IN FY 2021

- Support the unique scientific and engineering capabilities at each center by funding specialized equipment, services, and other costs associated with laboratories and facilities:
    - Conduct repairs and upgrades to mission-critical research and engineering laboratories
    - Upgrade or replace additional outdated / end-of-life computer systems in research and engineering labs, to mitigate Agency cybersecurity risks
    - Acquire high-tech equipment to design and test first-of-a-kind instruments and systems developed to keep up with emerging technological and mission requirements
    - Purchase additional life support equipment to meet increasing Spaceport demand
    - Replace the nitrogen pipeline protection system for the Booster Fabrication Facility (BFF), Orbiter Processing Facility (OPF), and Mobile Launch Platform (MLP)
    - Upgrade KSC's mobile helium compressor
    - Consolidate Unmanned Aerial Systems (UAS) labs within the B1230 complex
    - Enable aeronautic science and research at Langley Research Center (LaRC), with new nadir research portals, avionics interfaces, and accommodations for more researchers
    - Upgrade the computerized numerical control (CNC) milling machine to provide a unique fabrication capability unavailable anywhere in the Agency Fabrication Alliance
    - Transform LaRC's City Environment for Range Testing of Autonomous Integrated Navigation (CERTAIN) test range into a Smart City Digital Operations environment to enhance UAS testing and development

- Invest in partnerships, research, key infrastructure, and NASA's competitive bidding process to ensure centers are innovative and capable of supporting missions, today and in the future:
    - Outfit the new Research Support Building at Glenn Research Center (GRC)
    - Begin outfitting the new Aerospace Communication Facility at GRC, including the purchase of special communication test equipment
    - Partner with Purdue and International Business Machines (IBM) to apply quantum computing (QC) technology to model liquid rocket propellant chemistry design
    - Utilize ML to innovate and develop a class of smart polymers that will increase the performance thermal stability to generate and test targeted high-performance materials
    - Expand 3D printing capability to enable in-house prototyping fit checking, operational parts development, and other fabrication and testing needs
    - Leverage Space Act Agreements to allow industry partners to utilize unique testing capabilities that support development of new systems (e.g., MC2 Prototype Engine)
    - Ensure innovative and competitive solutions are developed across NASA by supporting the bid and proposal process
    - Investigate the use of automation technologies to review proposals and substantially reduce the tedious evaluation work and associated costs

- Ensure operational safety through the maintenance, repair, or replacement of equipment and facilities, or the management of hazardous or potentially hazardous conditions and materials:

CENTER ENGINEERING, SAFETY, & OPERATIONS

  - Acquire an Ultra-Violet (UV) light meter for the Medical Office at MSFC to assess the safety of systems and equipment which utilize UV and high-intensity light
  - Improve the electrical systems that protect NASA's astromaterial sample collections
  - Fund maintenance contracts that assure analytical instruments are working at full capacity and ensure mission-critical work is not impacted by failures or breakdowns
  - Implement a flu shot clinic across NASA centers to inoculate the workforce
  - Conduct independent studies to assess risk management for new NASA work
  - Replace 30 to 50 year-old propellant and life support infrastructure to meet current standards and support NASA partnerships with Department of Defense (DoD) and industry
  - Acquire aircraft ground support equipment and calibration devices to perform additional in-house maintenance on specialized, mission-critical aircrafts
  - Inspect pressure systems and recertify based on the Agency's high safety standards

- Support the independent, technical authority at the center-level that ensures NASA's high standard for health and safety, engineering excellence, and mission assurance:
  - Provide safety and engineering concurrence and oversight on NASA's entire mission set, including Artemis, Advance Air Mobility, Space Launch System (SLS) development, Orion, and more
  - Conduct Interim Center Assessment of Center Safety at GRC
  - Continue the Pressure System Program at MSFC to ensure 100 percent of pressure systems have been inspected and enough are certified to meet mission requirements
  - Continue to support Space Launch System with Green Run, Wet Dress, transport and testing of hardware, as well as support other programs/projects with testing
  - Conduct loads tests and associated nondestructive testing (NDT) to ensure all lifting device and equipment are compliant with safety and statutory regulations

- Support institutional administration and center administration, which includes leadership priorities and business innovations through process improvement and technologies:
  - Modernize the Product Lifecycle Data Management System
  - Support Agency-wide configuration and data managed and hardware operational logistics
  - Support the administration of the Green Run testing of the SLS Core Stage, a historic milestone in the development of long-distance space exploration
  - Participate in the Association for Unmanned Vehicle Systems International (AUVSI) to support NASA's leadership in the future of aeronautic transportation and research

- Support the development of Agency-wide policies, strategies, and guidelines at HQ, and the consistent implementation of policies across all NASA centers:
  - Support the administration and employee programs in response to COVID-19, including adapting technology, facilities, and procurement services to continue mission work
  - Conduct assessments and strategy planning associated with the future of work

KEY ACHIEVEMENTS PLANNED FOR FY 2022

- Support the unique scientific and engineering capabilities at each center by funding specialized equipment, services, and other costs associated with laboratories and facilities:
  - Purchase a Pulsed Laser Radiation Test System to reduce costs associated with electrical, electronic, and electro-mechanical (EEE) parts

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Support Agency-wide calibrations, function tests, and adjustments through the Metrology and Calibration Laboratory (MCL)
- Invest in planetary sample return curation, Cosmochemistry, Lunar advanced science, and Mars fundamental research
- Maintain contracts to ensure analytical instruments are working at full capacity
- Replace 30 to 50 year-old propellant and life support infrastructure to meet current standards and support NASA partnerships with DoD and industry

- Invest in partnerships, research, key infrastructure, and NASA's competitive bidding process to ensure centers are innovative and capable of supporting missions, today and in the future:
  - Open IRAD Program solicitations and investing in ideas that address, technology development gaps, innovative opportunities, lunar and Mars missions, and risk reduction
  - Utilize astromaterials facilities for samples from asteroids, the moon, and Phobos
  - Support partnerships with academia and industry that enable the Artemis Program, commercialization of low-Earth orbit (LEO), commercial lunar payload services, and space technology development
  - Convert LaRC's 8x15-foot Thermal Vacuum Chamber to the safer and simpler platen system which will reduce loading times and increase mass capability
  - Complete nadir research portals, avionics interfaces, and accommodations for more researchers in the Gulfstream III aircraft (NASA 520) to meet mission requirements
  - Ensure innovative and competitive solutions are developed across NASA by supporting the internal bid and proposal process for distributing work to the centers
  - Support the proposal for a new universal data acquisition system (DAS) for small Unmanned Aerial Systems (UAS) to reduce time to flight for new systems

- Ensure operational safety through the maintenance, repair, or replacement of equipment and facilities, or the management of hazardous or potentially hazardous conditions and materials:
  - Maintain occupational safety oversight for all centers, including the review and provision of essential safety equipment (e.g., hearing protection, noise controls, and other gear)
  - Manage hazardous conditions and materials including asbestos/heavy metals, construction safety, radiation, confined spaces, and more to avoid exposure and injury
  - Mitigate any identified risks associated with the aging infrastructure and systems associated with rocket engine testing, including the replacement of special equipment
  - Recertify critical pressure systems, including those at the National Transonic Facility (NTF) and 14x22-foot wind tunnel to support NASA mission priorities
  - Replace or refurbish end-of-life equipment across the Agency based on risks and mission criticality

- Support the independent, technical authority at the center-level that ensures NASA's high standard for health and safety, engineering excellence, and mission assurance:
  - Continue the multi-year Pressure Systems program to inspect and certify vital pressure vessels and associated systems for crucial mission work
  - Conduct routine, institutional safety programs, which include mishap investigations, building inspections, reviews, and other oversight activities
  - Conduct dimensional, tensile, hardness, and chemical testing to verify the safety, health, and quality standards of mission-essential equipment and materials

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Support institutional administration and center administration, which includes leadership priorities and business innovations through process improvement and technologies:
  - Promote and expand licensing agreements with commercial partners
  - Conduct LargE Area burst Polarimeter (LEAP) and Extreme-ultraviolet Stellar Characterization for Atmospheric Physics and Evolution (ESCAPE) Concept Study Reports
  - Reviews project plans and strategies for missions, including Europa Clipper and NASA-ISRO Synthetic Aperture Radar (NISAR)
  - Implement the advance Project Controls Integration (PCI) tool suite at ARC
  - Continue strategic analysis and master planning of facilities and capabilities to align with Agency leadership and mission requirements

Program Elements

AGENCY SUPPORT & HEADQUARTERS MANAGEMENT

CESO supports Agency-level strategic leadership and planning by funding corporate activities conducted at NASA Headquarters (HQ). Strategic planning, budget activities, workforce management, and other foundation business functions require strategic planning, policy development, monitoring, audits, and ongoing management. These activities dovetail with center operations through mission support functional offices and senior management. CESO funds also ensure there is enterprise-enabling support for centers and missions, in functional areas not aligned to a mission support enterprise office (which would then be funded through Mission Services and Capabilities).

INSTITUTIONAL ADMINISTRATION

CESO supports certain foundation business functions at the center-level by funding center management, center reserves, and certain unique functions that were not transitioned to enterprise management due to their unique value or specification at the center. Activities, deemed center-centric, remained under center management to ensure location-specific conditions and decisions were considered when supporting mission requirements. These center-level activities include occupational health, local information technology (IT) support, and local management personnel.

INSTITUTIONAL OPERATIONAL SAFETY

CESO funds safety and mission success requirements based upon Federal regulations and NASA standards, ensuring these requirements are properly implemented throughout NASA's programs and projects. Examples of such efforts include safety audits and assessments, safety surveillance, inspections, testing and observations, mishap investigation and reporting, hazard identification, and safety outreach.

SAFETY AND MISSION ASSURANCE (SMA) TECHNICAL AUTHORITY

The Office of Safety and Mission Assurance (OSMA) issues policies, guidance, and corporately managed communications that ensure the consistent application of safety and quality standards. At each center, Safety and Mission Assurance (SMA) personnel are responsible for the application and implementation of

CENTER ENGINEERING, SAFETY, & OPERATIONS

policies and instructions provided by OSMA and related governing organizations. This is accomplished through SMA Technical Authority (TA) member participation on program/project control boards, change boards, and internal review boards. SMA personnel also formulate and communicate the SMA TA position on significant technical issues, disposition changes, waivers, deviations, and exceptions to respective program/project SMA requirements. SMA TA independently assess program/project-owned risks and execute, implement, and otherwise maintain the checks and balance of safety and quality standards. It is critical that this money is independent of mission funding to ensure there is an independent process for identifying and managing safety and quality concerns.

SCIENCE AND ENGINEERING

Centers maintain highly technical laboratories, critical capabilities, and associated specialized skills and equipment thereby ensuring mission readiness. These capabilities support center mission work ensuring required technical capabilities are mission-ready. Such functions include providing for the on-site capability to fabricate test articles, test fixtures, prototype, proto-flight and flight articles necessary to support the design, development, and testing of research models, instruments, flight and related ground support hardware, technical components, and laboratory test apparatus. Centers also provide for the on-site capability to support research, development testing, and sustaining engineering for science and technologies necessary to support their program activities. These funds are specific to the centers because of the variety and distribution of highly technical work that is spread across the Agency's 10 distinct centers and other installations.

CENTER INVESTMENTS

Ensuring the right talent and technical capabilities are mission-ready for NASA priority projects and missions, centers utilize investment funding to maintain their technical skills and capabilities in support of local mission work. Investments fund institutional research that aligns with assigned center roles, development projects, and business innovation. Centers use a competitive approach to achieve this mission work and supports NASA's commitment to innovative and creativity. Center investments are also utilized through bid and proposal process ensuring mission work is distributed to the appropriate center and technical area. Centers have the flexibility to support independent research and development (IRAD) pursuing partnerships with academia and private industry so that NASA has the leading-edge capabilities needed to support NASA's missions, today and in the future.

ENGINEERING TECHNICAL AUTHORITY

The Office of the Chief Engineer (OCE) develops and distributes standards, policies, and guidance related to engineering safety, quality, and process. At each center, personnel are dedicated to providing independent oversight of programs and projects in support of safety and mission success as prescribed in the NASA technical authority model, thus ensuring requisite policies and processes are successfully implemented, thereby upholding NASA's high standard of engineering excellence. Key technical authority positions, including managers in research and engineering, testing, and fabrication, use these funds to conduct reviews, oversight, and management of quality and safety standards independent of mission directorates. These activities are a crucial part of NASA's checks and balances, which ensure the highest standard of engineering excellence and reporting.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Construction of Facilities	357.8	370.4	**315.6**	322.2	329.3	336.7	344.2
Environmental Compliance and Restoration	74.7	58.1	**74.7**	76.2	77.8	79.4	81.1
Total Budget	**432.5**	**428.5**	**390.3**	**398.4**	**407.1**	**416.1**	**425.3**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Construction of Facilities	357.8	370.4	**315.6**	322.2	329.3	336.7	344.2
Environmental Compliance and Restoration	74.7	58.1	**74.7**	76.2	77.8	79.4	81.1
Total Budget	**432.5**	**428.5**	**390.3**	**398.4**	**407.1**	**416.1**	**425.3**
Change from FY 2021			**-38.2**				
Percentage change from FY 2021			**-8.9%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

NASA's Instrument Development Facility at Goddard Space Flight Center (pictured above) is a new, Leadership in Energy and Environmental Design (LEED) certified, 54,000 square-foot facility and home to the Planetary Environments Laboratory operations, a cornerstone for the continued search for evidence of life on other planets.

Through the Construction and Environmental Compliance and Restoration (CECR) account, NASA manages two themes related to the Agency's large footprint and activities: capital repairs and improvements to NASA's infrastructure, and environmental compliance and restoration activities. Activities related to the design, construction, and demolition of infrastructure, including utility systems and facilities, are funded through Construction of Facilities (CoF). Environmental compliance, cleanup, and restoration activities are funded through Environmental Compliance and Restoration (ECR). (See Themes at the bottom of this section for a full description of CoF and ECR).

More than 83 percent of NASA's infrastructure is beyond its design life, creating significant risk of failure, inefficiency, and impacts to health and wellness. Apollo-era infrastructure is inefficient and costly to maintain, as well as insufficient to accomplish NASA's future missions. Commercialized space, continuous human presence on the Moon, Earth and space science, advanced science and engineering research, and long-term Mars expeditions require facilities with leading-edge capabilities. As NASA's Office of Inspector General (OIG) noted in its annual NASA's Top Management and Performance Challenges (2020), "while NASA strives to keep these facilities operational, the Agency faced a deferred maintenance backlog of $2.66 billion as of 2020." This has resulted in unscheduled maintenance rather than scheduled maintenance costing up to three times more to repair or replace equipment after it has failed." To address these challenges, CECR is focused on modernizing and consolidating NASA’s infrastructure into fewer, more efficient, and more sustainable facilities while repairing and upgrading failing infrastructure.

CECR ensures that NASA’s assets are ready, available, and appropriately sized to conduct NASA’s current and future missions while remaining compliant with facility and environmental regulations. Aligned with NASA's 2018 Strategic Plan (Objective 4.6: sustain infrastructure capabilities and operations) and Annual Performance Plans, CECR endeavors to create a more sustainable and capable NASA, while reducing the Agency's overall footprint.

CECR Priorities

CECR focuses on ensuring the viability and excellence of mission-critical infrastructure while also supporting NASA's commitment to environmental stewardship and sustainability. The key priorities below outline how CECR allocations are made:

- Construct new facilities and replace or upgrade existing infrastructure to support NASA's mission requirements and timeline
- Design facilities and infrastructure solutions to support construction and repairs while optimizing sustainability, increasing efficiency, and reducing NASA's footprint
- Demolish unneeded and degraded facilities to avoid costs and improve sustainability
- Invest in energy and water savings opportunities to improve NASA's environmental stewardship
- Comply with mandates, regulations, and general best practices to protect the health and wellness of the environment, NASA's workforce, and the general public

Balancing SSMS & CECR

NASA's mission support portfolio is divided between two accounts: Safety, Security, and Mission Services (SSMS) and Construction and Environmental Compliance and Restoration (CECR). The Mission Support Directorate (MSD) utilizes both accounts to maintain NASA's critical infrastructure. MSD must balance spending on the maintenance of assets and infrastructure, repairs and renewal of failing assets, and the replacement and demolition of unneeded assets. Maintenance activities drive SSMS spending decisions, while repairs, renewals (including new construction), and associated demolition drive CECR spending.

Much of NASA's infrastructure dates back to Apollo-era space exploration and often cannot sustain the increased requirements and mission demands of Artemis-era spaceflight. Maintenance activities funded by SSMS are necessary to prevent costly delays to missions and risks to health and safety. Meanwhile, failures require immediate repairs and account for an increasing share of the maintenance budget. Although these activities do not enhance NASA's technical capabilities, they are vital to maintain existing capabilities which support evolving mission requirements. MSD takes an Agency-wide approach to make difficult trade-off decisions that ensure critical capabilities and assets are mission-ready while also investing in the long-term asset health, sustainability, and footprint reductions that ensure NASA's future mission success.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

EXPLANATION OF MAJOR CHANGES IN FY 2022

Mission-Critical Capabilities

NASA's exploration program has expanded to include a human presence on the Moon and expeditions to Mars, a generational challenge and mission to inspire the Nation. The new technologies, systems, and operational tempo needed will challenge NASA program capabilities and require robust, reliable, and resilient facilities and infrastructure to safely and successfully support this new exploration enterprise.

CECR's CoF program focuses on supporting multiple missions, with emphasis on reducing the highest institutional risks to our Nation's next-generation aeronautics and space enterprises. Additionally, emerging institutional risks to human life, health, and mission success (e.g., arc flash, pressure systems degradation) are being identified and quantified, and advanced planning for mitigation measures has begun.

Adjustments Due to COVID-19

Upon closure of NASA's centers due to COVID-19 in FY 2020, the majority of ongoing CoF projects were halted and contractors were denied access to the centers. To date, the total cost associated with the halted projects has yet to be realized. In the absence of supplemental/recovery funds, planned FY 2021 and/or FY 2022 CoF projects may be deferred to ensure availability of funds for the ongoing COVID-19 recovery.

ACHIEVEMENTS IN FY 2020

CECR reached significant milestones despite limited access due to the Agency's response to COVID-19. The following list provides highlights from high-priority FY 2020 projects. A more robust list with project descriptions is available in each program section.

- Constructed, repaired, or revitalized institutional infrastructure and facilities that have capabilities and impacts that span across centers and enable all mission work:
    - Initiated construction on the Flight Electronics Integration Facility at Jet Propulsion Laboratory (JPL), the Flight Dynamics Research Facility at Langley Research Center (LaRC), and the high-pressure water system at Stennis Space Center (SSC)
    - Completed new construction of the Instrument Development Facility (IDF) at the Goddard Space Flight Center (GSFC) for studies of extraterrestrial atmospheres and surfaces
    - Completed construction on the Biosciences Collaborative Facility at the Ames Research Center (ARC) to support life and physical sciences research across NASA
    - Restored more than 4.5 miles of coastal shoreline at Kennedy Space Center (KSC) to protect launch facilities from the impact of storm surge and inundation
    - Repaired/replaced sanitary sewer system at Johnson Space Center (JSC)
    - Reduced arc flash risk to the workforce with electrical system improvements at ARC
    - Repaired the Wallops Island Causeway Bridge at WFF

- Supported exploration mission work with the construction, repair, or revitalization of critical facilities and infrastructure:
    - Upgraded the Vehicle Assemble Building at Kennedy Space Center (KSC), including installation of High Bay 3 and new environmental controls for critical mission work

  - Continued fabrication and installation of an approximately 1.25 million gallon liquid hydrogen (LH2) sphere at KSC launch complex
  - Began construction on a multi-year project to upgrade KSC launch infrastructure for SLS, replacing Apollo-era equipment and key capabilities
  - Continued modifications to the Michoud Assembly Facility (MAF) to enable SLS work

- Supported operations in space work with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Continued progressing on the Deep Space Network Aperture Enhancement Project (DEAP), with the completion of new Deep Space Station (DSS)-56 antenna
  - Installed the antenna cooling towers and expect to return DSS-43 to service in FY 2021

- Demolished unneeded or degraded facilities to support a more sustainable NASA with a smaller footprint while avoiding repair and operational costs:
  - Demolished 51 facilities with approximately 68,000 square feet of non-mission critical assets

- Invested in energy savings projects that reduce operational costs and utility usage across NASA:
  - Initiated the energy conservation measures and retro-commissioning project at JSC
  - Implemented HVAC efficiency improvements at various buildings at SSC and WFF

- Conducted facility planning and design associated with all construction and revitalization projects in order to ensure optimal consolidation, energy savings, cost-effectiveness, and other outcomes:
  - Designed the roof replacements for the Booster Fabrication Facility (BFF) Complex at KSC, to support SLS programs

- Maintained NASA's commitment to environmental stewardship by conducting critical cleanup efforts, maintaining compliance with regulatory requirements, and managing environmental issues:
  - Conducted essential cleanup activities at Santa Susana Field Laboratory (SSFL)
  - Resumed groundwater treatment after reconstructing the fire-damaged piping system at SSFL
  - Conducted cleanup activities across NASA for groundwater and soil remediation, including the investigation of per- and polyfluoroalkyl substance (PFAS) contamination
  - Continued JPL groundwater contamination remediation to protect public drinking water
  - Removed contaminated soil at MSFC and began remediation of groundwater

WORK IN PROGRESS IN FY 2021

CECR will continue to enable critical mission work in FY 2021 while maintaining NASA's dedication to environmental stewardship. The following list highlights high-priority FY 2021 projects. A more robust list with project descriptions is available in each program section.

- Construct, repair, or revitalize institutional infrastructure and facilities that have capabilities and impacts that span the centers and enable all mission work:
  - Begin construction of the Vehicle and Aerospace Ground Equipment Maintenance Facility at AFRC
  - Modify the launch infrastructure at KSC for SLS (e.g., nitrogen system upgrades, environmental controls, air supply)

- Replace a section of the roof of the Michoud Assembly Facility (MAF) building 103, an approximately 1.7 million square foot facility that houses NASA's major system construction
- Repair SSC's potable water system, a more than 50-year-old system of approximately 65 miles of iron pipe
- Repair water and steam distribution systems, including cooling towers, at GRC
- Repair the degraded and dangerous electrical distribution systems at GRC
- Restore the electrical infrastructure at GSFC and WFF
- Install seismic bracing to protect assets against earthquakes at JPL
- Replace the central heating and cooling plant chiller at JSC
- Upgrade the institutional power systems at KSC
- Install a utility control system at MSFC for increase efficiency and reliability
- Repair SSC's canal impoundment system, miter gates, and closure valves to allow mission-critical transportation through the waterways

- Support exploration mission work with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Modify KSC's launch infrastructure to support SLS missions
  - Install the Emergency Egress System (EES) at KSC for crew evacuation during launch
  - Construct the Environmental Control System (ECS) for SLS and Orion flight systems
  - Replace the roofs of the manufacturing building and engineering and administration building at KSC
  - Upgrade the communication infrastructure of the BFF Complex at KSC
  - Continue refurbishing the Neil Armstrong Operations and Checkout Building to address defects in the exterior surface at KSC
  - Continued modifications to the Michoud Assembly Facility (MAF) to enable SLS work

- Support operations in space work with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Complete testing activities for the DEAP project in Madrid and deliver it into operation
  - Complete construction of DSS-53 facilities
  - Complete excavation at the Goldstone Deep Space Communication Complex and begin antenna fabrication work for the new DSS-23 antenna
  - Upgrade site-wide uninterruptible power supplies (UPS) for increased safety and reliability

- Demolish unneeded or degraded facilities to support a more sustainable NASA with a smaller footprint, while avoiding repair and operational costs:
  - Demolish Building 4200 at MSFC
  - Demolish the Indian River Bridge at KSC

- Invested in energy savings projects that reduce operational costs and utility usage across NASA:
  - Install various energy efficiency improvements at ARC
  - Optimize the AFRC HVAC System, specifically in Building 4838

- Conduct facility planning and design associated with all construction and revitalization projects in order to ensure optimal consolidation, energy savings, cost-effectiveness, and other outcomes:
  - Begin to design the VAB rehabilitation to include heavy-weight cranes

- Design all scheduled projects included in the MAF roof replacement plan

- Maintain NASA's commitment to environmental stewardship by conducting critical cleanup efforts, maintaining compliance with regulatory requirements, and managing environmental issues:
  - Conduct essential cleanup activities at SSFL, including demolition of Bravo Test Stands
  - Conduct cleanup activities across NASA, including groundwater treatment, contaminated soil removal, and ongoing monitoring at KSC, MSFC, JPL, WSTF, and WFF
  - Continue PFAS characterization and remediation work at KSC, GRC, and WFF
  - Complete the LaRC CERCLA Five Year Review which examines the remedial actions implemented to ensure the protection of human life and the environment

KEY ACHIEVEMENTS PLANNED FOR FY 2022

CECR will continue to enable critical mission work in FY 2022 while maintaining NASA's dedication to environmental stewardship. The following list highlights high-priority FY 2022 projects. A more robust list with project descriptions is available in each program section.

- Construct, repair, or revitalize institutional infrastructure and facilities that have capabilities and impacts that span the centers and enable all mission work:
  - Construct the JSC Operations and Maintenance Facility to consolidate 28 buildings and approximately 100,000 square feet of degrading buildings into an approximately 63,000 square foot facility
  - Upgrade LaRC's core and cross-center electrical infrastructure to support vital mission activities and research in wind tunnels, research labs, and testing facilities
  - Restore the reliability of the Arc Jet gas flow controllers at ARC
  - Repair center-wide fire systems and an electrical substation at AFRC
  - Repair the electrical distribution system at GRC to increase safety and reliability
  - Upgrade the electrical feeders and fire alarm systems at GSFC to increase safety and reliability
  - Build seismic bracing at JPL to protect NASA people and assets against earthquakes
  - Replace JPL's electrical substation to address vital electrical needs
  - Replace potable water storage and elevated tanks at JSC for Center-wide operations
  - Upgrade the safety and reliability of KSC's institutional power systems
  - Repair SSC's sewage system and water treatment facilities for improve efficiency

- Support exploration mission work with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Modify the launch infrastructure at KSC for SLS missions, including critical systems for nitrogen, temperature/humidity control, air, fabrication, and emergency evacuation
  - Replace a section of the approximately 1.7 million square foot MAF building 103 roof to enable SLS construction, avoid costly delays, preserve employee safety, and improve building energy usage
  - Repair and upgrade the VAB Water Distribution System at KSC
  - Renovate the 200-ton bridge crane at KSC
  - Replace essential infrastructure within MAF, including fire systems and restrooms

- Support operations in space work with the construction, repair, or revitalization of critical facilities and infrastructure:
    - Complete the DEAP BWG antennae at the Goldstone and Canberra Deep Space Communication Complexes to enable both radio frequency and optical communications for deep space exploration missions
    - Expand the underground fiber optic cable from the Mars site to the Apollo site at the Goldstone Deep Space Communication Complex to ensure continuous connectivity during missions

- Demolish unneeded or degraded facilities to support a more sustainable NASA with a smaller footprint, while avoiding repair and operational costs:
    - Demolish approximately 11 facilities with more than 253,000 square feet, including the Research Laboratory and the Pearl Young Conference Center at LaRC

- Invest in energy savings projects that reduce operational costs and utility usage across NASA:
    - Construct a second thermal energy storage tank at MSFC
    - Upgrade the energy monitoring and control system at GRC

- Conduct facility planning and design associated with all construction and revitalization projects in order to ensure optimal consolidation, energy savings, cost-effectiveness, and other outcomes:
    - Study and assessment of engineering, design and construction management, facility operations and maintenance, condition-based maintenance, and facility utilization

- Maintain NASA's commitment to environmental stewardship by conducting critical cleanup efforts, maintaining compliance with regulatory requirements, and managing environmental issues:
    - Conduct essential cleanup activities at SSFL, including demolition of Bravo and Coca Test Stands, groundwater treatment, and long-term air and water monitoring
    - Conduct cleanup activities across NASA, including groundwater and soil remediation, contaminated soil removal, water treatment, and continuous monitoring at KSC, JPL, MSFC, and WSTF
    - Continue to support site wide remedial efforts at the eight other centers and facilities, and Environmental Compliance and Functional Leadership projects

Themes

CONSTRUCTION OF FACILITIES (COF)

CoF funds capital repairs and improvements to NASA's infrastructure to provide NASA programs and projects with the research, development, and testing facilities required to accomplish their missions. CoF repairs the facilities that have suffered degradations, recent failures, or deterioration from reduced maintenance over time. Due to mission priorities, several projects to address immediate needs are displacing renewal or new construction projects planned for the replacement of obsolete facilities. These tradeoffs prevent the new construction of facilities and infrastructure that would reduce costs and increase sustainability in the long run.

CoF is comprised of two programs: Institutional CoF and Programmatic CoF. Institutional CoF activities are divided across five project definitions: discrete projects costing over $10 million; minor revitalization and construction less than $10 million; facility planning and design; demolition; and investments in energy savings. Programmatic CoF is focused on mission directorate-funded projects for specialized capabilities that align to specific NASA mission, separated between two project definitions of either discrete projects costing over $10 million or minor revitalization and construction costing less than $10 million.

NASA's CoF budget funds the Agency's highest priority construction projects and continues to replace obsolete and deteriorating facilities that directly support NASA's mission. Institutional CoF is balanced against SSMS activities and does not fund routine maintenance and repairs with estimates of less than $1 million.

ENVIRONMENTAL COMPLIANCE AND RESTORATION (ECR)

Environmental Compliance and Restoration (ECR) mitigates environmental risk at NASA installations and NASA-owned industrial plants supporting NASA activities. The remediation program at SSFL site in California consumes approximately 42 percent of the ECR annual budget. ECR also supports remediation at current or former sites where NASA operations have contributed to environmental problems or where the Agency is legally obligated due to past releases of pollutants, including emerging contaminants such as polyfluoroalkyl substances (PFAS).

At every center, ECR is investigating contaminated sites; remediating contaminated soil, water, and other media; and monitoring for continued compliance with Agency objectives and obligations. ECR ensures NASA’s compliance with environmental requirements, including the Resource Conservation and Recovery Act (RCRA); Comprehensive Environmental Response, Compensation, Liability Act (CERCLA); state regulatory requirements; consent orders; and legal obligations.

CONSTRUCTION OF FACILITIES

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Institutional CoF	211.8	262.9	**205.8**	322.2	329.3	336.7	344.2
Exploration CoF	109.9	60.3	**89.3**	0.0	0.0	0.0	0.0
Space Operations CoF	20.0	23.9	**20.5**	0.0	0.0	0.0	0.0
Science CoF	16.1	23.3	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**357.8**	**370.4**	**315.6**	**322.2**	**329.3**	**336.7**	**344.2**
Change from FY 2021			**-54.8**				
Percentage change from FY 2021			**-14.8%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The recently completed Biosciences Collaborative Facility at the Ames Research Center (pictured above) is a ~40,000 square-foot laboratory that enables cutting-edge biology research.

NASA's Construction of Facilities (CoF) program includes both institutional and programmatic construction projects. These projects reduce facility-related risk to mission success, increase sustainability, and improve technical infrastructure capabilities in support of NASA missions. CoF provides for the design and construction of facilities projects that enable NASA's infrastructure to meet mission needs. The CoF program mitigates risks associated with real property assets, defined by NASA as "risks to infrastructure, information technology, resources, personnel, assets, processes, operations, occupational safety and health, environmental management, security, or programmatic constraints that affect capabilities and resources necessary for mission success, including institutional flexibility to respond to changing mission needs and compliance with internal (e.g., NASA) and external requirements (e.g., Environmental Protection Agency or Occupational Safety and Health Administration regulations)."

CoF Priorities

CoF spans two programs: institutional and programmatic (for a full description of these two program areas, see the Program Elements section). All CoF projects are prioritized through Agency and center leadership based upon immediate mission requirements and long-term NASA sustainability. Project

CONSTRUCTION OF FACILITIES

priorities are best defined by desired outcomes (for a full description of these project categories, see the Program Elements in each program section):

- Construct or revitalize facilities and infrastructure with discrete projects (greater than $10 million) and minor projects (less than $10 million) to meeting mission and center requirements for NASA priorities.
- Plan and design facilities to ensure optimal outcomes and comply with statutory and mission requirements.
- Demolish unnecessary or degraded buildings following the consolidation or new construction of replacement facilities to reduce costs and NASA's footprint.
- Invest in energy savings projects that significantly change utility usage, including energy and water, for reduced operational costs and increased sustainability.

EXPLANATION OF MAJOR CHANGES IN FY 2022

CoF funds are continuously adjusted to account for evolving mission requirements and to address issues that arise from degradation and chronic maintenance issues.

ACHIEVEMENTS IN FY 2020

See each program area for a complete list of achievements in FY 2020.

WORK IN PROGRESS IN FY 2021

See each program area for a complete list of work in progress in FY 2021.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

See each program area for a complete list of key achievements planned for FY 2022.

Program Elements

INSTITUTIONAL CONSTRUCTION OF FACILITIES (INSTITUTION COF)

Institutional CoF addresses infrastructure and facilities that span mission areas and enable the work of a center. Horizontal infrastructure and center-wide systems, such as roads and utilities, support all mission activities and are therefore considered "institutional." Institutional CoF also funds activities that support the overall Agency goals of reducing operating costs, maintenance obligations, and utility usage through demolition and energy savings projects.

CONSTRUCTION OF FACILITIES

PROGRAMMATIC CONSTRUCTION OF FACILITIES (PROGRAMMATIC COF)

Programmatic CoF is funded by Mission Directorates for construction of specialized capabilities that directly support specific NASA missions. Facilities and infrastructure that apply to a single mission or have a unique capability that cannot be utilized by multiple mission programs are funded through Programmatic CoF. Construction, repairs, and revitalization funded by Programmatic CoF do not have center- or Agency-wide applications. Because projects funded through Programmatic CoF are unique to the missions they support, the description of projects are included below by mission area.

INSTITUTIONAL COF

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**211.8**	**262.9**	**205.8**	**322.2**	**329.3**	**336.7**	**344.2**
Change from FY 2021			**-57.1**				
Percentage change from FY 2021			**-21.7%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

The Space Launch System (SLS) Core Stage is shown here arriving at Stennis Space Center through the Stennis Navigational Locks and the Bascule Bridge (one of NASA's 27 bridges). Many of NASA's bridges are beyond their design life.

Institutional CoF sustains a state of readiness in NASA's physical infrastructure. Real property assets include all horizontal and vertical infrastructure and the associated collateral equipment. Repair and revitalization projects are prioritized using a risk-informed process that evaluates mission risks in terms of safety, schedule, cost, and technical capability. For each major facility replacement project, NASA develops a business case that includes a cost-benefit analysis.

NASA maintains an ongoing effort to identify, quantify, and prioritize institutional risks. Significant risks to a mission attributed to institutional real property are mitigated through the Institutional CoF program. The criticality of mission risks may be reassessed as the risk posture changes due to mission and/or infrastructure condition. Currently, NASA has approximately $1.8 billion of repairs that need to be made to mitigate all risks.

Institutional CoF Priorities

Institutional CoF funding evolves based on mission requirements in order to address critical risks that threaten NASA's prioritized missions. Institutional CoF is divided across different projects depending on facility and infrastructure criticality, long-term sustainability, and mission needs, with an emphasis on risk reduction:

- Reduce institutional risks, including risks to personal safety and deficiencies, and enable missions with discrete (greater than $10 million) and minor (less than $10 million) projects that address critical mission requirements
- Demolish unnecessary and degraded buildings to avoid costs, eliminate risks, and reduce NASA's overall footprint for increased sustainability

INSTITUTIONAL COF

- Plan and design facilities to optimize capabilities, enhance sustainability, and comply with all Federal and State obligations
- Invest in energy savings projects that enhance sustainability and support NASA's commitment to environmental stewardship

EXPLANATION OF MAJOR CHANGES IN FY 2022

In FY 2022, the selection of Institutional CoF projects reflects a continued focus on supporting multiple missions with emphasis on reducing the Agency's highest institutional risks, reducing operational costs, and reducing NASA's footprint.

ACHIEVEMENTS IN FY 2020

Due to center closures more than 90 percent of the NASA workforce worked from home in response to COVID-19, and more than 90 of approximately 140 on-going construction projects were halted. Approximately 60 projects were restarted by the end of the fiscal year, but the stoppage resulted in schedule slips and costs of $4.3M to date from Requests for Equitable Adjustment (REAs), with an anticipated total cost of $34.7M. Despite this challenge, there were still significant achievements.

Discrete Projects

- Initiated construction of the Flight Electronics Integration Facility at Jet Propulsion Laboratory (JPL)
- Initiated construction of the Flight Dynamics Research Facility at Langley Research Center (LaRC)
- Initiated the revitalization of the high-pressure water system at Stennis Space Center (SSC)
- Completed construction of the Instrument Development Facility (IDF) at the Goddard Space Flight Center (GSFC) for studies of extraterrestrial atmospheres and surfaces
- Completed construction on the Biosciences Collaborative Facility at the Ames Research Center (ARC) to support life and physical sciences research across NASA
- Completed the repair/revitalization of Compressor Station Upgrades (Phase 1) at LaRC, the first of a four-phase approach to increase reliable delivery of High-Pressure Air (HPA) across the Center
- Restored more than 4.5 miles of coastal shoreline at Kennedy Space Center (KSC) to protect launch facilities from the impact of storm surge and inundation
- Completed the repair of Glenn Research Center's (GRC) Lewis Field domestic water system, which will improve water pressure, eliminate leaks, and reduce utility costs

Minor Projects

- Repaired the steam distribution system (Phase 3 of 4) at GRC
- Upgraded high voltage electrical feeders (Phase 1) at GSFC for improved safety and efficiency
- Restored main base electrical infrastructure at Wallops Flight Facility (WFF) for increased safety and efficiency
- Repaired/replaced the sanitary sewer system at Johnson Space Center (JSC)
- Upgraded the safety and reliability features of Kennedy Space Center's (KSC) institutional power systems (Phase 1 of 5)
- Completed significant renovations to repair and upgrade the steam-based electrical generation and distribution system at LaRC
- Repaired Bascule Bridge and replaced cathodic protection at SSC

INSTITUTIONAL COF

- Initiated a project to reduce seismic risk with building improvements in critical facilities at ARC
- Reduced arc flash risk to the workforce with electrical system improvements at ARC (Phase 1 of 4)
- Repaired the Wallops Island Causeway Bridge at GSFC
- Upgraded the high voltage electrical feeders at GSFC for improved health and safety (Phase 1 of 2)
- Upgraded electrical substation and replaced the 300 Area Tech Initiated Building, at White Sands Test Facility (WSTF)
- Initiated a project to relocated utilities running through the Indian River Bridge at KSC
- Initiated the repair of Utility Tunnels 1 and 2 (Phase 2) and completed repairs of Utility Tunnels 3 and 4 at LaRC

Demolition

- Demolished 51 facilities with approximately 68,000 square feet of non-mission critical assets

Energy Savings

- Initiated the energy conservation measures and retro-commissioning project (Phase 3) at JSC
- Started energy upgrades at various buildings at MSFC
- Consolidated HVAC chillers at SSC
- Replaced window walls at the Mall Area Buildings at JSC
- Implemented HVAC efficiency improvements at various buildings at WFF

Facility Planning and Design

Institutional CoF conducted facility planning and design as a routine requirement for all projects.

WORK IN PROGRESS IN FY 2021

NASA will continue projects initiated in FY 2020 and prior years along with five new discrete projects and 13 minor projects:

Discrete Projects

- Begin new construction of the Vehicle and Aerospace Ground Equipment Maintenance Facility at AFRC, which will consolidate the functions of five degraded buildings into an approximately 25,000 square foot, state-of-the-art facility to support NASA's aeronautics research and aviation advancement
- Modify or upgrade the launch infrastructure at KSC for the Space Launch System (SLS) (e.g., nitrogen system, environmental controls, air supply)
- Replace a section of the roof of the Michoud Assembly Facility (MAF) building 103 (Phase 2 of 5), an approximately 1.7 million square foot facility that houses NASA's major system construction and threatens mission milestones and employee safety with its quickly degrading infrastructure
- Revitalize MSFC's failing HVAC, water, and energy systems within the Structures, Dynamics, and Thermal Vacuum Laboratory, one of NASA's mission-critical laboratories with unique capabilities in structural strength and dynamics testing, experimental fluids and environmental testing, guidance, navigation, and control simulation.
- Repair SSC's potable water system (Phase 3 of 4), a more than 50-year-old system of around 65 miles of iron pipe that is prone to failures, causing damage and mission-threatening delays

INSTITUTIONAL COF

Minor Projects

- Repair water and steam distribution systems (including cooling towers) at GRC (Phase 4)
- Repair the degraded and dangerous electrical distribution systems at GRC (Phase 3 of 5)
- Restore the main base electrical infrastructure for increased safety and reliability at WFF (Phase 1)
- Restore vital, cross-Center systems at GSFC, including fire alarms and chillers
- Install seismic bracing to protect assets against earthquakes at JPL
- Replace central heating and cooling systems at JSC
- Replace the natural gas system at WSTF
- Upgrade the KSC power systems with safety and reliability features (Phase 4 of 5)
- Rehab vital utility and electrical systems at LaRC including tunnels, environmental controls, and electrical distribution systems (Phase 1)
- Install a utility control system at MSFC for increase efficiency and reliability
- Revitalize the pressure and propellant distribution system at MSFC for vital mission work (Phase 3)
- Repair and upgrade vital electrical systems at SSC that threaten employee safety and mission success, including new arc flash mitigation measures as well as electrical distribution and generation systems.
- Repair SSC's canal impoundment system, miter gates, and closure valves to allow mission-critical transportation through the waterways

Demolition

- Demolish Building 4200 at MSFC
- Demolish the Indian River Bridge at KSC

Energy Savings

- Install various energy efficiency improvements at ARC
- Implement energy improvement measures and strategies at SSC
- Optimize the AFRC HVAC System, specifically in Building 4838

Facility Planning and Design

Institutional CoF conducts facility planning and design as a routine requirement for all projects.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

NASA's Institutional CoF program for FY 2022 includes two discrete projects, 15 minor projects, two energy savings investment projects, and numerous demolition projects. Depending on appropriated budgets and because all CoF projects are prioritized based on criticality and mission urgency, NASA may address some deferred projects before addressing the planned FY 2022 activities.

INSTITUTIONAL COF

Discrete Projects

- Construct the JSC Operations and Maintenance Facility to consolidate and enhancing foundational support services for all vital mission work at the Center
    - FY 2022 Estimated $25 million; Total Project Costs $25 million
    - Consolidate work to this approximately 63,000 square foot facility, allowing the demolition of 28 buildings and approximately 100,000 square feet of existing, degraded buildings
    - Results in significant footprint reduction, energy savings, and cost avoidances
    - Provide improved mission support service for all NASA missions at JSC, including the International Space Station, Orion, Commercial Crew, and numerous scientific and engineering research programs

- Upgrade LaRC's core and cross-Center electrical infrastructure
    - FY 2022 Estimated $18.2 million; Total Project Costs $18.2 million
    - Complete the underground 22 kilovolt (kV) electrical distribution infrastructure (including cables, feeders, and surge controls) to avoid risks caused by obsolete design and equipment
    - Support vital mission activities and research conducted in LaRC's wind tunnels, research labs, flight system integration and testing facilities, and all other offices and buildings

Minor Projects

Institutional CoF will spend an estimated $106.5 million on minor projects in FY 2022, prioritized based on asset criticality and mission urgency. NASA may reprioritize some projects, depending on final allocations from Congress and evolving mission requirements and asset conditions.

- Restore the reliability of the Arc Jet Gas Flow Controllers at ARC
- Repair Center-wide fire systems and at AFRC (Phase 1)
- Repair AFRC's electrical substation to improve reliability and efficiency
- Repair GRC's storm sewer system (Phase 3 of 3)
- Repair the electrical distribution system at GRC to increase safety and reliability (Phase 4 of 5)
- Upgrade the electrical feeders at GSFC to increase safety and reliability (Phase 2 of 2)
- Install Center-wide fire alarm upgrades at GSFC for improved safety (Phase 2)
- Restore the main base electrical infrastructure at WFF (Phase 2)
- Build seismic bracing at JPL to protect equipment, assets, and research against earthquakes
- Replace JPL's electrical substation to address vital electrical needs and improve reliability
- Replace potable water storage and elevated tanks at JSC for Center-wide operations
- Upgrade the safety and reliability of KSC's institutional power systems (Phase 5 of 5)
- Repair and upgrade electrical systems at MSFC, including utility controls (Phase 2)
- Repair SSC's sewage system and water treatment facilities for improve efficiency (Phase 1)
- Replace the potable water supply line for SSC's Test Complex

Energy Savings Investments

Institutional CoF will spend an estimated $8 million on energy savings investments in FY 2022, resulting in an estimated $1.2 million in avoided utilities expenditures after a 6.7-year, simple payback period. These projects support NASA's dedication to environmental stewardship and efficiency.

- Construct a second thermal energy storage tank at MSFC
- Upgrade the energy monitoring and control system at GRC

INSTITUTIONAL COF

Demolition of Facilities

Institutional CoF will spend an estimated $15 million on demolition to reduce the Agency's footprint, reduce operational costs, and increase environmental sustainability.

- Demolition of approximately 11 facilities with more than 253,000 square feet, including the Research Laboratory and the Pearl Young Conference Center at LaRC

Facility Planning and Design

Institutional CoF will spend an estimated $33.1 million on facility planning and design in FY 2022. Facility planning and design is a requirement for all CoF projects to ensure optimal outcomes, including consolidation and utility usage.

- Master planning for all projects, including efforts to consolidate work and leverage work-from-home options which have proven effective during the Agency's response to COVID-19
- Study and assessment of engineering, design and construction management, facility operations and maintenance, condition-based maintenance, and facility utilization
- Support for engineering in facilities management systems, oversight, and capital leveraging research
- Assessment of footprint reduction, consolidation, and environmental stewardship options

EXPLORATION COF

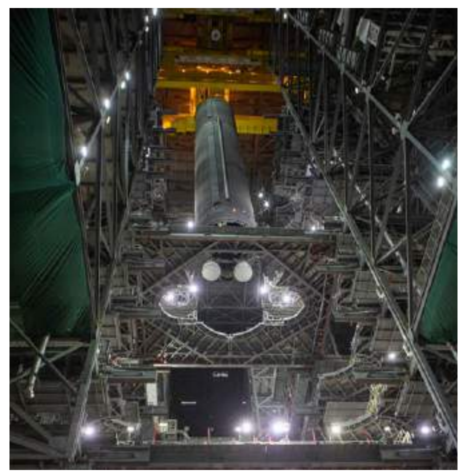
FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**109.9**	**60.3**	**89.3**	**0.0**	**0.0**	**0.0**	**0.0**
Change from FY 2021			**29.0**				
Percentage change from FY 2021			**48.1%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Exploration Construction of Facilities (CoF) supports NASA's exploration missions, including the Space Launch System (SLS), Orion, and Exploration Ground Systems (EGS) programs. Exploration CoF is managed in collaboration with institutional projects but funded through the Human Exploration and Operations Mission Directorate (HEOMD).



Technicians use a crane to lower the Space Launch System Core Stage pathfinder into High Bay 3 inside the Vertical Assembly Building at Kennedy Space Center.

Exploration CoF Priorities

Exploration construction priorities in FY 2022 continue to support facility upgrades and modernization for the Artemis Program at the Kennedy Space Center and the Michoud Assembly Facility.

EXPLANATION OF MAJOR CHANGES IN FY 2022

N/A.

ACHIEVEMENTS IN FY 2020

NASA continued to address critical capabilities and infrastructure related to HEOMD programs, including launch activities, SLS and Orion projects, and other exploration activities.

Discrete Projects

- Completed upgrades to the Vehicle Assemble Building (VAB) high bay 3 at Kennedy Space Center (KSC), including installation, commissioning, and fit-checks with mobile launcher to ensure platforms are operational for Artemis I flight hardware.
- Continued fabrication and installation of an approximately 1.25 million gallon liquid hydrogen (LH2) sphere at KSC launch complex

EXPLORATION COF

- Began construction on a multi-year project to upgrade KSC launch infrastructure for SLS, replacing Apollo-era equipment and key capabilities (e.g., helium system pumps) to enable mission work
- Began refurbishing the Neil Armstrong Operations and Checkout Building to address defects in the exterior surface of the wall and enable clean room activities for Orion capsule processing at KSC
- Continued modifications to the Michoud Assembly Facility (MAF) to enable SLS work, including replacement of the steam and water system, pumping stations, electrical systems and transformers, and major equipment installations (e.g., cranes, weld tools, gas, pressure systems)

Minor Projects

- Completed numerous key lifecycle replacements of degraded and failing infrastructure and facilities at KSC

Facility Planning and Design

- Designed the Rotation Processing Surge Facility (RPSF) fire protection system, which ensures safety code compliance during solid booster processing
- Designed the roof replacements of the manufacturing building and the engineering and administration building as part of the SLS program at the Booster Fabrication Facility (BFF) Complex at KSC, including the replacement and upgrade of HVAC equipment and exhaust fans
- Designed KSC Logistic Facility HVAC system replacement
- Designed key repairs and replacements of water systems (e.g., pumps, piping, valves, potable water, sewage) for KSC's VAB

WORK IN PROGRESS IN FY 2021

EGS continues development of programmatic infrastructure modifications necessary to support SLS and Orion launch processing operations.

Discrete Projects

- Modify KSC's launch infrastructure to support SLS and other exploration mission requirements
    - Install the Emergency Egress System (EES) to enable emergency evacuation of the flight crew from the Mobile Launcher (ML)
    - Construct the Environmental Control System (ECS) to continuously maintain critical temperature and humidity air supply for SLS and Orion flight systems during launches
    - Upgrade nitrogen compression pumps, vaporizers, valves, and piping configurations
    - Address infrastructure concerns resulting from long-term deferred maintenance, including code compliance updates to replace obsolete systems and increase efficiency

Minor Projects

- Replace KSC Logistic Facility HVAC system to meet design life cycle replacement requirements
- Replace the roofs of the manufacturing building and engineering and administration building at KSC
- Upgrade the communication infrastructure of BFF Complex at KSC, including the replacement of legacy wiring and critical information technology equipment
- Continue refurbishing the Neil Armstrong Operations and Checkout Building to address defects in the exterior surface of the wall and enable clean room activities for Orion capsule processing at KSC

EXPLORATION COF

- Continued modifications to the Michoud Assembly Facility (MAF) to enable SLS work, including replacement of the steam and water system, pumping stations, electrical systems and transformers, and major equipment installations (e.g., cranes, weld tools, gas, pressure systems)

Facility Planning and Design

- Begin to design VAB rehabilitation to include heavy-weight cranes in critical facilities
- Begin the designs to replace the aging HVAC systems and associated controls throughout Launch Control Center (LCC) and VAB, which will address long-term deferred maintenance, significantly increase energy efficiency, and remove hazardous materials
- Design all scheduled projects included in MAF roof replacement and associated redesign (i.e., Phases 2 through 4)
- Design BFF Complex improvements, including the Oxygen Deficiency Monitoring System (OMDS), replacement of remaining roofs, interior renovations, and crane refurbishment

KEY ACHIEVEMENTS PLANNED FOR FY 2022

Exploration CoF will continue infrastructure modifications necessary to support SLS and Orion launch operations, along with other exploration missions:

Discrete Projects

- Modify the launch infrastructure at KSC for SLS activities and new exploration missions
    - FY 2022 Estimate: $3.5M to complete project funding; Total Project Estimate: $61.6M
    - Funded jointly with Institutional CoF to ensure success in future mission launches
    - Upgrade critical systems for nitrogen, temperature and humidity control, air supply, fabrication, and emergency evacuation
    - Enable the Artemis Program and long-distance exploration programs with SLS activities

- Rehabilitate KSC's LCC HVAC system to enable critical mission work
    - FY 2022 Estimate: $15.8 million to fund Phase 1 of 2; Total Project Estimate: $31.6 million
    - Rehabilitate HVAC systems to support personnel and ongoing operations of critical launch equipment (e.g., monitoring systems, firing and computer rooms)
    - Ensure mission-critical operations (e.g., launch countdowns, controls, communication) are not impacted by system failures
    - Replace vital, high-tech equipment that supports launch operations (e.g., Air Handle Units (AHU), computer room air conditioning units, fan coils, chilled water pumps, valves)
    - Utilize new HVAC systems that save energy and reduce operational costs

- Replace MAF roof and relocate the fan house to enable SLS construction and manned spaceflight
    - FY 2022 Estimate: $35 million to complete Phase 3 of 5; Total Project Estimate: $174 million
    - Replace the approximate 1.7 million square foot roof, which houses NASA's primary, large-scale, and environmentally controlled aerospace
    - Avoid costly delays and potential harm caused by failures and collapses from the existing, deteriorating roof, which is beyond design life and impacted by weather
    - Utilize modern materials and methods to greatly enhance sustainability, reduce energy usage and associated costs, and uphold NASA's environmental stewardship goals

EXPLORATION COF

Minor Projects

In FY 2022, Exploration CoF will spend an estimated $35 million to conduct critical repairs, modernization, and upgrades for facilities, infrastructure, and assets that support exploration projects.

- Repair and upgrade VAB Water Distribution System at KSC
- Renovate the 200-ton bridge crane at KSC's RPSF
- Repair and revitalize BFF Complex at KSC, including interior renovations; HVAC and security upgrades; replacement of air systems, elevators, and oxygen monitors; and plumbing refurbishment
- Repair MAF roadways
- Replace essential infrastructure within MAF, including fire systems and restrooms

Facility Planning and Design

In FY 2022, Exploration CoF and the mission directorate will conduct facility planning and design activities associated with all projects.

SPACE OPERATIONS COF

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**20.0**	**23.9**	**20.5**	**0.0**	**0.0**	**0.0**	**0.0**
Change from FY 2021			**-3.4**				
Percentage change from FY 2021			**-14.2%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Space Operations CoF provides construction to support Space Communications and Navigation (SCaN), the International Space Station (ISS) program, and the Launch Services Program (LSP). Funds required for the planning and design of out-year programmatic construction remain in the applicable program accounts.

Space Operations CoF Priorities

Space Operations CoF is prioritized based on HEOMD mission requirements and the criticality of mission assets.

NASA's Deep Space Network Aperture Enhancement Project DSS-54 antenna at Madrid (shown above) is undergoing installation, integration, and testing.

EXPLANATION OF MAJOR CHANGES IN FY 2022

N/A.

ACHIEVEMENTS IN FY 2020

Discrete Projects

- Made progress on the Deep Space Network Aperture Enhancement Project (DEAP), which includes the development of a new, 34-meter antennae in Spain
    - Completed antenna mechanical alignments leading to the delivery of the antenna structure on Deep Space Station (DSS)-56
    - Transitioned from construction activities into system level testing, calibration, and commissioning activities
    - Continued developing DSS-53 with the completion, mechanical installation, alignment, and delivery of the antennae

SPACE OPERATIONS COF

- Continued repairs on several DSS-43 70-meter antennae at the Canberra Deep Space Communication Complex
    - Installed medium voltage switchgear and new hardware accepted by the regulator
    - Upgraded the Operational Buildings HVAC system
    - Installed the antenna cooling towers and expect to return DSS-43 to service in FY 2021

Minor Projects

- Completed the geotechnical study and preliminary antenna layout for the DSS-23 antenna
- Continued seismic upgrades and fire detection projects at Fort Irwin although some activities were placed on hold due to COVID-19 access restrictions

Facility Planning and Design

- Designed the perimeter fencing at the Goldstone Deep Space Communication Complex to protect assets and employees

WORK IN PROGRESS IN FY 2021

Discrete Projects

- Complete testing activities for the DEAP project in Madrid and deliver it into operation
    - Complete construction of DSS-53 facilities
    - Transition the antennae into the testing and commissioning phase and conduct the geotechnical study for the pedestal remediation project for DSS-54 antenna
- Complete excavation at the Goldstone Deep Space Communication Complex
- Begin antenna fabrication work for the new DSS-23 antenna

Minor Projects

- Replace the beam waveguide (BWG) antenna drives at Goldstone Deep Space Communication Complex for greater reliability
- Upgrade the site-wide uninterruptible power supplies (UPS) for increased safety and reliability

Facility Planning and Design

Space Operations CoF will conduct routine planning and design activities required by all construction, repair, and revitalization activities.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

Discrete Projects

- Complete the DEAP BWG antennae at the Goldstone and Canberra Deep Space Communication Complexes
    - FY 2022 Estimate: $12.5 million to complete Phase 4 of 8; Total Project Estimate: $93.7 million

SPACE OPERATIONS COF

- Complete construction and start operations of DSS-53 antenna at the Madrid Deep Space Communication Complex, enabling the array of four antennae for an enhanced aperture
- Complete the DSS-23 antenna pedestal at the Goldstone Deep Space Communication Complex, along with other critical infrastructure including flood controls, water, and HVAC systems, electrical, surveillance, and fire detection systems
- Enable both radio frequency and optical communications for deep space exploration missions

Minor Projects

In FY 2022, Space Operations CoF will spend an estimated $8 million to conduct repairs, modernization, and upgrades to ensure the safe and reliable continued operations of vital communication and monitoring systems. Repairs and upgrades will address crucial systems in current assets, including electrical and fire systems, accessibility and code compliance, and other necessary refurbishment.

- Upgrade the switchgear to provide redundancy and ensure reliability at the Apollo site
- Install an additional underground backup power feed from the Mars site to the Apollo site to support vital communications during long-term expeditions
- Expand the underground fiber optic cable from the Mars site to the Apollo site at the Goldstone Deep Space Communication Complex to ensure continuous connectivity during missions

Facility Planning and Design

Space Operations CoF and the Mission Directorate will conduct routine planning and design activities required by all construction, repair, and revitalization activities.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**74.7**	**58.1**	**74.7**	**76.2**	**77.8**	**79.4**	**81.1**
Change from FY 2021			**16.6**				
Percentage change from FY 2021			**28.6%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Cleanup of Santa Susana Field Laboratory (pictured above), including groundwater and soil remediation, comprises ~42 percent of ECR funds and supports NASA's ethical and legal requirement to address environmental impacts.

NASA’s Environmental Compliance and Restoration (ECR) program cleans up hazardous materials and waste products released to the surface or groundwater at current and former NASA installations or associated facilities. Over the years, NASA activities have contributed to environmental problems. It is the Agency's ethical and legal responsibility to address hazardous pollutants and environmental impacts.

ECR activities include projects, studies, assessments, investigations, sampling, plans, designs, construction, engineering, program support, monitoring, and regulatory oversight. Funding also covers land acquisitions required to ensure operation of remedial treatment processes and facilities as part of remediation and cleanup measures.

ECR Priorities

Cleanup, studies, and other activities related to environmental stewardship are prioritized based on a combination of legal and statutory requirements, assessed risk, and mission requirements. ECR activities align to the following priority areas (more detailed descriptions of project areas are in the Program Element section below):

- Ensure the public and the NASA workforce are not exposed to harmful chemicals from current or previous mission activities
- Restore natural resources and reduce the Agency's liability for environmental impacts
- Connect with local stakeholders, lawmakers, regulatory entities, and other government agencies to understand current and new environmental policies and develop plans based on shared goals
- Update NASA's policies and remediation plans based on the most recent science, guidelines, and statutory requirements

ENVIRONMENTAL COMPLIANCE AND RESTORATION

EXPLANATION OF MAJOR CHANGES IN FY 2022

NASA plans to demolish the Santa Suzanna Field Laboratory (SSFL) Coca Test Stand and expansion of SSFL groundwater restoration activities, as well as Site Inspections of potential PFAS release sites identified at multiple centers during the Agency Preliminary Assessment.

ACHIEVEMENTS IN FY 2020

ECR includes cleanup activities at all NASA centers, with priority given to protecting health and conforming to environmental regulations and statutory requirements:

- Conducted essential cleanup activities at Santa Susana Field Laboratory (SSFL):
  - Published the SSFL Supplemental Environmental Impact Statement (EIS), which assessed the impacts associated of soil cleanup alternatives
  - Prepared a Record of Decision (ROD) to support work plans for soil cleanup
  - Retained the Alfa Test Stands and Control House and decided to demolish the remaining test stands after consulting with the Office of the Inspector General
  - Resumed groundwater treatment after reconstructing the fire-damaged piping system
  - Continued planning for groundwater remediation and long-term water and air monitoring
  - Managed cultural resources and designated SSFL a Traditional Cultural Property per the agreement with the State Historic Preservation Office and local Native American tribes

- Conducted cleanup activities across NASA for groundwater and soil remediation:
  - Investigated and addressed per- and polyfluoroalkyl substance (PFAS) contamination by installing groundwater treatment systems, excavating, and removing contaminated soils, and sampling over 700 monitoring wells
  - Initiated an Agency-wide Preliminary Assessment (PA) of PFAS contamination
  - Continued JPL groundwater contamination remediation to protect public drinking water
  - Removed contaminated soil at MSFC and began remediation of groundwater
  - Operated treatment systems and groundwater and soil monitoring across NASA locations
  - Completed significant effort towards the Risk-Based Closure (RBC) of the SSC groundwater contamination clean-up Area D
  - Completed several studies to understand subsurface geology to more effectively continue groundwater remediation
  - Continued cleanup at the abandoned GRC wastewater treatment facility and lead contamination at Plum Brook Station
  - Completed construction of a groundwater treatment system to address PFAS contamination of drinking water in the town of Chincoteague

- Changed, enhanced, and otherwise improved policies, guidelines, and plans for ECR activities:
  - MSFC sites OU12 and OU9 were delisted from the nationwide Superfund site list and will be recognized by the EPA in an on-site ceremony in 2021
  - Completed the proposed plan for LaRC's Construction Debris Landfill (CDL), the last step prior to the ROD in the CERCLA process

ENVIRONMENTAL COMPLIANCE AND RESTORATION

WORK IN PROGRESS IN FY 2021

ECR will continue cleanup activities at all NASA centers, with priority given to protecting health and conforming to environmental regulations and statutory requirements:

- Conduct essential cleanup activities at SSFL:
    - Demolish of SSFL Bravo Test Stands
    - Conduct pilot tests for groundwater cleanup and finalize soil and groundwater cleanup plans
    - Continue operation of groundwater treatment systems and continue long term monitoring and management of air, groundwater, surface water, and treatment efforts
    - Continue cultural resource management per the agreement with the State Historic Preservation Office and Native Americans tribes

- Conduct cleanup activities across NASA for groundwater and soil remediation:
    - Sample soil, groundwater, surface water and sediments at various centers to verify PFAS contamination and determine whether further action is warranted
    - Continue PFAS characterization and remediation work at KSC, GRC and WFF
    - Investigate contamination at KSC and continue the installation of new groundwater treatment systems, removal of contaminated soils, investigation of potential contamination, and sampling of over 700 monitoring wells
    - Complete contaminated soil removal at MSFC and implement interim actions to address sources of groundwater contamination
    - Continue to operate and maintain systems to clean up contaminated groundwater emanating from JPL and impacting drinking water
    - Continue to clean up ground water contamination and investigate soil contamination at WSTF, including completing closure activities, conducting investigations, long-term monitoring of groundwater, and continued operation of ground water treatment systems
    - Complete construction of the LaRC CDL ROD
    - Complete the risk-based cleanup of Area D at SSC and remove the extraction and monitoring wells, demolish the support building, and remove pump and treat equipment
    - Remediate groundwater pollutants from the JSC B 358 Surface Impoundment Area, formerly used for retention and treatment of process wastewater from the adjacent Energy Systems Testing Area

- Change, enhance, and otherwise improve policies, guidelines, and plans for ECR activities:
    - Complete the LaRC CERCLA Five Year Review which examines the remedial actions implemented to ensure the protection of human life and the environment
    - Continue remediation and closure efforts at centers and facilities, as well as environmental compliance and functional leadership projects

KEY ACHIEVEMENTS PLANNED FOR FY 2022

ECR will continue cleanup activities at all NASA centers, with priority given to protecting health and conforming to environmental regulations and statutory requirements:

- Conduct essential cleanup activities at SSFL:
    - Continue to demolish SSFL Bravo Test Stands and begin demolition of Coca Test Stands
    - Continue groundwater cleanup, operation of groundwater treatment systems, and long-term monitoring of air and groundwater

ENVIRONMENTAL COMPLIANCE AND RESTORATION

  - Conduct onsite storm water and surface water management and treatment
  - Manage cultural resources per the agreement with the State Historic Preservation Office and local Native American tribes

- Conduct cleanup activities across NASA for groundwater and soil remediation:
  - Continue to investigate and cleanup contamination at KSC, including the installation of new groundwater treatment systems, removal of contaminated soils, investigation of potential contamination, and sampling over 700 monitoring wells
  - Continue MSFC site wide restoration activities including implementing interim actions to address the groundwater plume operable unit source areas
  - Continue to operate and maintain JPL contaminated groundwater treatment systems and continue to operate the Lincoln Avenue and Monk Hill drinking water treatment systems
  - Continue site wide restoration activities, contaminated groundwater cleanup, and investigate soil contamination at WSTF
  - Complete the closure activities and receive a "No Further Action" notification from the regulator for Area A at SSC

- Change, enhance, and otherwise improve policies, guidelines, and plans for ECR activities:
  - Continue to support site wide remedial efforts at the eight other centers and facilities, and Environmental Compliance and Functional Leadership projects

INSPECTOR GENERAL

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**41.7**	**44.2**	**46.0**	**47.0**	**48.0**	**49.1**	**50.2**

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

INSPECTOR GENERAL

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2020	Enacted FY 2021	Request FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Total Budget	**41.7**	**44.2**	**46.0**	**47.0**	**48.0**	**49.1**	**50.2**
Change from FY 2021			**1.8**				
Percentage change from FY 2021			**4.1%**				

FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2021 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

For FY 2022, the NASA Office of Inspector General (OIG) requests a total of $46 million to support the work of auditors, investigators, analysts, specialists, lawyers, and support staff located at NASA Headquarters in Washington, DC, and 12 other locations throughout the United States.

The mission of the OIG is to improve the Agency's programs and operations through independent and objective oversight. OIG conducts audits, investigations, and reviews of NASA programs to prevent and detect fraud, waste, abuse, and mismanagement and to assist NASA leaders and Congress in promoting economy, efficiency, and effectiveness through its oversight role. OIG's operational offices are the Office of Audits (OA) and the Office of Investigations (OI).

OA conducts independent and objective audits of NASA programs, projects, operations, and contractor activities, and oversees the work of the independent public accounting firm that conducts the Agency's annual financial statement audit. In its work, OA reviews NASA's top management and performance challenges and the Agency's most important projects and missions. OIG audits provide fact-based analysis with actionable recommendations that helps NASA improve its operations and achieve its space exploration, scientific, and aeronautics goals more effectively and efficiently.

OI investigates allegations of cybercrime, fraud, waste, abuse, and misconduct related to NASA programs, operations, and resources. OI refers its findings to the U.S. Department of Justice (DOJ) for criminal prosecution and civil litigation or to NASA managers for administrative action. Through its investigations, OI develops recommendations to reduce the Agency's vulnerability to criminal activity or administrative inefficiency. Given that NASA spends approximately 81 percent of its total resources on contracts, grants, and cooperative agreements, OI's caseload includes investigations of suspected false claims submitted by NASA contractors, product substitution and counterfeit parts, and conflict of interest cases that involve NASA employees who place private gain before public service.

With the FY 2022 request of $46 million, OIG will be able to fund the following:

- $39 million for personnel and related costs, including salaries, benefits, monetary awards, worker's compensation, permanent change of station costs, and Government contributions for Social Security, Medicare, health and life insurance, retirement, and the Thrift Savings Plan including increased rates for retirement contributions. Salaries include the required additional 25 percent law enforcement availability pay for OIG's approximately 55 criminal investigators;

- $2 million for the statutorily required annual audit of the Agency's financial statements;
- $1 million for employee travel, per diem, and related expenses; and
- $4 million for equipment, training, Government vehicles, special equipment for criminal investigators, transit subsidies, and information technology equipment unique to OIG.[1]

EXPLANATION OF MAJOR CHANGES IN FY 2022

For FY 2022, the budget requests a total of $46 million in direct appropriations with two-year funding authority. This is an increase of $1.8 million from the FY 2021 enacted. Salaries and benefits and the contract with a private accounting firm to conduct the statutorily required audit of NASA's financial statements consume 90 percent of the annual budget. The budget funds an additional three Full-Time Equivalent (FTE) for expanded OIG activities in support of NASA's Lunar Program, known as Artemis, particularly in light of increased funds the Agency has received to support this effort. In addition, the budget funds OIG payroll and benefits, including retirement costs, a 2.7 percent increase in base pay for civilian and Law Enforcement Officer (LEO) employees in 2022, and increases in employee awards for FY 2022. OIG is a personnel-driven organization with salaries and benefits representing 85 percent of the total budget.

PROPOSED FUNDING AUTHORITY AND APPROPRIATIONS LANGUAGE CHANGE

For FY 2022, OIG is requesting two-year budget authority for its total direct appropriations. This change is consistent with all other NASA appropriations. This budget request will allow OIG to streamline its financial, procurement, and other year-end processes within NASA's centralized systems to more efficiently carry out its oversight mission. It will also provide more certainty in funding and efficiencies in hiring for an organization that is 85 percent salaries and benefits. Two-year funding will give OIG the flexibility to more efficiently manage hiring and keep our workforce at stable levels.

Requested appropriations language: "For necessary expenses of the Office of Inspector General in carrying out the Inspector General Act of 1978, $46,000,000, shall remain available until September 30, 2023."

[1] *This number includes $500,000 for staff training and $100,000 to support the Council of Inspectors General on Economy and Efficiency (CIGIE). In accordance with Public Law 110-409, the Inspector General Reform Act of 2008, the Inspector General certifies that these amounts are sufficient to satisfy all training requirements and contributions to CIGIE.*

INSPECTOR GENERAL

ACHIEVEMENTS IN FY 2020

In FY 2020, OIG issued 18 audit products containing 159 recommendations for improvement and identifying approximately $214 million in potential savings for NASA. Audit products included reports examining NASA's management of:

- Crew Transportation to the International Space Station;
- Space Launch System Stages Costs and Contracts;
- Mobile Launchers;
- Orion Multi-Purpose Crew Vehicle Program;
- Low Boom Flight Demonstrator Project;
- Stratospheric Observatory for Infrared Astronomy Program;
- Distributed Active Archive Centers; and
- Use of Non-Agency Information Technology Devices

In FY 2020, OI investigated a wide variety of criminal and administrative matters involving procurement fraud, theft, counterfeit parts, ethics violations, and computer intrusions leading to more than $6.2 million in criminal, civil, and administrative penalties and settlements with approximately $3.2 million of these funds returned directly to NASA. Overall, OI's efforts in FY 2020 resulted in 15 indictments, 14 convictions, 10 civil settlements, 31 administrative actions, and 32 suspensions or debarments. Examples of OI's work over the past year include:

- As the result of a NASA OIG investigation, the former President and the former Executive Director of a Palmdale, California, research institute both pled guilty to charges related to the fraudulent use of NASA funds. The former President was sentenced to three years of supervised release and fined $2,070. The former Executive Director was sentenced to two years of supervised release and ordered to pay restitution of $341,266 to NASA.

- Based on the results of a Qui Tam lawsuit filed with DOJ and an investigation by NASA OIG, a parts supplier agreed to pay $375,000 to resolve claims it falsely certified that it cleaned and purged critical ground support equipment used to access Orion.

- As a result of a joint investigation by NASA OIG and the Internal Revenue Service, a former Center for the Advancement of Science in Space senior official pled guilty to filing a false tax return after he allegedly used Government funds to pay for escorts and other unallowable expenses while on official company business. The official understated his total income by approximately $209,916 and failed to report approximately $158,000 in gross receipts earned from clients for whom he was a consultant. In addition, he improperly deducted business expenses of approximately $51,500, despite being reimbursed for the expenses, some of which were unnecessary.

- NASA OIG investigated a conspiracy involving several individuals defrauding the Government to obtain more than $15 million in set-aside contracts under the Service-Disabled Veteran-Owned and 8(a) Programs. One of the contracts was for the construction of a $5.5 million security building at the main entrance to NASA's Plum Brook Station in Sandusky, Ohio. At a November 2019 trial, a Florida business owner was found guilty of one count of conspiracy to commit wire fraud, five counts of wire fraud, one count of conspiracy to submit false claims, three counts of false claims, and three counts of major fraud against the United States related to the Plum Brook construction contract and U.S. Department of Veterans Affairs and Department of Defense contracts. Prior to the trial, four other individuals pled guilty to multiple fraud charges. The U.S. Department of the Navy also suspended seven individuals and 14 firms from Federal Government contracting relating to these charges. Seven individuals were sentenced in the U.S. District Court for the Northern District of Ohio. These sentences ranged from one-to-three years of supervised release and home confinement and included fines ranging from $5,000 to $15,000.

- Following an investigation by NASA OIG, a former flight operations contractor employee at Ellington Field, Texas, was sentenced to two years of imprisonment and ordered to pay $15,000 in restitution for selling NASA flight jackets and other stolen NASA property on eBay.
- A New Mexico-based contractor that provided fire protection services at Ames Research Center agreed to pay $1.2 million to NASA to resolve allegations that it made false claims by overcharging the Agency hundreds of thousands of dollars in inflated workers' compensation rates.
- After a multi-year investigation by the NASA OIG, U.S. Department of Health and Human Services OIG, U.S. Army Criminal Investigation Command, National Science Foundation OIG, and U.S. Department of Education OIG, the University of Virginia agreed to repay the Federal Government $1 million for rebates and credits it should have credited to the Government across numerous contracts spanning several years. The settlement covered all claims on behalf of the Government and returned the one million to the U.S. Treasury.
- As the result of a proactive investigation by NASA OIG, a Colorado Springs, Colorado, small business agreed to a settlement of $374,184 to resolve allegations that it accepted Small Business Innovation Research (SBIR) grants from NASA and the U.S. Department of Energy that its principal investigator was not eligible to receive.
- Based on a proactive investigation by NASA OIG, two former contractors, one of whom previously pleaded guilty to conspiracy to commit wire fraud, reached civil settlements with DOJ wherein each agreed to pay the Government $250,000. These settlements resulted from the submission of materially false statements in proposals for awards to NASA's, the National Science Foundation's, and the U.S. Department of Energy's SBIR programs.
- A former subcontractor quality assurance engineer was sentenced to three years of supervised release and ordered to pay $126,813 in restitution after pleading guilty to falsifying inspection reports and test certifications for flight-critical components to be used on Space Exploration Technologies Corporation (SpaceX) rocket missions for NASA, the U.S. Air Force, and the National Oceanic and Atmospheric administration.

WORK IN PROGRESS IN FY 2021

In the first three months of FY 2021, OIG issued audit reports examining NASA's management of its Acquisition Workforce and NASA's management of the Gateway Program for the Artemis missions. Additionally, OIG issued the mandated Audit of NASA's Fiscal Year 2020 Financial Statements and Assessment of Compliance with the Geospatial Data Act.

During the remainder of the fiscal year, OIG will examine NASA's efforts to encourage commercialization of low-Earth orbit, construction of facilities and leasing practices, multi-mission cost estimation, astrophysics portfolio, and management of the astronaut corps and space suit development activities. OIG continues to provide oversight in the information technology realm with an audit of cybersecurity readiness and a planned audit related to cyber insider threats. Additionally, OIG is reviewing the impact of COVID-19 on major NASA programs and plans additional work related to NASA's response to the pandemic to include funding received as part of the CARES Act. Ongoing OI work includes proactive initiatives designed to identify acquisition and procurement fraud schemes. Additionally, representatives from both OI and OA are working together to use OIG's advanced data analytics capabilities to help identify indicators of potentially fraudulent activity.

KEY ACHIEVEMENTS PLANNED FOR FY 2022

In FY 2022, OIG will continue to focus its audit work on NASA's top management and performance challenges identified in our November 2020 report. Specifically, OIG plans to undertake work in the following areas:

- Landing the First Woman and Next Man on the Moon;
- Improving Management of Major Projects;
- Sustaining a Human Presence in Low-Earth Orbit;
- Attracting and Retaining a Highly Skilled and diverse Workforce;
- Improving Oversight of Contracts, Grants, and Cooperative Agreements;
- Managing and Mitigating Cybersecurity Risks; and
- Addressing Outdated Infrastructure and Facilities.

OIG will also continue oversight in a variety of Financial Management and Quality Control areas to include:

- Improper Payments Information Act Compliance;
- Desk and Quality Control Reviews of Selected Single Audit Reporting Packages;
- Oversight of Financial Statement Audit;
- Risk Assessment of Purchase and Travel Card Programs;
- Geospatial Data Act;
- Management of Non-reimbursable Agreements; and
- Federal Information Security Modernization Act.

As NASA works toward landing the first woman and next man on the Moon, additional OIG funding will enhance independent oversight of the major component projects that make up the Artemis Program. Additionally, OIG will continue to evaluate the impact of COVID-19 on Agency programs and operations to ensure these emergency pandemic relief funds are used properly and effectively.

From an investigative perspective, the FY 2022 request will continue support for investigations of cybercrime, fraud, waste, abuse, and misconduct related to NASA programs, projects, personnel, operations, and resources.

Given the important role of NASA's contracting practices in all its missions, the majority of OIG's proactive initiatives focus on acquisition activities that are susceptible to procurement fraud schemes. Examples of ongoing proactive initiatives that will continue to be active throughout FY 2022 include the following:

- A project to monitor and aggregate data related to NASA's Artemis Program in an attempt to identify indications of fraud on the part of prime contractors and subcontractors;
- A project with OIG's Audit component to conduct incurred cost audits of specific NASA subcontractors;

- A Criminal and Cyber Threat Intelligence (CaCTI) project that will identify sensitive procurement information and other critical data that may have been improperly exfiltrated from NASA computer systems; and
- Multiple initiatives commenced to identify, detect, and deter fraud involving grant and contract recipients who surreptitiously receive significant financial support from foreign governments and/or fail to identify potential foreign-based conflicts of interest in violation of NASA policies and/or Federal law.

In FY 2022, OIG intends to continue to place additional emphasis on proactive initiatives designed to identify antitrust crimes (e.g., bid-rigging conspiracies and related fraudulent schemes) that undermine competition in Government procurement, grant, and program funding. Additionally, OIG plans to prioritize investigative referrals involving NASA employees, contractors, and grant recipients who fraudulently applied for and/or received CARES Act funds intended to help individuals and businesses during the pandemic.

Supporting Data

FUNDS DISTRIBUTION BY INSTALLATION

DISCRETIONARY BUDGET REQUEST BY MISSION BY NASA CENTER

Budget Authority ($ in millions)	FY 2022*
Deep Space Exploration Systems	37.7
Space Technology	55.9
Space Operations	6.9
Science	253.6
Aeronautics	177.7
STEM Engagement	3.1
Safety, Security, and Mission Services	190.6
Construction and Environmental Compliance and Restoration	7.7
Ames Research Center (ARC) Total	**733.2**
Deep Space Exploration Systems	0.0
Space Technology	21.0
Space Operations	0.1
Science	23.5
Aeronautics	172.3
STEM Engagement	12.7
Safety, Security, and Mission Services	60.9
Construction and Environmental Compliance and Restoration	17.7
Armstrong Flight Research Center (AFRC) Total	**308.1**
Deep Space Exploration Systems	170.9
Space Technology	104.8
Space Operations	46.2
Science	65.2
Aeronautics	181.4
STEM Engagement	6.3
Safety, Security, and Mission Services	204.2
Construction and Environmental Compliance and Restoration	16.8
Glenn Research Center (GRC) Total	**795.7**
Deep Space Exploration Systems	7.7
Space Technology	236.2
Space Operations	179.2
Science	2,882.5
Aeronautics	0.0
STEM Engagement	9.4
Safety, Security, and Mission Services	385.8
Construction and Environmental Compliance and Restoration	13.9
Goddard Space Flight Center (GSFC) Total	**3,714.6**

FUNDS DISTRIBUTION BY INSTALLATION

Budget Authority ($ in millions)	FY 2022*
Deep Space Exploration Systems	3.0
Space Technology	43.4
Space Operations	174.8
Science	1,598.9
STEM Engagement	2.2
Safety, Security, and Mission Services	9.8
Construction and Environmental Compliance and Restoration	40.8
Jet Propulsion Laboratory (JPL/NMO) Total	**1,873.0**
Deep Space Exploration Systems	1,938.8
Space Technology	30.9
Space Operations	2,985.0
Science	309.0
Aeronautics	0.0
STEM Engagement	8.2
Safety, Security, and Mission Services	339.2
Construction and Environmental Compliance and Restoration	39.8
Johnson Space Center (JSC) Total	**5,650.9**
Deep Space Exploration Systems	610.9
Space Technology	27.2
Space Operations	232.6
Science	434.5
Aeronautics	0.0
STEM Engagement	23.6
Safety, Security, and Mission Services	341.2
Construction and Environmental Compliance and Restoration	37.5
Kennedy Space Center (KSC) Total	**1,707.5**
Deep Space Exploration Systems	27.3
Space Technology	62.3
Space Operations	2.9
Science	321.2
Aeronautics	283.7
STEM Engagement	30.6
Safety, Security, and Mission Services	263.9
Construction and Environmental Compliance and Restoration	19.0
Langley Research Center (LaRC) Total	**1,011.1**
Deep Space Exploration Systems	2,495.1
Space Technology	74.9
Space Operations	137.5
Science	248.4
Aeronautics	0.0
STEM Engagement	4.0
Safety, Security, and Mission Services	509.5
Construction and Environmental Compliance and Restoration	83.7
Marshall Space Flight Center (MSFC) Total	**3,553.2**

FUNDS DISTRIBUTION BY INSTALLATION

Budget Authority ($ in millions)	FY 2022*
Deep Space Exploration Systems	1,557.7
Space Technology	766.2
Space Operations	220.1
Science	1,794.5
Aeronautics	99.7
STEM Engagement	25.8
Safety, Security, and Mission Services	691.9
Construction and Environmental Compliance and Restoration	94.9
Office of Inspector General	46.0
NASA Headquarters (HQ) and Inspector General (IG) Total	**5,296.7**
Deep Space Exploration Systems	31.3
Space Technology	2.2
Space Operations	32.1
Science	0.1
Aeronautics	0.0
STEM Engagement	21.1
Safety, Security, and Mission Services	52.3
Construction and Environmental Compliance and Restoration	18.5
Stennis Space Center (SSC) Total	**157.6**
	24,801.5

**Totals may not add due to rounding*

NOTE: Funds will not be fully distributed to the centers until after final acquisition decisions are made. Thus, FY 2022 allocations by center should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

NASA's workforce continues to be one of its greatest assets for enabling missions in space and on Earth. The Agency remains committed to applying this asset to benefit society, address contemporary environmental and social issues, lead or participate in emerging technology opportunities, collaborate and strengthen the capabilities of commercial partners, and communicate the challenges and results of Agency programs and activities. The civil service staffing levels proposed in the FY 2022 Budget support NASA's scientists, engineers, researchers, managers, technicians, and business operations workforce. It includes civil service personnel at NASA centers, Headquarters, and NASA-operated facilities.

NASA continually assesses and adjusts the mix of skills in its workforce to address changing mission priorities, leveraging industry and academic partnerships, and on and near-site support contracts to operate effectively in a leaner fiscal environment. A knowledgeable and well-trained civil service workforce is critical for conducting mission-essential work in research and technology. The Agency will apply the valued civil service workforce to priority mission work, adjusting the mix of skills where appropriate. Centers will explore cross-mission retraining opportunities for employees whenever possible, offer targeted buyouts in selected surplus skill areas, and continue to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.

CIVIL SERVICE FULL-TIME EQUIVALENT (FTE) DISTRIBUTION BY CENTER – DIRECT FUNDED

	Actual	Estimate	Request				
	FY 2020	**FY 2021**	**FY 2022**	**FY 2023**	**FY 2024**	**FY 2025**	**FY 2026**
ARC	1,186	1,178	1,168	1,168	1,168	1,168	1,168
AFRC	483	521	521	521	521	521	521
GRC	1,490	1,530	1,572	1,572	1,572	1,572	1,572
GSFC	2,991	3,058	2,987	2,987	2,987	2,987	2,987
JSC	2,928	3,126	3,112	3,112	3,112	3,112	3,112
KSC	2,007	2,079	2,107	2,107	2,107	2,107	2,107
LaRC	1,766	1,715	1,727	1,727	1,727	1,727	1,727
MSFC	2,261	2,415	2,469	2,469	2,469	2,469	2,469
SSC	266	247	250	250	250	250	250
HQ	1,172	1,260	1,274	1,274	1,274	1,274	1,274
NSSC	8	-	-	-	-	-	-
NASA Total*	**16,557**	**17,130**	**17,188**	**17,188**	**17,188**	**17,188**	**17,188**
OIG	**175**	**187**	**190**	**190**	**190**	**190**	**190**

**Totals may not add due to rounding.*

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2022 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

CIVIL SERVICE FULL-TIME EQUIVALENT (FTE) DISTRIBUTION BY CENTER – REIMBURSABLE FUNDED

	Actual	Estimate	Request				
	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
ARC	23	22	22	22	22	22	22
AFRC	32	15	15	15	15	15	15
GRC	11	3	3	3	3	3	3
GSFC	172	219	219	219	219	219	219
JSC	24	-	-	-	-	-	-
KSC	14	1	1	1	1	1	1
LaRC	8	15	15	15	15	15	15
MSFC	36	-	-	-	-	-	-
SSC	10	25	25	25	25	25	25
HQ	-	-	-	-	-	-	-
NSSC	156	169	169	169	169	169	169
NASA Total*	**486**	**469**	**469**	**469**	**469**	**469**	**469**
OIG	**6**	**6**	**6**	**6**	**6**	**6**	**6**

**Totals may not add due to rounding.*

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2022 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

FY 2022 FTE DISTRIBUTION BY ACCOUNT BY CENTER

	Deep Space Exploration Systems	Space Technology	Space Operations	Science	Aeronautics	STEM Engagement	Safety, Security, and Mission Services	Reimbursable / Working Capital Fund**	Inspector General	NASA-Funded Total	Agency TOTAL
ARC	93	106	12	185	244	2	526	22		1,168	1,190
AFRC	0	17	0	89	220	3	191	15		521	536
GRC	217	213	100	99	410	5	529	3		1,572	1,575
GSFC	21	140	118	1,322	-	3	1,383	219		2,987	3,206
JSC	1,027	80	1,092	57	-	8	849	-		3,112	3,112
KSC	676	74	499	19	-	4	834	1		2,107	2,108
LaRC	110	144	4	193	542	6	728	15		1,727	1,742
MSFC	1,094	170	176	152	-	4	873	-		2,469	2,469
SSC	53	9	38	-	-	4	146	25		250	275
HQ	33	22	47	150	18	5	999	-		1,274	1,274
NSSC	-	-	-	-	-	-	-	169		-	169
NASA Total*	**3,325**	**975**	**2,085**	**2,266**	**1,434**	**45**	**7,058**	**469**	-	**17,188**	**17,657**
OIG	-	-	-	-	-	-	-	6	190	190	196

**Totals may not add due to rounding*

***Includes 169 FTE funded by Working Capital Fund; and 306 FTE funded by reimbursable customers*

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2022 allocations should not be considered final or directly comparable to prior year allocations.

WORKING CAPITAL FUND

NASA established the Working Capital Fund (WCF) to satisfy specific recurring needs for goods and services through use of a business-like buyer and seller approach under which NASA's WCF entities provide goods or services pursuant to contracts and agreements with their customers. The overarching aim of WCF is to promote economy, efficiency, and accountability with fully reimbursed rates and by focusing on streamlining operations, measuring performance, and improving customer satisfaction.

NASA's WCF is comprised of four entities:

- NASA Shared Services Center (NSSC);
- Solutions for Enterprise-Wide Procurement (SEWP) Government-Wide Acquisition Contract;
- Information Technology (IT) Infrastructure Integration Program (I3P); and
- National Center for Critical Information Processing and Storage (NCCIPS).

WORKING CAPITAL FUNDS BUDGET SUMMARY

Spending Authority from Offsetting Collections ($ in millions)	Actual FY 2020	Estimate FY 2021	Request FY 2022
NSSC	80	86	86
SEWP	24	39	35
I3P	391	429	420
NCCIPS	23	26	33
Total New Spending Authority	**518**	**580**	**574**
Unobligated Brought Forward, Oct. 1	31	27	18
Recoveries of Prior Yr. Unpaid Obligations	4	6	6
Total Budgetary Resources	**553**	**613**	**598**
NSSC	85	88	88
SEWP	24	27	29
I3P	391	433	421
NCCIPS	26	47	33
Total Obligations	**526**	**595**	**571**
Unobligated Balance (end-of-year)*	**27**	**18**	**27**

**Unobligated balance end-of-year is budgetary resources less obligations*

NASA SHARED SERVICES CENTER (NSSC)

NSSC opened in March 2006 to provide centralized administrative processing services and customer contact center operations for support of human resources, procurement, financial management, Agency IT, and Agency business support services. NASA established NSSC, a function under the NASA Headquarters Mission Support Directorate, as a public/private partnership. NSSC has awarded its major business management and IT services contract to CSRA (Computer Sciences Corporation merged with SRA International). Typical expenditures are related to the civil service workforce, support contractor, other direct procurements, and Agency training purchases.

NSSC is located on the grounds of Stennis Space Center (SSC) and operates in a manner that provides for transparency and accountability of costs and services. NASA has reduced its administrative costs through centralized processing at NSSC. The work performed by NSSC reduces duplicative efforts and increases cost efficiencies.

NSSC's revenue streams include funding from the NASA centers, mission directorates, and various NASA mission support offices. During FY 2021, NSSC will continue to offer similar services as in FY 2020 expanding the scope to include two additional services, Staffing and Classification and Training Administration. During FY 2022, NSSC will continue to offer similar services as in FY 2021 making minor expansions to existing services.

SOLUTIONS FOR ENTERPRISE-WIDE PROCUREMENT (SEWP)

SEWP refers to operations related to the Government-Wide Acquisition Contract that was established under the authority of section 5112 of the Information Technology Management Reform Act (40 U.S.C. 1412(e)), enacted in 1996, under which NASA is designated by the Office of Management and Budget (OMB) as a Federal Government Executive Agent for SEWP contracts.

SEWP was established as a WCF entity to allow all Federal agencies use of a best value tool to purchase IT product solutions and services. Under this approach, the buying power of Federal Agencies is combined to acquire best value for IT products and services more efficiently. Typical acquisitions include a wide range of advanced technologies, such as: UNIX-Linux and Windows-based desktops and servers, peripherals, network equipment, storage devices, security tools, software, and other IT products and product-based solutions.

SEWP promotes aggressive pricing using online tools to obtain multiple, competitive quotes from vendors. On average for FY 2020, SEWP quotes have a 20 percent savings for any Federal customer using SEWP contracts. In addition, SEWP offers a low surcharge to recover NASA's costs to operate the program with an average 0.36 percent fee as compared to the Government standard of 0.75 percent. SEWP revenue is generated solely from the surcharge fees on all transactions processed. For FY 2020, the Federal Government saved about $37 million in fees, based on the difference between General Services Administration (GSA) and SEWP surcharge fees.

IT INFRASTRUCTURE INTEGRATION PROGRAM (I3P)

WCF operations supporting I3P began in early FY 2012. WCF enables I3P to improve the efficiency and economy in which contract services and management are provided to support NASA's IT strategic initiatives and to increase visibility into NASA's IT budget and expenditures. Under I3P, NASA has consolidated 19 separately managed contracts into five centrally managed ones described as follows:

- The Enterprise Applications Service Technologies contract supports Agency Applications Office (AAO) applications hosted by Marshall Space Flight Center (MSFC). The AAO operates and maintains a broad spectrum of NASA's enterprise applications, with an emphasis on fully integrating business process expertise with application and technical knowledge. A small team of civil servants and support contractors sustain operations, implement new applications and capabilities, and provide business readiness support to the stakeholders and end-users.

- The NASA Integrated Communications Services contract (NICS) provides wide and local area network, telecommunications, video, and data services hosted at MSFC.
- The Web Enterprise Service Technologies contract provides public website hosting, web content management and integration, and search services. Goddard Space Flight Center (GSFC) and Ames Research Center (ARC) host these services.
- The Agency Consolidated End-User Services (ACES) contract provides program management, provisioning, and support of desktops, laptops, cell phones, personal digital assistants, office automation software, and video conferencing. NSSC hosts these services. The ACES/Bridge Contract came to an end August 31, 2019. The work transitioned to the follow-on contract, End User Services Contract on September 1, 2019 with increased pricing for the first two years of the base contract.
- The Networx Telecommunications Circuits contract provides telecommunication services, which includes tele-conferencing services, core circuit services, mission network services, and regional circuit services hosted at MSFC. The work under the Networx contract slowly started transitioning to the follow-on contract, Enterprise Infrastructure Solutions Contract (EIS) in July 2019 with some services transitioning to the NICS Contract.

I3P's consolidated contracting approach benefits NASA by providing cost saving opportunities, such as the reduction in administrative burden involved with the business management of contracts and a significant reduction in procurement request transaction volume. Other I3P benefits include: streamlining the budgeting, funding, and costing of I3P services; achieving transparency through the provision of detailed customer monthly billings; and providing consolidated, consistent reporting of Agency-wide consumption of I3P-related goods and services.

I3P is unique in that revenue streams and expenditures are limited to contract costs for its five service contracts. Revenue streams include funding from the NASA centers, NASA mission directorates, and various NASA mission support offices. As reflected in the FY 2021 anticipated funding level, the I3P WCF will continue to offer similar services as in FY 2020 with an increase in cost under the End User Services Contract that transitioned from ACES/Bridge on September 1, 2019. The increase in cost is due to an increase in pricing for desktops, laptops, cell phones, personal digital assistants, office automation software, and video conferencing. The increased cost under the End User Services Contract will be incurred during the first two years of the contract which is FY 2020 and FY 2021. During FY 2022 NSSC will continue to offer similar services as in FY 2021 with no significant scope changes anticipated however we will start to see a reduction in cost on the End User Services contract which is year 3 of this contract.

NATIONAL CENTER FOR CRITICAL INFO. PROCESSING AND STORAGE (NCCIPS)

NCCIPS is a federal shared services data center (as defined by the Uptime Institute) designed for sensitive and secure processing and storage. NCCIPS is a 200,000 sq. ft. secure data center facility on a 64-acre campus within SSC. NCCIPS offers federal customers collocation services from a state-of-the-art data center. NCCIPS offers 24x7x365 availability at a Tier III level, with complete redundancy in the electrical distribution system from the national grid to the rack-level.

NCCIPS provides the following infrastructure/services:

- Four Layer Security – Buffer Zone/perimeter fencing, armed security at all gates, roving guards, and NCCIPS Guards (Internal NCCIPS Security Systems)
- Two separate National Power Grid feeds to SSC and three separate power feeds available to NCCIPS
- Tier III redundant (N + 1) power from two national grids with diesel generator backup
- Power infrastructure fully redundant from National Power Grid down to the racks on the floor
- Expert IT staff with a proven track record of uninterrupted service
- 24x7 facility operations staff monitoring
- Robust network infrastructure with multiple, discreet communication paths
- FE-25 clean agent fire suppression

The NASA WCF provides NASA with a mechanism to collect amounts sufficient to finance continuing operations, acquire capital assets, and adjust for prior year results of operations, in addition to normal operating expense recovery at NCCIPS. NCCIPS WCF benefits NASA and its customers by:

- Enabling funds to be collected over time and (once earned) used for new equipment and technology;
- Allowing the NSSC to incorporate a level of equipment replacement, maintenance, and technology refresh costs into client rates;
- Helping to normalize rates charged to NCCIPS clients from year-to-year, as the need for facility repairs, infrastructure upgrades, and routine equipment maintenance increases, thus enabling NCCIPS clients to maintain their appropriation funding without incurring potentially large unplanned expenses;
- Facilitating NCCIPS business opportunities for new clients; and
- Reducing the probability of hardware failure within the NCCIPS operational environment.

NCCIPS' revenue streams include funding from the NASA SSC and NSSC Centers and external Federal Agencies, including Department of Homeland Security (DHS), U.S. Army Program Executive Office - Missiles and Space (ARMY – PEO), U.S. Navy Department of Defense Supercomputing Resource Center (NDSRC), DOD HPC Modernization Program – Engineer Research and Development Center (ERDC), National Reconnaissance Office (NRO), Government Services Administration (GSA), Department of Transportation OCIO (DOT-OCIO) and Department of Housing and Urban Development (HUD). During FY 2020, NCCIPS's customer base increased which drives the rate per square footage as well as implementation and utilities costs. During FY 2021 and FY 2022, NCCIPS will continue to offer similar services as in FY 2020 with no significant scope changes anticipated.

BUDGET BY OBJECT CLASS

FY 2022 Estimated Direct Discretionary Obligations
($ millions)

Code	Object Class	Deep Space Exploration Systems	Exploration Research and Technology	Space Operations	Science	Aeronautics	STEM Engagement	Safety, Security, and Mission Services	Construction & Environmental Compliance & Restoration	Office of Inspector General	NASA Total
11.1	Full-time permanent	459	117	298	337	187	7	928	-	27	2,360
11.3	Other than full-time permanent	5	3	3	5	6	-	24	-	1	47
11.5	Other personnel compensation	2	-	2	1	-	-	50	-	1	56
11.8	Special Personal Services Payments	1	-	-	-	-	-	-	-	-	1
11.9	*Subtotal Personnel Compensation*	*467*	*120*	*303*	*343*	*193*	*7*	*1,002*	-	*29*	*2,464*
12.1	Civilian personnel benefits	164	42	107	122	68	2	376	-	10	891
13.0	Benefits to former personnel	-	-	-	-	-	-	1	-	-	1
	Total Personnel Compensation & Benefits	**631**	**162**	**410**	**465**	**261**	**9**	**1,379**	-	**39**	**3,356**
21.0	Travel & transport. of persons	14	3	15	19	7	1	16	-	1	76
22.0	Transportation of things	-	3	1,544	3	-	-	1	-	-	1,551
23.1	Rental payments to GSA	-	-	-	-	-	-	36	-	-	36
23.2	Rental payments to others	1	-	1	9	-	-	3	-	-	14
23.3	Communications, utilities & misc.	30	-	7	9	2	-	75	1	-	124
24.0	Printing & reproduction	-	-	-	1	-	-	3	-	-	4
25.1	Advisory & assistance services	473	58	106	169	15	1	259	12	-	1,093
25.2	Other services from non-Federal sources	45	77	111	259	49	6	219	38	2	806
25.3	Other purchases of goods & services from Government accounts	45	81	35	276	9	-	45	52	1	544
25.4	Operation & maintenance. of facilities	161	4	26	13	70	-	233	44	-	551
25.5	Research & development contracts	4,840	892	1,447	5,565	350	6	185	9	-	13,294
25.6	Medical care	-	-	-	-	-	-	9	-	-	9
25.7	Operation & maintenance of equipment	240	31	233	159	51	6	479	6	1	1,206
26.0	Supplies & materials	52	12	25	38	15	-	18	-	1	161
31.0	Equipment	223	10	11	39	26	-	35	1	1	346
32.0	Land & structures	65	-	5	2	7	-	32	227	-	338
41.0	Grants, subsidies, & contributions	60	92	41	905	53	118	19	-	-	1,288
42.0	Insurance claims and indemnities	-	-	-	-	-	-	3	-	-	3
	Other Object Classes	**6,249**	**1,263**	**3,607**	**7,466**	**654**	**138**	**1,670**	**390**	**7**	**21,444**
	NASA Total, Direct	**6,880**	**1,425**	**4,017**	**7,931**	**915**	**147**	**3,049**	**390**	**46**	**24,801**

**Totals may not add due to rounding*

NOTE: The table only reflects the FY 2022 request and does not include remaining funding from previous direct or supplemental appropriations.

STATUS OF UNOBLIGATED FUNDS

The table below displays actual and estimated unobligated balances of direct and reimbursable budget authority in each NASA account at the end of each fiscal year.

END OF YEAR UNOBLIGATED FUNDS SUMMARY BY APPROPRIATIONS ACCOUNT

Budget Authority ($ millions)	Unobligated Balances Sept. 30, 2020	Estimated Unobligated Balances Sept. 30, 2021	Estimated Unobligated Balances Sept. 30, 2022
Deep Space Exploration Systems	198	310	422
Space Operations	112	514	916
Space Technology	82	112	142
Science	639	758	877
Aeronautics	29	50	71
STEM Engagement	8	14	16
Safety, Security, and Mission Services	941	989	1,037
Construction and Environmental Compliance and Restoration	288	363	428
Working Capital Fund	27	18	27
Science, Space, and Technology Education Trust Fund	1	1	1
Total NASA	2,325	3,129	3,937

**Totals may not add due to rounding*

REIMBURSABLE ESTIMATES

Reimbursable agreements are agreements where the NASA costs associated with the undertaking are borne by the non-NASA partner. NASA undertakes reimbursable agreements when it has equipment, facilities, and services that it can make available to others in a manner that does not interfere with NASA mission requirements. Reimbursable agreements are executed under various legal authorities including:

- National Aeronautics and Space Act of 1958, as amended [P.L. 85–568] - Space Act Agreements (SAAs) and Enhanced Use Leasing (EUL) authority [incorporated through P.L. 108-7].
- Commercial Space Launch Act [P.L. 98-575] – authority to outsource the use of its launching facilities and services to private companies.
- National Historic Preservation Act (NHPA) [P.L. 89-665] – leasing authority for historic property.
- Government Employees Training Act [P. L. 85-507] – authority to conduct employee training for other government organizations.
- Economy Act [P.L. 31–15359] – authority for agencies to obtain supplies or services from another agency.

The agreements are transacted in three accounts (SSMS, CECR, and OIG). Most of the work is managed by a specific NASA center and performed by the relevant mission directorate or office program at the center (i.e., Aeronautics, Human Exploration and Operations, Exploration Technology, Mission Support, Office of STEM Engagement, and Office of Inspector General). Examples include the use of NASA-operated wind tunnel test facilities and rocket test stand facilities by other Government agencies or private sector users. Some larger agreements and those that involve multiple centers or mission directorates are managed by NASA Headquarters. For example, NASA serves as the acquisition agent for the *GOES* series of satellites operated by the National Oceanographic and Atmospheric Administration.

The table below presents the budget authority for NASA's reimbursable work. As most reimbursable requests to NASA do not occur until the year of execution, the FY 2021 and FY 2022 estimates are based on anticipated reimbursable agreements reported by NASA centers and Headquarters units.

REIMBURSABLE BUDGET AUTHORITY BY APPROPRIATIONS ACCOUNT

($ millions)	Actual **FY 2020**	Estimate **FY 2021**	Estimate **FY 2022**
Safety, Security, and Mission Services (including EUL and NHPA)	1,702	1,932	1,458
Construction and Environmental Compliance and Restoration (including EUL)	22	30	20
Office of Inspector General	1	2	2
Total	**1,725**	**1,964**	**1,480**

ENHANCED USE LEASING

In 2003, Congress authorized NASA to enter into leasing arrangements at two centers. In 2007 and 2008, Congress expanded that authority such that NASA may enter into leasing arrangements at all centers. Enhanced Use Leasing (EUL) is currently authorized through December 31, 2021. EUL revenues help NASA maintain critical facilities and address deferred maintenance challenges as well as support centers' revitalization plans. Additionally, NASA's EUL authority supports important relationships with industry, academia, and non-profit organizations.

After deducting the costs of administering the leases, centers are permitted to retain 65 percent of net receipt revenue. The balances are made available to NASA for use Agency-wide. These funds are in addition to annual appropriations. The table below depicts the estimated FY 2022 EUL expenses and revenues. The amounts identified under Capital Asset Account Expenditures may be adjusted between projects listed based on actual contract award. There are no civil servants funded from EUL income.

SUMMARY OF PROJECTED FY 2022 EUL ACTIVITY

FY2022 EUL Expenses and Revenues ($ Thousands)	ARC	GRC	GSFC	JPL(NMO)	MSFC	SSC	KSC	Agency	Total
Base Rent	12,086.0	48.2	54.1	100.5	254.7	88.1	2,660.3	3,000.0	18,291.9
Institutional Support Income	985.9	6.0	6.5		244.4	8.9	231.8		1,483.5
Additional Reimbursable Demand Services Requested by Lessees (including overhead)	8,081.8				0.0	18.5	30.5	749.0	8,879.8
Total Lease Income (N + E Funds Lease Project Code) - Program Year 2022	**21,153.7**	**54.2**	**60.6**	**100.5**	**499.1**	**115.5**	**2,922.6**	**3,749.0**	**28,655.2**
Institutional Support Costs	-985.9	-6.0	-6.5		-15.5	-7.0	-231.8	0.0	-1,252.7
Lease Management and Administration	-2,250.0				-106.4	-1.9		0.0	-2,358.3
Tenant Building Maintenance and Repair					0.0			-2,000.0	-2,000.0
Cost to Fulfill Reimbursable Demand Services (including overhead)	-8,081.8	0.0	0.0	0.0	0.0	-18.5	-30.5	-749.0	-8,879.8
Total Cost Associated with Leases (N Fund) - Program Year 2022	**-11,317.7**	**-6.0**	**-6.5**	**0.0**	**-121.9**	**-27.4**	**-262.3**	**-2,749.0**	**-14,490.8**
Net Revenue from Lease Activity (E Fund)- Program Year 2022	**9,836.0**	**48.2**	**54.1**	**100.5**	**377.2**	**88.1**	**2,660.3**	**1,000.0**	**14,164.4**
Projected Balance, Capital Asset Account - Prior Program Years	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Net Revenue from Lease Activity Retained at Center - Program Year 2022	**6,393.4**	**31.3**	**35.2**	**65.3**	**245.2**	**57.3**	**1,729.2**	**5,607.5**	**14,164.4**
Total Available, Capital Assest Account - All Program Years (OSI Project Codes)	**6,393.4**	**31.3**	**35.2**	**65.3**	**245.2**	**57.3**	**1,729.2**	**5,607.5**	**14,164.4**
Planned Maintenance, Various Buildings	-6,750.4						-500.0		-7,250.4
Replace Roofs on Varous Buildings									0.0
Misc. Renewable Solar Energy Expansion							-500.0		
Replace Bldg 1 main steam condensate piping									0.0
Upgrade Lighting Systems (Green Project)					-160.0				-160.0
Energy and Sustainability Upgrades, Various Buildings (Stennis)						-55.0			-55.0
Energy and Sustainability Upgrades, Various Buildings (Various Centers)								-6,934.6	-6,934.6
Capital Asset Account (OSI Project Codes) Expenditures	**-6,750.4**	**0.0**	**0.0**	**0.0**	**-160.0**	**-55.0**	**-1,000.0**	**-6,934.6**	**-14,900.0**
Capital Asset Account (OSI Project Codes) Ending Balance	**-357.0**	**31.3**	**35.2**	**65.3**	**85.2**	**2.3**	**729.2**	**-1,327.1**	**-735.6**
In Kind Activity	**175.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**39.1**	**0.0**	**214.1**

DEFINITIONS

Base Rent

Revenue collected from the tenant for rent of land or buildings lease.

Institutional Support Costs

Cost for institutional shared services, such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, as well as routine administrative support and management oversight (e.g., environmental).

ENHANCED USE LEASING

Total Lease Income

Total gross proceeds from EUL activities including expenses due to renting NASA property.

In-Kind Activity

Consideration accepted in lieu of rent payment (only applies to selected leases signed prior to January 1, 2009).

Reimbursable Demand Services

Services such as janitorial, communications, and maintenance that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

NATIONAL HISTORIC PRESERVATION ACT

The National Historic Preservation Act (NHPA) 54 U.S.C. §306121-306122 provides that:

> [(a) Notwithstanding any other provision of law, any Federal agency after consultation with the Council [the Advisory Council on Historic Preservation], shall, to the extent practicable, establish and implement alternatives for historic properties, including adaptive use, that are not needed for current or projected agency purposes, and may lease an historic property owned by the agency to any person or organization, or exchange any property owned by the agency with comparable historic property, if the agency head determines that the lease or exchange will adequately insure the preservation of the historic property.
>
> (b) The proceeds of any lease under subsection (a) may, notwithstanding any other provision of law, be retained by the agency entering into such lease and used to defray the costs of administration, maintenance, repair, and related expenses incurred by the agency with respect to such property or other properties which are on the National Register which are owned by, or are under the jurisdiction or control of, such agency. Any surplus proceeds from such leases shall be deposited into the Treasury of the United States at the end of the second fiscal year following the fiscal year in which such proceeds were received.
>
> (c) The head of any Federal agency having responsibility for the management of any historic property may, after consultation with the Advisory Council on Historic Preservation, enter into contracts for the management of such property. Any such contract shall contain such terms and conditions as the head of such agency deems necessary or appropriate to protect the interests of the United States and insure adequate preservation of historic property.]

In FY 2014, NASA established a program for leasing its historic properties based upon the NHPA authorities. Funds received from historic property leases are expended for the purposes of operating, maintaining, and managing the properties, or for authorized demolition or removal of buildings. Federal workforce costs associated with executing the leasing program are funded from annual appropriations not leasing revenues.

NATIONAL HISTORIC PRESERVATION ACT

The table below depicts the estimated amounts of anticipated NHPA expenses and revenues for FY 2022. NASA currently expects total rental income of approximately $25.2 million. Of the $25.2 million in total rental income, approximately $7.0 million represents net revenue from lease activities. The net revenue amount of $7.0 million will be used for historic building maintenance and repairs at Ames Research Center (ARC).

FY2022 NHPA Expenses and Revenues ($ thousands)	Ames Research Center
Base Rent	15,500.0
Security Deposit (Reissue)	2,000.0
Institutional Support Income	-
Cost to Fulfill Reimbursable Demand Services	7,713.4
Total Rental Income	**25,213.4**
Institutional Support Costs	(8,038.1)
Security Deposit (Reissue)	(2,000.0)
Lease Management and Administration	(435.0)
Reimbursable Demand Services Requested by Lessees	(7,713.4)
Total Cost Associated with Leases	**(18,186.5)**
Net Revenue from Lease Activity	**7,026.9**
Unobligated Proceeds Prior Years (as of 9/30/2021)	**-**
Deferred Maintenance for Buildings 2, 10, 15, 16, 17, 19, 20, 25, 26, N200, N226, N227, N234, N238 & N243	(1,713.6)
Renovate Building 20, Phase 2 of 3	(5,278.3)
Section 106 Consultation with SHPO	(35.0)
Capital Asset Account Expenditures	**(7,026.9)**
Capital Asset Account Ending Balance	**-**
In Kind Activity	**-**

NATIONAL HISTORIC PRESERVATION ACT

DEFINITIONS

Base Rent

Revenue collected from the tenant for rent of land or buildings.

In-Kind

Consideration accepted in lieu of rent payment.

Institutional Support Costs

Cost for institutional shared services such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, as well as routine administrative support and management oversight (e.g., environmental).

Reimbursable Demand Services

Services such as janitorial, communications, and maintenance that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

Total Rental Income

Total gross proceeds from NHPA activities including expenses due to renting NASA property.

BUDGET FOR MICROGRAVITY SCIENCE

The Human Exploration and Operations Mission Directorate (HEOMD) and Science Mission Directorate (SMD) support research which takes advantage of the unique environment of reduced gravity on the International Space Station (ISS). ISS Research is conducted in two broad categories: Exploration ISS Research and Non-Exploration ISS Research.

$ in millions	FY 2020 Actual	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Exploration ISS Research (includes SMD funding)	$295	$268	$266	$272	$280	$290	$293
Non- Exploration ISS Research (includes SMD funding)	$185	$148	$148	$142	$144	$149	$154
Total	**$480**	**$415**	**$415**	**$413**	**$425**	**$439**	**$447**
% of Non-Exploration to Total (includes SMD funding)	39%	36%	36%	34%	34%	34%	34%

The amounts included for FY 2020 reflect actuals. FY 2021 through FY 2026 are reflective of NASA out-year planning.

FY 2020 reflects funding amounts specified in Public Law 116-093, Consolidated Appropriations Act, 2020, as adjusted by NASA's FY 2021 Operating Plan.

Exploration ISS Research

Exploration ISS Research supports the Agency's need for improved knowledge about working and living in space to enable future long-duration human exploration missions. The Human Research Program provides research results that reduce risks to crew health and performance from prolonged exposure to reduced gravity, space radiation, and isolation during exploration missions. Research on the ISS is mitigating risks to humans in space and on Earth by conducting research in human health countermeasures; space human factors and habitability; behavioral health and performance; and exploration medicine, tools, and technologies. ISS Research investigates the underlying gravity-dependent phenomena in areas vital to the design of future space vehicles and systems: fire prevention, detection, and suppression; boiling and multiphase flow; capillary phenomena; and the response to the space environment of microbes, plants, and higher lifeforms. These applied research investigations will provide the necessary data for the future design of the following technology areas: life support systems, propellant storage, power generation, thermal control, and advanced environmental monitoring and control. Multi-User System Support (MUSS) is responsible for the integration of all ISS payloads including NASA, international partners, and non-NASA users and supports both Exploration and Non-Exploration ISS Research. This includes coordinating payload completion schedules, ISS mission schedules, and the space available on the launch vehicles. The Exploration ISS Research category in the table above includes funding for MUSS.

Non-Exploration ISS Research

Both HEOMD and SMD provide funding for ISS research. More than 15 percent of these funds support ground-based, free-flyer, and ISS life and physical science research that is not directly related to supporting the human space exploration program, in accordance with Section 204 of the NASA Authorization Act of 2005. The purpose of non-exploration ISS research is to support space-based basic and applied scientific research that can be advanced significantly through the use of the microgravity environment and provide broad national benefits. Non-exploration research aboard ISS advances knowledge in the fields: physiological research, fluid physics, combustion science, atomic physics, cell science, materials science, and plant research. This research helps to sustain U.S. scientific expertise and capability in microgravity research and to identify new areas for participation by commercial entities or other government agencies. The Non-Exploration ISS Research category in the table above includes funding for the SMD Biological and Physical Sciences Division, the ISS National Laboratory, the Alpha Magnetic Spectrometer (AMS), and MUSS. AMS is a particle physics and astrophysics experiment on the ISS that is searching for dark matter, anti-matter, and strange matter.

BUDGET FOR SAFETY OVERSIGHT

The following table provides the safety oversight budget request. This includes the Agency-wide surveillance functions as well as the project specific safety, reliability, maintainability, and quality assurance elements embedded within individual projects. NASA does not have a single safety oversight budget line item, but instead amounts are embedded in program, project, and mission support budgets.

BUDGET SUMMARY FOR SAFETY OVERSIGHT

	Actual	Estimate	Request				
Budget Authority ($ millions)	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Safety and Mission Assurance	50.0	47.9	51.0	52.1	53.2	54.3	55.4
Institutional Operational Safety	37.7	37.7	37.4	37.5	37.5	37.6	37.6
SMA Technical Authority	52.8	52.8	53.3	53.3	53.3	53.4	53.4
Agency-Wide Safety Oversight	**140.5**	**138.4**	**141.8**	**142.9**	**144.0**	**145.3**	**146.5**
Program Specific*	**300.0**	**300.0**	**300.0**	**300.0**	**300.0**	**300.0**	**300.0**
NASA Total, Safety**	**440.5**	**438.4**	**441.8**	**442.9**	**444.0**	**445.3**	**446.5**

* *Estimated values*
***Totals may not add due to rounding*

Agency-Wide Safety Oversight – Agency-level programs and activities that support the overarching NASA Safety and Mission Success program.

Safety and Mission Assurance – The Safety and Mission Assurance (S&MA) program administers and refines the pertinent policies, procedural requirements, and technical safety standards. The program participates in forums that provide advice to the Administrator, Mission Directorates, Program Managers, and Center Directors who are ultimately accountable for the safety and mission success of all NASA programs, projects, and operations. Specific program responsibilities include, but are not limited to, managing NASA's Orbital Debris program, NASA's Electronic Parts program, and the NASA Safety Center. The budget for the Safety and Mission Assurance is part of the Agency Technical Authority (ATA) program under the Safety, Security, and Mission Services (SSMS) mission account.

Institutional Operational Safety – NASA's Institutional Operational Safety program is driven by the Office of Occupational Safety and Health Administration (OSHA) 29 CFR 1960, OSHA Standards, NASA Procedural Requirement (NPR) 8715.1A, NASA Occupational Safety and Health Programs, NPR 8715.3D, and NASA's General Safety Program Requirements. The program includes: risk management, safety training, safety awareness, construction safety, the voluntary protection program, safety metrics and trend analysis, contractor insight/oversight, support to safety boards and committees, support to the emergency preparedness and fire safety programs, aviation safety, explosives and propellants safety, nuclear safety, radiation safety, confined space entry, fall protection, lifting devices, pressure vessel safety, hazard reporting and abatement systems, cryogenic safety, electrical safety requirements (lock out/tag out), facility systems safety, institutional safety policy development, visitor and public safety, institutional safety engineering, and a mishap prevention program including a reporting system and investigations. The Institutional Operational Safety program requires significant federal state and local coordination. The budget for Institutional Operation Safety is part of the Center Engineering, Safety, and Operations (CESO) program under the SSMS mission account.

BUDGET FOR SAFETY OVERSIGHT

S&MA Technical Authority – S&MA Technical Authority provides independent oversight of programs and projects in support of safety and mission success and is a key part of NASA's overall system of checks and balances. The S&MA Technical Authority program includes travel and labor only for all S&MA supervisors, branch chiefs or above and designated deputies. In addition, where the principal job function of a non-supervisory S&MA person consists of rendering authoritative decisions on S&MA matters relating to the design or operation of a program or project, that person's salary is included. Often, these positions are the lead S&MA managers for large programs where the decision-making process is nearly a full-time demand. This category does not include salaries for individuals who only occasionally work on an authority task; however, the program budget does include travel funds in direct support of these tasks when needed. The budget for S&MA Technical Authority is part of the CESO program under the SSMS mission account.

Program Specific – Program specific S&MA costs are included in individual project budgets and are not reflected in the table above. These costs include the technical and management efforts of directing and controlling the safety and mission assurance elements of the project. This incorporates the design, development, review, and verification of practices and procedures and mission success criteria intended to assure that the delivered spacecraft, ground system, mission operation, or payload meets performance requirements and function for their intended lifetimes.

PHYSICIANS' COMPARABILITY ALLOWANCE

Department and component:

National Aeronautics and Space Administration (NASA)

Purpose: The purpose of this document is to describe the agency's plan for implementing the Physicians' Comparability Allowance (PCA) program. Per 5 CFR 595.107, the Office of Management and Budget (OMB) must approve this plan prior to the agency entering into any PCA service agreement. Changes to this plan must be reviewed and approved by OMB in accordance with 5 CFR 595.107.

Reporting: In addition to the plan, each year, components utilizing PCA will include their PCA worksheet in the OMB Justification (OMBJ), typically in September. OMB and the Office of Personnel Management (OPM) will use this data for budget development and congressional reporting.

Plan for Implementing the PCA program:

1) Identify the categories of physician positions the agency has established are covered by PCA under § 595.103. Please include the basis for each category. If applicable, list and explain the necessity of any additional physician categories designated by your agency (for categories other than I through IV-B). List Any Additional Physician Categories Designated by Your Agency: Pursuant to 5 CFR 595.107, any additional category of physician receiving a PCA, not covered by categories I through IV-B, should be listed and accompanied by an explanation as to why these categories are necessary.

Number of Physicians Receiving PCAs by Category (non-add)	**Category of Physician Position**	**Covered by Agency** (mark "x" if covered)	**Basis for Category**
21	Category I Clinical Position	x	Difficulty recruiting and retaining: Physicians in this category perform both operational medical support that is mission-critical and provide medical subject matter expertise in the development of future programs, including Artemis, Gateway, and the Lunar Lander. Much of the work they do is inherently governmental, as it requires establishing requirements, both for spaceflight programs and for commercial offers in NASA procurements for spaceflight capabilities. These specialized physicians are often called on to evaluate commercial and international partner proposals for medical capabilities. These physicians also provide leadership in NASA's multilateral medical operations, representing NASA in multilateral fora. Civil Servant physicians are also required to provide oversight of key contract functions that support mission-critical activities.
0	Category II Research Position	N/A	N/A

PHYSICIANS' COMPARABILITY ALLOWANCE

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Covered by Agency (mark "x" if covered)	Basis for Category
0	Category III Occupational Health	N/A	N/A
0	Category IV-A Disability Evaluation	N/A	N/A
6	Category IV-B Health and Medical Admin.	x	Difficulty recruiting and retaining: Management physicians play a critical role in ensuring NASA's ability to meet its' ambitious goals of returning humans to the Moon in 2024, expanding commercial access to space, and eventually sending humans out into the solar system. These physicians occupy positions that are primarily comprised of inherently governmental activities, including: supervision of other civil servant physicians; oversight of significant projects and programs, such as the Johnson Space Center (JSC) Clinic; providing independent oversight of NASA's health and medical activities through the Health and Medical Technical Authority; developing and assessing the risk associated with NASA standards that are applicable to all human spaceflight programs and NASA's commercialization activities; and serving as Chief Medical Officer at the Agency, Center, and Program levels to make ultimate determinations that affect Agency action and resources.

2) Explain the recruitment and retention problem(s) for each category of physician in your agency (this should demonstrate that a current need continues to persist). § 595 of 5CFR Ch. 1 requires that an agency may determine that a significant recruitment and retention problem exists only if all of the following conditions apply:
- Evidence indicates that the agency is unable to recruit and retain physicians for the category;
- The qualification requirements being sought do not exceed the qualifications necessary for successful performance of the work;
- The agency has made efforts to recruit and retain candidates in the category; and
- There are not a sufficient number of qualified candidates available if no comparability allowance is paid.

PHYSICIANS' COMPARABILITY ALLOWANCE

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Recruitment and retention problem
21	Category I Clinical Position	NASA physicians who receive PCA are located at JSC in Houston, Texas; Goddard Space Flight Center in Greenbelt, Maryland; and Headquarters in Washington D.C. Physician salaries in the Houston area and across the country continue to rise and the General Schedule (GS) salaries that JSC may offer are consistently lower than private sector salaries and those offered by our prime contractors. According to the 2019 Medscape Physician Compensation Report, the average physician compensation in the South-Central geographical area was $300,000. In 2020, the maximum GS salary payable for GS employees is $166,500. In addition, significantly higher physician pay scales under Title 38 in the Veterans Administration (VA) and Department of Defense (DoD) provide a potential incentive for NASA physicians to continue their government service and receive higher pay by transferring to those agencies. Further, NASA is now competing with commercial space companies that are attempting to expand their human spaceflight capabilities and need physicians experienced in human spaceflight. NASA physicians are supporting more critical program activities simultaneously than at any time in the past. This includes supporting the NASA Health and Medical Technical Authority, International Space Station crew (operating 24/7), Commercial Crew, Orion, Gateway, and Lunar activities; the active astronaut corps; and the operation of the Lifetime Surveillance of Astronaut Health program, which includes all retired astronauts. The implementation of the TREAT Act means that they will also be providing life-long care for former astronauts. Physicians who are board-certified in Aerospace Medicine and who have operational experience are a rare and valuable commodity. There is a shortage of aerospace medicine specialists nationwide and other government and military organizations are actively recruiting qualified physicians. Many of the JSC physicians with aerospace medicine training and experience are also board-certified in other clinical specialties including internal medicine, emergency medicine, and psychiatry. The double board-certified physicians are an especially rare commodity and their dual areas of expertise are extraordinarily valuable to NASA. The training period after medical school, including on-the-job training at NASA after hire, is nearly a full decade. Retaining such physicians, after they are hired and have completed NASA Flight Surgeon training requirements, is critical to the success of the human space flight program. All of these factors affect NASA's ability to attract and retain qualified physicians. Without offering PCA, NASA would not be able to recruit and retain qualified physicians.

PHYSICIANS' COMPARABILITY ALLOWANCE

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Recruitment and retention problem
0	Category II Research Position	N/A
0	Category III Occupational Health	N/A
0	Category IV-A Disability Evaluation	N/A
6	Category IV-B Health and Medical Admin.	NASA faces challenges recruiting and retaining physicians who are willing and able to serve in physician management and leadership roles. Because physicians are at the top of the GS pay scale, and previously, NASA had only one PCA category, there has been no pay incentive to accompany the increase in responsibility and authority. In 2019, NASA placed four physicians who occupy significant medical management and leadership positions into a separate PCA category that provides the opportunity for additional pay. Physician leaders are in even greater demand than skilled aerospace physicians. Additional PCA for those holding these critical roles helps to attract the best physicians to these roles and retain them in leadership and management positions. Over the past few years, NASA has been unable to fill critical branch and division leadership positions that require physicians, and, as a result, has been unable to develop a robust succession management plan to ensure physician leaders are developed and retained to fill critical Agency roles (e.g., Chief Medical Officer, Chief Health and Medical Officer). Providing enhanced PCA for those physicians willing to step up to roles of increased responsibility will encourage young physicians to apply for these challenging roles and ensure a cadre of skilled physician leaders for the future.

3) Explain how the agency determines the amounts to be used for each category of physicians.

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Basis of comparability allowance amount
21	Category I Clinical Position	The PCA amounts paid are the minimum needed to deal with the recruitment and retention problems. The amount $22,000 - $24,000 is offered to many of our physicians in this category (or

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Basis of comparability allowance amount
		$14,000 per regulations, depending on tenure), and we have determined that amount is justified via two means: (1) Market Data relevant to the most applicable field of practice, Emergency Medicine, includes the following: - According to a March 2019 publication by Doximity, a reputable source, Single Board-Certified Emergency Medical Physicians in America make an average of $336,000 per year. - According to a September 2018 publication by the Houston Medical Journal, a reputable source, the average salary for an Emergency Medical Physician in the Houston Metropolitan Area makes $350,000 per year. Double Board-Certified physicians can easily make more. References to that data include: Glassdoor Inc., (2018, August); Kane, L., MA. (2018, April); and Medscape Physician Compensation Report 2018 (2018, July). (2) NASA Centers have had success hiring candidates with the offers of $14,000 - $24,000 of PCA; therefore, a higher amount of PCA would not be justifiable for physicians in this category.
0	Category II Research Position	Currently no physician positions in this category
0	Category III Occupational Health	Currently no physician positions in this category
0	Category IV-A Disability Evaluation	Currently no physician positions in this category
6	Category IV-B Health and Medical Admin.	The PCA amounts paid are the minimum needed to deal with the recruitment and retention problems. Similar research and rationale went into making initial offers for PCA for Physicians in this category; however, we have determined that $14,000 - $24,000 has not been satisfactory in recruiting NASA physicians to take on the additional work burdens of Health and Medical Administration duties and retaining them in such a position. The maximum amount of PCA Allowed by law, $30,000 will be required to satisfy this recruitment and retention effort.

4) Does the agency affirm that the PCA plan is consistent with the provisions of 5 U.S.C. 5948 and the requirements of § 595 of 5 CFR Ch. 1?

Yes

IT STATEMENT OF AFFIRMATION

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

Reply to Attn of: **Office of the Chief Information Officer**

TO: NASA Chief Financial Officer, Steve Shinn

FROM: NASA Chief Information Officer, Jeff Seaton

SUBJECT: Fiscal Year 2022 NASA IT Budget Justification Statement of Affirmation

As required by the Office of Management and Budget (OMB) Circular A-11 and the Federal Information Technology Acquisition Reform Act (FITARA), and based on the information presented from the Offices of the Chief Information Officer, and on insights into the current Information Technology (IT) Portfolio over which the Chief Information Officer (CIO) has direct budget authority, this letter affirms the following:

1. The CIO's common baseline rating for Element D ("CIO reviews and approves major IT Investment portion of budget request") is fully implemented;
2. The Chief Financial Officer (CFO) and the CIO jointly affirm that the CIO had a significant role in reviewing planned IT support for major program objectives;
3. Significant increases and decreases in IT resources are reflected in the Agency's current services baseline budget submission for those items over which the CIO has direct budget authority;
4. The CIO has reviewed and approved the use of incremental development for all investments submitted as major investments in the IT Portfolio;
5. The CIO holds the role of NASA's Senior Agency Official for Privacy (SAOP) and has therefore reviewed the IT Budget submission to ensure that privacy requirements and any associated costs, are explicitly identified and included with respect to any IT resources that will be used to create, collect, use, process, store, maintain, disseminate, disclose, or dispose of personally identifiable information (PII);
6. Agency budget request funding levels will include expected contributions to the E-Gov Line-of-Business initiatives;
7. The CIO collaborated with the Information Technology Council (ITC) comprised of Missions, Centers and Mission Support including the CFO on the IT Budget submission;

IT STATEMENT OF AFFIRMATION

8. The IT Portfolio (OMB Circular A-11, Section 55.6 and as described herein) includes appropriate estimates of all IT resources included in the President's Budget; and

9. The CIO has reviewed and had significant input in approving all IT Investments included in the President's Budget.

STEPHEN SHINN Digitally signed by STEPHEN SHINN Date: 2021.05.14 08:34:19 -04'00'

Stephen A. Shinn
Chief Financial Officer (Acting)

JEFFREY SEATON Digitally signed by JEFFREY SEATON Date: 2021.05.10 22:27:55 -04'00'

Jeffrey M. Seaton
Chief Information Officer

BUDGET FOR PUBLIC RELATIONS

The NASA budget for Communications is funded within the Safety, Security, and Mission Services account under Mission Services & Capabilities, Mission Enabling Services. These budgets include the strategic planning, coordination, and consistency of information disseminated to the public through the news media, digital interfaces, and NASA websites. Content includes support for internal and external communications; public inquiries; NASA TV; the nasa.gov portal (see: http://www.nasa.gov); Freedom of Information Act requests; history, archival, and artifact management; public affairs/public relations; Center newsletters; guest operations (including bus transportation) and other multimedia support.

NASA COMMUNICATIONS BUDGET SUMMARY, BY CENTER

	Actual	Estimate	Request				
Budget Authority ($ millions)	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
ARC	4.6	4.5	4.5	4.5	4.5	4.5	4.5
AFRC	1.3	1.6	1.6	1.6	1.6	1.6	1.6
GRC	4.5	4.7	4.8	4.8	4.8	4.8	4.8
GSFC	4.6	5.6	5.8	5.8	5.8	5.8	5.8
HQ	14.4	12.1	20.6	21.8	23.0	24.2	25.5
JSC	5.2	7.5	5.1	5.1	5.1	5.1	5.1
KSC	10.3	9.1	9.2	9.2	9.2	9.2	9.2
LaRC	2.7	3.2	3.2	3.2	3.2	3.2	3.2
MSFC	5.1	5.1	5.2	5.2	5.2	5.2	5.2
SSC	1.8	1.5	1.5	1.5	1.5	1.5	1.5
NASA Total	**54.5**	**54.9**	**61.6**	**62.8**	**64.0**	**65.2**	**66.5**

Public Affairs per baseline service level definition as part of the Safety, Security, and Mission Services Budget.

**Totals may not add due to rounding.*

CONSULTING SERVICES

NASA uses paid experts and consultants to provide advice and expertise beyond that which is available from its in-house civil service workforce. Management controls ensure that there is ample justification for consulting services before these services are obtained. Much of the Agency's expert and consultant support is for the NASA Advisory Council and the Aerospace Safety Advisory Panel. NASA uses experts and consultants to provide expertise on the selection of experiments for future space missions. The use of these experts and consultants provides the Agency with an independent view that promotes the selection of experiments likely to have the greatest scientific merit. Other individuals provide independent views of technical and functional problems to offer senior management a wide range of information to support decision-making. Historically, each mission directorate engages a few consultants to primarily support programmatic and Aerospace Safety Advisory Panel issues.

NASA CONSULTING SERVICES BUDGET SUMMARY

	Actual	Estimate	Request
(Cost in $ millions)	**FY 2020**	**FY 2021**	**FY 2022**
Number of Paid Experts and Consultants	27	27	27
Annual FTE Usage	6.5	6.5	6.5
Salaries	$0.8	$0.8	$0.8
Benefits Costs	$0.2	$0.2	$0.2
Travel Costs	$0.2	$0.2	$0.2
Total Costs	**$1.2**	**$1.2**	**$1.2**

FY 2020 are actual obligations. FY 2021 and FY 2022 are estimated Budget Authority

A broader definition of consulting services could include the total of the Advisory and Assistance Services object class as shown in the Supporting Data - Budget by Object Class section of this volume. Advisory and Assistance Services includes: (1) Quality Control, Testing, & Inspection Services; (2) Management and Professional Support Services; (3) Studies, Analysis, & Evaluations; (4) Engineering and Technical Services; and (5) IT Services.

	Actual	Estimate	Request
(Cost in $ millions)	**FY 2020**	**FY 2021**	**FY 2022**
Quality Control, Testing & Inspection Services	$45.0	$46.2	$48.9
Management and Professional Support Services	$750.4	$769.8	$815.3
Studies, Analysis, & Evaluations	$85.2	$87.4	$92.6
Engineering and Technical Services	$7.0	$7.2	$7.6
IT Services	$118.4	$121.4	$128.6
Total Costs, Advisory & Assistance Services	**$1,006.0**	**$1,032.0**	**$1,093.0**

CONSULTING SERVICES

DEFINITIONS

Consultant - A person who can provide valuable and pertinent advice generally drawn from a high degree of broad administrative, professional, or technical knowledge or experience. When an agency requires public advisory participation, a consultant also may be a person who is affected by a particular program and can provide useful views from personal experience.

Expert - A person who is specially qualified by education and experience to perform difficult and challenging tasks in a particular field beyond the usual range of achievement of competent persons in that field. An expert is regarded by other persons in the field as an authority or practitioner of unusual competence and skill in a professional, scientific, technical, or other activity.

These definitions are located under 5 CFR 304.102. The appointments are made under 5 U.S.C. 3109, and the use of this authority is reported to Office of Personnel Management (OPM).

E-GOV INITIATIVES AND BENEFITS

E-GOVERNMENT FUNDING CONTRIBUTIONS AND SERVICE FEES BY INITIATIVE

NASA will provide funding contributions in FY 2022 for each of the following E-Government initiatives:

Initiative	2022 Contributions (Includes In- Kind) ($ In Dollars)	2022 Service Fees* ($ In Dollars)
E-Rulemaking	-	12,197
Grants.gov	75,000	-
E-Training	-	1,583,625
Recruitment One-Stop	-	129,375
Enterprise HR Integration	-	357,500
E-Payroll	-	3,950,075
E-Travel	-	89,520
Integrated Award Environment (IAE)	-	719,644
Financial Management LoB	124,236	-
Human Resources Management LoB	68,478	-
Geospatial LoB	225,000	-
Budget Formulation and Execution LoB**	120,000	-
Federal PKI Bridge	-	169,792
Hiring Assessment	66,000	-
Unique Entity Identifier Implementation (UEI)	328,572	-
NASA Total	**$1,007,286**	**$7,011,728**

**Service fees are estimates as provided by the E-Government initiative Managing Partners*

***Final FY 2022 commitments have yet to be finalized by Managing Partners (OMB MAX)*

After submission of the budget, NASA will post FY 2022 Exhibit 300 IT business cases on the IT Dashboard located at: https://www.itdashboard.gov

The E-Government initiatives serve citizens, businesses, and federal employees by delivering high-quality services more efficiently at a lower price. Instead of expensive "stove-piped" operations, agencies work together to develop common solutions that achieve mission requirements at a reduced cost, which makes resources available for higher priority needs. Benefits realized by NASA through these initiatives in FY 2022 are described below:

e-Rulemaking (Managing Partner EPA) FY 2022 Benefits

NASA has benefited from the e-Rulemaking initiative by being able to better provide the public with one-stop access to the Agency's information on rulemakings and non-rulemaking activities via the Regulations.gov website (see: https://www.regulations.gov/).

NASA uses the Federal Docket Management System (FDMS) to post its rulemakings so that the public can gain access to review and comment on these rulemakings. NASA relies on Regulations.gov to retrieve public comments on its rulemakings. NASA's use of the FDMS and Regulations.gov substantially improves the transparency of its rulemaking actions and increases public participation in the regulatory process. Direct budget cost savings and cost avoidance has resulted from the FDMS and Regulations.gov.

Grants.gov (Managing Partner HHS) FY 2022 Benefits

In addition to the federal requirement for all grant-issuing agencies to, at a minimum, post a synopsis of all new grant and cooperative agreement funding opportunities to Grants.gov (see: https://www.grants.gov/), the Grants.gov initiative benefits NASA and its grant programs by providing a single location with broader exposure to publish grant and cooperative agreement funding opportunities and application packages. Posting internally, NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES), as well as externally (Grants.gov), makes the process easier for applicants to apply for funding with multiple agencies. All 26 major Federal grant-making agencies post 100 percent of their synopses for discretionary funding opportunity announcements on Grants.gov.

In addition, Grants.gov provides a single site for the grantee community to apply for grants using a standard set of forms, processes, and systems. This gives grantees greater access and ability to apply for Federal funding. Through the continued use of Grants.gov, NASA can reduce operating costs associated with online grant posting and application evaluation. Additionally, the Agency is able to improve operational effectiveness through the use of Grants.gov by increasing data accuracy and reducing processing cycle times.

e-Training (Managing Partner OPM) FY 2022 Benefits

The e-Training initiative provides access to premier electronic training systems and tools that support the training and development of the Federal workforce. The initiative supports Agency missions through efficient one-stop access to e-Training products and services. The availability of an electronic training environment enhances the ability of the Federal government and NASA to attract, retain, manage, and develop highly skilled professionals needed for a flexible and high-performing government workforce.

The e-Training initiative benefits NASA by reducing redundancies and achieving economies of scale in the purchase, development, and deployment of e-learning content and in the management of learning technology infrastructure. The System for Administration, Training, and Educational Resources at NASA (SATERN) is a web-based talent management tool that serves as NASA's training system of record for over 100K active civil servants and contractor accounts tracked within the system. This centralized approach allows NASA to reduce and leverage training costs by eliminating unique systems, standardizing training processes, and maintain valid data. In 2018 NASA migrated SATERN to a software as a service (SaaS) cloud hosted solution.

Through SATERN, employees can view required training, launch online content, view training history, and self-register for approved courses and conferences. In addition, the system allows NASA officials to identify groups and individuals who have not met basic training requirements and ensure accountability for mission-critical and Federally mandated training and development. SATERN also offers employees access to career planning tools, individual development plans, and competency management assistance. Currently, SATERN offers learners access to more than 2,500 online courses and 18,000 online books and training videos. SATERN is available at all times and can be accessed from work or at home.

E-GOV INITIATIVES AND BENEFITS

Recruitment One-Stop (Managing Partner OPM) FY 2022 Benefits

USAJOBS simplifies the Federal Job Search Process for Job Seekers and Agencies. The USAJOBS.gov website (see: https://www.usajobs.gov/) provides a place where citizens can search for employment opportunities throughout the Federal Government. USAJOBS is a fully operational, state-of-the-art recruitment system that simplifies the Federal job search process for job-seekers and agencies. Through USAJOBS.gov users have access to:

- A centralized repository for all competitive service job vacancies;
- Job vacancies;
- A resume repository used by agencies to identify critical skills;
- A standardized online recruitment tool and services;
- A standard application process; and
- Intuitive job searches including e-mail notifications for jobs of interest.

Integration with Recruitment One-Stop allows NASA to better attract individuals who can accomplish the Agency's mission. The USAJOBS interface allows job-seekers to view and apply for all NASA employment opportunities, as well as those from other Federal agencies.

In 2005, NASA adopted the USAJOBS resume as the basic application document for all NASA positions, except for astronaut positions. To date NASA has not identified any specific savings, either in terms of budgeted savings or cost avoidance. Although the Agency believes that implementation of Recruitment One-Stop has resulted in significant intangible benefits in terms of providing better vacancy information to applicants, it has not resulted in any specific cost savings to NASA. The numerous intangible benefits Recruitment One-Stop provides to NASA and other agencies include:

- Decreasing hiring time for managers;
- Providing an integrated solution to agency applicant assessment systems;
- Providing a cost-effective marketing and recruitment tool;
- Realizing cost savings over commercial job posting boards;
- Reducing the delay associated with filling critical agency vacancies; and
- Enhancing competition with the private sector for the best and brightest talent for Federal service.

Enterprise HR Integration (Managing Partner OPM) FY 2022 Benefits

The Enterprise HR Integration (EHRI) Program supports the strategic management of human capital by providing agency customers access to timely and accurate Federal workforce data. In support of this objective, EHRI has the following goals: 1) Streamline and automate the exchange of Federal employee human resources (HR) information Government wide; 2) Provide comprehensive knowledge management and workforce analysis, forecasting, and reporting across the Executive Branch; 3) Maximize cost savings captured through automation; and 4) Enhance retirement processing throughout Executive Branch.

A key initiative of EHRI is the electronic Official Personnel Folder (eOPF), a web-based application capable of storing, processing, and displaying the OPFs of all current, separated, and retired Federal Employees. Specific EHRI/eOPF benefits to NASA include improved convenience in searching for information, better security and safety for electronic files, decreased costs, streamlined business processes, and the ability to have a central repository of OPF records for the Agency. NASA deployed the eOPF capability of electronic transfer of eOPFs between agencies in FY 2010. Specific NASA employee benefits include secure online access to OPFs, automatic notification when documents are added, exchange of retirement and HR data across agencies and systems, and the elimination of duplicate and repetitive personnel data in personnel folders. NASA completed its implementation to eOPF in March 2008, and transitioned personnel actions processing to the NASA Shared Service Center.

E-Payroll FY 2022 Benefits

The E-Payroll Initiative standardizes and consolidates government-wide Federal civilian payroll services and processes by simplifying and standardizing HR/payroll policies and procedures and better integrating payroll, HR, and finance functions. Since 2004, the Department of Interior (DOI) has served as NASA's payroll provider. DOI’s system (Federal Personnel and Payroll System [FPPS]) processes NASA's HR and Payroll transactions and supplies all key delivery aspects of its payroll operation functions. The E-Payroll Initiative benefits NASA by permitting the Agency to focus on its mission-related activities rather than on administrative payroll functions. Payroll processing costs are reduced through economies of scale and avoiding the cost of duplicative capital system modernization activities. The initiative also promotes standardization of business processes and practices and unified service delivery.

E-Travel (Managing Partner GSA) FY 2022 Benefits

NASA completed migration of its travel services to Electronic Government Travel System 2 (ETS2) - Concur Government Edition (CGE) (formerly HP Enterprise Services [FedTraveler]). Completed in 2014, this migration has allowed NASA to provide more efficient and effective travel management services. ETS2 is a streamlined, adaptable, world-class travel management service that continually applies commercial best practices to realize travel efficiencies and deliver a transparent, accountable, and sustainable service that yields exceptional customer satisfaction.

Integrated Award Environment (Managing Partner GSA) FY 2022 Benefits

The Integrated Award Environment (IAE) initiative is designed to support a common, secure business environment which facilitates and supports the cost-effective acquisition of and payment for goods and services; effective management of Federal acquisition and assistance awards; and consistent transparency into Federal awards. The IAE services enable NASA to do business with industry, whether it is through contracts, grants or loans, in a smart, streamlined, shared services platform. Services range from entity management, pre-award, post award, and common services (e.g., data governance, security, hosting, help desk, single sign-on, and search). Use of the IAE common services allows agencies to focus on specific needs (e.g., strategy, operations, and management), while leveraging shared services for common functions. Furthermore, use of a Government-wide business focused service environment reduces funding and resources for technical services and support for acquisition systems originally housed by individual agencies.

Through adoption of the tools and services provided by IAE, NASA improves its ability to make informed and efficient purchasing decisions and allows it to replace manual processes. If NASA did not use IAE systems, the Agency would need to build and maintain separate systems to record vendor and contract information and to post procurement opportunities. Agency purchasing officials would not have access to databases of important information from other agencies on vendor performance and could not use systems to replace paper-based and labor-intensive work efforts.

E-GOV INITIATIVES AND BENEFITS

Integrated Award and Environment – Loans & Grants FY 2022 Benefits

All agencies participating in the posting and/or awarding of Contracts and Loans & Grants are required by the Federal Funding Accountability and Transparency Act (FFATA) of 2006 and the Digital Accountability and Transparency Act of 2014 (DATA Act) reporting requirements to disclose award information on a publicly accessible website. On December 14, 2007, OMB launched USASpending.gov (see: http://www.USASpending.gov) to meet the FFATA statutory requirements. NASA analyzes the past and present total funding amounts of each proposing entity, as well as its total number of awards to assist in assessing each grant proposer's risk level and score during the 2 Code of Federal Regulations (CFR) 200 required pre-award risk assessment process. This information is submitted and housed in USASpending.gov by funding agency. Understanding the total dollar amounts managed and the number of awards provides insight on a proposer's experience with managing federal funds.

Federal PKI Bridge - FY 2022 Benefits

The Federal Public Key Infrastructure (FPKI) is the primary, secure mechanism that allows for electronic business transactions across Government and between Government and industry. It is the backbone and trust anchor for HSPD-12 and PIV cards and is critical to enabling cyber security via identity management. The FPKI enables secure physical and logical access using strong credentials, such as the PIV card, and allows NASA documents to be digitally signed, sent, encrypted, and archived in digital media without fear that they will be compromised, spoofed, or altered. A number of core government-wide documents mandate NASA's use of the FPKI.

LINES OF BUSINESS

Financial Management LoB (Managing Partners DOE and DOL) FY 2022 Benefits

NASA's contribution to the FM Line of Business (LoB) supports efforts to transform Federal financial management, reduce costs, increase transparency, and improve delivery of agencies' missions by operating at scale, relying on common standards, shared services, and using state-of-the-art technology. NASA benefits from the FM LoB because it provides a forum in which Federal agencies can share information and weigh pros and cons of various initiatives (e.g., shared services). A shared services solution may be an alternative considered by NASA as part of its financial system improvements.

Human Resources Management LoB (Managing Partner OPM) FY 2022 Benefits

The HR LoB vision is to create government-wide, modern, cost-effective, standardized, and interoperable HR solutions to provide common core functionality to support the strategic management of Human Resources through the establishment of Shared Service Centers (SSCs).

NASA works in partnership with one of the approved service providers, the Department of Interior's Business Center (IBC). Through this partnership, NASA shares and receives "best-in-class" HR solutions. The IBC delivers NASA-developed solutions to their customer agencies, enabling improved efficiencies and system integrations at a fraction of the cost and delivery time of similar solutions that could have been produced by the Interior Business Center. NASA achieves the benefits of "best- in-class" HR solutions through the implementation and integration of IBC and NASA-developed HR solutions. NASA's participation in the HR LoB provides the Agency opportunities to implement modern HR solutions and benefit from government-wide strategic HR management best practices. NASA participates in the ongoing development of a 10-year Federal Human Resources Strategic Plan with the HR LoB managing partner (OPM) and member agencies.

Geospatial LoB (Managing Partner DOI) FY 2022 Benefits

The Geospatial LoB was sunset when OMB released the Federal IT Shared Services Strategy in 2012. However, NASA continues to be active in the Federal Geographic Data Committee (FGDC) and supports FGDC standards wherever applicable. NASA also continues to provide support and data to the Geoplatform and supports three National Geospatial Data Assets in partnership with USGS.

Budget Formulation & Execution LOB (Managing Partner Education) FY 2022 Benefits

The Budget Formulation and Execution LoB (BFELoB) provides significant benefits to NASA and other partner agencies by encouraging best practices crossing all aspects of Federal budgeting – from budget formulation and execution to performance to human capital needs. To benefit all agencies, BFELoB continues to support the idea of shared service budget systems. As NASA currently has its own budgeting tools, the Agency has not chosen to move to a new budget system; however, a shared service budget system is an option in the future.

COMPARABILITY ADJUSTMENT TABLES

FY 2020 Budget Structure Crosswalk to FY 2022 Budget Structure Budget Authority ($ in millions)	FY 2020 Structure[1/]	FY 2022 Structure[1/]
NASA TOTAL	**$22,615.7**	**$22,615.7**
Deep Space Exploration Systems	**$6,396.4**	**$6,396.4**
Exploration Technology	**$1,146.3**	**$1,146.3**
LEO and Spaceflight Operations	**$4,285.7**	**$4,209.3**
International Space Station	**$1,458.2**	**$1,458.2**
Space Transportation	**$1,828.6**	**$1,828.6**
Space and Flight Support (SFS)	**$848.9**	**$772.4**
Space Communications and Navigation	$611.0	$534.6
Space Communications Networks	*$468.1*	*$416.4*
Communications Service Office (CSO)	$76.4	
Mission Directorate Support (SCaN)		$24.7
Space Communications Support	*$142.9*	*$118.2*
Mission Directorate Support (SCaN)	$24.7	
Human Space Flight Operations	$99.8	$99.8
Launch Services	$88.6	$88.6
Rocket Propulsion Test	$46.5	$46.5
Communications Services Program	$3.0	$3.0
Commercial LEO Development	**$150.0**	**$150.0**
Science	**$6,393.7**	**$6,393.7**
Earth Science	**$1,779.8**	**$1,779.8**
Earth Science Research	$447.9	$447.9
Earth Systematic Missions	$719.2	$719.2
Earth System Science Pathfinder	$275.4	$250.4
Venture Class Missions	*$199.2*	*$199.2*
Other Missions and Data Analysis	*$76.1*	*$51.1*
Small Satellite Constellation Initiative	$25.0	
Earth Science Data Systems	$214.4	$239.4
Earth Science Data Systems (ESDS)	*$214.4*	*$239.4*
Small Satellite Constellation Initiative		$25.0
Earth Science Technology	$69.6	$69.6
Applied Sciences	$53.3	$53.3
Planetary Science	**$2,712.1**	**$2,712.1**
Planetary Science Research	$266.2	$266.2
Planetary Defense	$150.0	$150.0
Lunar Discovery and Exploration	$300.0	$300.0
Discovery	$502.7	$502.7
New Frontiers	$190.4	$190.4
Mars Exploration	$546.5	$546.5
Mars Rover 2020	*$278.0*	
Other Missions and Data Analysis	*$268.5*	*$546.5*
Mars Rover 2020		$278.0
Outer Planets and Ocean Worlds	$608.4	$608.4
Radioisotope Power	$147.9	$147.9

COMPARABILITY ADJUSTMENT TABLES

Astrophysics	**$844.8**	**$844.8**
Astrophysics Research	$250.7	$250.7
Cosmic Origins	$185.3	$185.3
Hubble Space Telescope (HST)	*$83.3*	*$83.3*
Stratospheric Observatory for Infrared Astronomy (SOFIA)	*$73.0*	
Other Missions and Data Analysis	*$29.0*	*$102.0*
Stratospheric Observatory for Infrared Astronomy (SOFIA)		$73.0
Physics of the Cosmos	$148.4	$148.4
Exoplanet Exploration	$46.4	$46.4
Astrophysics Explorer	$214.1	$214.1
Heliophysics	**$704.5**	**$704.5**
Heliophysics Research	$237.0	$237.0
Living with a Star	$107.6	$107.6
Solar Orbiter Collaboration	*$4.1*	
Other Missions and Data Analysis	*$103.5*	*$107.6*
Solar Orbiter Collaboration		**$4.1**
Solar Terrestrial Probes	$177.9	$177.9
Interstellar Mapping and Acceleration Probe (IMAP)		*$125.2*
Other Missions and Data Analysis	*$177.9*	*$52.7*
Interstellar Mapping and Acceleration Pr	$125.2	
Heliophysics Explorer Program	$182.0	$182.0
ICON	*$1.4*	
Other Missions and Data Analysis	*$180.6*	*$182.0*
Ionospheric Connection Explorer		$1.4
James Webb Space Telescope	**$352.6**	**$352.6**
Aeronautics	**$666.9**	**$783.9**
Aeronautics	**$666.9**	**$783.9**
Airspace Operations and Safety Program	$121.2	$96.2
Airspace Operations and Safety Program	*$121.2*	*$96.2*
Advanced Air Mobility	$25.0	
Advanced Air Vehicles Program	$188.1	$188.1
Integrated Aviation Systems Program	$233.2	$258.2
Low Boom Flight Demonstrator	*$103.5*	*$103.5*
Integrated Aviation Systems Program	*$129.7*	*$126.7*
Advanced Air Mobility		$25.0
Ultraefficient Subsonic Transport	$28.0	
Electrified Powertrain Flight Demonstration		*$28.0*
Transformative Aero Concepts Program	$124.4	$124.4
Aerosciences Eval. & Test Capab. Program		$117.0
STEM Engagement	**$0.0**	**$0.0**
Safety, Security, and Mission Services	**$3,084.6**	**$3,044.0**
Center Management and Operations	**$2,065.0**	
Center Management and Operations	$2,065.0	
Agency Management and Operations	**$1,019.6**	
Agency Management	$390.4	
Safety and Mission Success	$192.0	
Agency IT Services (AITS)	$275.7	
Strategic Capabilities Asset Program	$161.5	
Strategic Capabilities Assets Program	*$161.5*	
Aerosciences Evaluation and Test Capabil	$117.0	

COMPARABILITY ADJUSTMENT TABLES

Mission Services & Capabilities		$1,814.6
Information Technology (IT)		$613.2
Communications Service Office (CSO)		$76.4
Mission Enabling Services		$519.8
Infrastructure & Technical Capabilities		$681.6
Engineering, Safety, & Operations		$1,229.5
Agency Technical Authority		$192.0
Center Engineering, Safety, & Operations		$1,037.5
Construction & Envrmtl Compl Restoration	$600.4	$600.4
Inspector General	$41.7	$41.7
NASA TOTAL	$22,615.7	$22,615.7

1/ - Reflects FY 2020 President's Budget Request (Amended) funding amounts

NOTE: Chart represents changes in budget structure and does not reflect funding changes.

COMPARABILITY ADJUSTMENT TABLES

FY 2021 Budget Structure Crosswalk to FY 2022 Budget Structure Budget Authority ($ in millions)	FY 2021 Structure[1/]	FY 2022 Structure[1/]
NASA TOTAL	**$25,246.0**	**$25,246.0**
Deep Space Exploration Systems	**$8,761.7**	**$8,761.7**
Exploration Technology	**$1,578.3**	**$1,578.3**
LEO and Spaceflight Operations	**$4,187.3**	**$4,187.3**
International Space Station	**$1,400.7**	**$1,400.7**
Space Transportation	**$1,877.8**	**$1,877.8**
Space and Flight Support (SFS)	**$758.7**	**$758.7**
Space Communications and Navigation	$506.0	$506.0
Space Communications Networks	*$388.2*	*$392.7*
Mission Directorate Support (SCaN)		$4.6
Space Communications Support	*$117.8*	*$113.2*
Mission Directorate Support (SCaN)	$4.6	
Human Space Flight Operations	$89.9	$89.9
Launch Services	$91.9	$91.9
Rocket Propulsion Test	$47.6	$47.6
Communications Services Program	$23.4	$23.4
Commercial LEO Development	**$150.0**	**$150.0**
Science	**$6,306.5**	**$6,306.5**
Earth Science	**$1,768.1**	**$1,768.1**
Earth Science Research	$447.3	$447.3
Earth Systematic Missions	$608.3	$608.3
Earth System Science Pathfinder	$338.9	$313.9
Venture Class Missions	*$263.6*	*$263.6*
Other Missions and Data Analysis	*$75.3*	*$50.3*
Commercial SmallSat Data Acquisition	$25.0	
Earth Science Data Systems	$245.4	$270.4
Earth Science Data Systems (ESDS)	*$245.4*	*$270.4*
Commercial SmallSat Data Acquisition		$25.0
Earth Science Technology	$74.2	$74.2
Applied Sciences	$53.9	$53.9
Planetary Science	**$2,659.6**	**$2,659.6**
Planetary Science Research	$305.4	$305.4
Planetary Defense	$150.0	$150.0
Lunar Discovery and Exploration	$451.5	$451.5
VIPER		*$67.5*
Other Missions and Data Analysis	*$451.5*	*$384.0*
Volatiles Investiga Polar Explortn Rover	$67.5	
Discovery	$484.3	$484.3
New Frontiers	$179.0	$179.0
Mars Exploration	$528.5	$528.5
Mars Rover 2020	*$162.3*	
Other Missions and Data Analysis	*$366.2*	*$528.5*
Mars Rover 2020		$162.3
Outer Planets and Ocean Worlds	$414.4	$414.4
Radioisotope Power	$146.3	$146.3

COMPARABILITY ADJUSTMENT TABLES

Astrophysics	**$831.0**	**$831.0**
Astrophysics Research	$269.7	$269.7
Cosmic Origins	$124.0	$124.0
Hubble Space Telescope (HST)	*$88.3*	*$88.3*
Stratospheric Observatory for Infrared Astronomy (SOFIA)	*$12.0*	
Other Missions and Data Analysis	*$23.7*	*$35.7*
Stratospheric Observatory for Infrared Astronomy (SOFIA)		$12.0
Physics of the Cosmos	$143.9	$143.9
Exoplanet Exploration	$47.2	$47.2
Astrophysics Explorer	$246.2	$246.2
SPHEREx		*$90.8*
Other Missions and Data Analysis	*$246.2*	*$155.4*
Spectro-Photometer for the History of th	$90.8	
Heliophysics	**$633.1**	**$633.1**
Heliophysics Research	$230.5	$230.5
Living with a Star	$127.9	$127.9
Solar Orbiter Collaboration	*$8.1*	
Other Missions and Data Analysis	*$119.7*	*$127.9*
Solar Orbiter Collaboration		$8.1
Solar Terrestrial Probes	$126.3	$126.3
Interstellar Mapping and Acceleration Probe (IMAP)		*$72.6*
Other Missions and Data Analysis	*$126.3*	*$53.7*
Interstellar Mapping and Acceleration Pr	$72.6	
Heliophysics Explorer Program	$148.4	$148.4
James Webb Space Telescope	**$414.7**	**$414.7**
Aeronautics	**$819.0**	**$819.0**
Aeronautics	**$819.0**	**$819.0**
Airspace Operations and Safety Program	$90.4	$90.4
Advanced Air Vehicles Program	$212.7	$212.7
Aerosciences Eval. & Test Capab. Program	$117.0	$117.0
Integrated Aviation Systems Program	$269.0	$269.0
Low Boom Flight Demonstrator	*$79.1*	*$79.1*
Electrified Powertrain Flight Demonstration		*$85.3*
Integrated Aviation Systems Program	*$190.0*	*$104.7*
Electric Powertrain Flight Demonstration	$85.3	
Transformative Aero Concepts Program	$129.9	$129.9
STEM Engagement	**$0.0**	**$0.0**
Safety, Security, and Mission Services	**$3,009.9**	**$3,009.9**
Construction & Envrmtl Compl Restoration	**$539.1**	**$539.1**
Inspector General	**$44.2**	**$44.2**
NASA TOTAL	**$25,246.0**	**$25,246.0**

1/ - Reflects FY 2021 President's Budget Request funding amounts

NOTE: Chart represents changes in budget structure and does not reflect funding changes.

RE-BASELINED PROJECTS

In accordance with NPR 7120.5, NASA re-baselined the estimated Life Cycle Costs for the following projects. The original baselines are shown for comparison.

($ in millions)

EGS	Date	Prior	FY20	FY21	FY22	FY23	FY24	FY25	FY26	BTC	Total
Original Life Cycle Cost	**2014**	**2,813**	**-**	**-**							**2,813**
Rebaselined Life Cycle Cost	**2020**	**3,039**	**166**	**193**	**16**	**-**	**-**	**-**	**-**	**-**	**3,413**

LCRD	Date	Prior	FY20	FY21	FY22	FY23	FY24	FY25	FY26	BTC	Total
Original Life Cycle Cost	**2017**	**263**									**263**
Rebaselined Life Cycle Cost	**2020**	**263**	**31**	**17**	**-**	**-**	**-**	**-**	**-**	**-**	**310**

SLS	Date	Prior	FY20	FY21	FY22	FY23	FY24	FY25	FY26	BTC	Total
Original Life Cycle Cost	**2014**	**9,695**	**-**							**-**	**9,695**
Rebaselined Life Cycle Cost	**2020**	**10,654**	**511**	**464**	**154**	**-**	**-**	**-**	**-**	**-**	**11,782**

Webb	Date	Prior	FY20	FY21	FY22	FY23	FY24	FY25	FY26	BTC	Total
Original Life Cycle Cost	**2009**	**4,821**	**76**	**54**	**12**	**-**	**-**	**-**	**-**	**-**	**4,964**
Rebaselined Life Cycle Cost	**2019**	**8,018**	**423**	**415**	**175**	**172**	**172**	**172**	**115**	**-**	**9,663**

**Totals may not add due to rounding*

COST AND SCHEDULE PERFORMANCE SUMMARY

2021 Major Program Annual Report Summary

The 2021 Major Program Annual Report (MPAR) is provided to meet the requirements of section 103 of the NASA Authorization Act of 2005 (P.L. 109-155; 42 U.S.C. 16613). The 2021 MPAR consists of this summary and FY 2022 Congressional Justification pages designated as "Projects in Development," for the projects outlined below. These project pages constitute each project's annual report, or if this is the first year for which it is in reporting, the baseline report. The MPAR summary also includes the confidence level of achieving the commitments as requested in the Conference Report accompanying the FY 2010 Consolidated Appropriations Act (P.L. 111-117).

Changes in MPAR Composition since the FY 2021 NASA Budget Estimates

There are four new projects with estimated lifecycle costs greater than $250 million that received authority to proceed into the development phase since NASA submitted its 2020 MPAR in the FY 2021 NASA Congressional Justification. All four projects have a joint confidence level of 70 percent.

- The On-orbit Servicing, Assembly, and Manufacturing (OSAM-1) project with a baseline development cost of $974.4 million;
- The Roman project with a baseline development cost of $2,898.1 million;
- The Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx) project with a baseline development cost of $367.8 million; and
- The Volatiles Investigating Polar Exploration Rover (VIPER) project with a baseline development cost of $336.2 million.

There are two projects that successfully launched since NASA submitted its 2020 MPAR in the FY 2021 NASA Congressional Justification.

1. The Mars 2020 project successfully launched on July 30, 2020; and
2. The Solar Orbiter Collaboration (SOC) project successfully launched on February 9, 2020.

Changes in Development Cost and Schedule Estimates from the 2020 MPAR

Five projects (Double Asteroid Redirection Test (DART), Landsat-9, Lucy, Solar Electric Propulsion (SEP), and Surface Water and Ocean Topography (SWOT) had no changes in their development cost or schedule estimates over the last year.
There are four projects that have been rebaselined EGS and SLS both with development cost increases and revised LRD, and both LCRD and Webb have revised LRD with no changes in development cost. The development cost is up 3% for the PACE project. While there were development cost decreases for the PSYCHE (-5%), Sentinel-6 (-13%), and Europa-Clipper (-1%) projects. Projects with changes to both development cost and LRD include LBFD with development cost up 14% and LRD moved to 6/2023, NISAR with development cost up 20% and LRD moved to 9/2023, and Orion with development cost down 1% and LRD moved to 9/2023. The Webb project revised LRD is 10/2021 with no change in development cost.

MPAR Summary Table

Figure 1 provides cost, schedule, and confidence level information for NASA projects currently in development with lifecycle cost estimates of $250 million or more. NASA records the estimated development cost and a key schedule milestone and then measures changes from them. NASA tracks one of several key milestones, listed below, for reporting purposes:

- Launch Readiness Date (LRD);

COST AND SCHEDULE PERFORMANCE SUMMARY

- Full Operational Capability (FOC);
- Initial Operating Capability (IOC); or
- Launch Readiness for Artemis I or Artemis II.

As a note for clarification, LRD schedule milestones, as reported here, are not typically the launch dates on the NASA launch manifest, but are the desired launch dates as determined by the payload mission and approved by the NASA Flight Planning Board (FPB). A launch manifest is a dynamic schedule that is affected by real world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. The launch dates shown on the NASA FPB launch manifest are a mixture of confirmed range dates for missions launching within approximately six months and contractual/planning dates for the missions beyond six months from launch. The NASA FPB launch manifest date is typically earlier than the reported schedule dates reported here, thereby allowing for the operationally driven fluctuations to the launch schedule that may be outside of the Project's control. The NASA FPB launch manifest is updated on a periodic basis throughout the year.

Additional explanations for the data in the summary table are provided here:

- Orion, SLS and EGS: The Artemis I and II launch dates are under review pending completion of several assessments. NASA is conducting a Program Status Assessment of the overall Artemis effort, of which Orion, SLS and EGS are key components. This assessment includes review of the schedule and technical approaches as well as systems engineering integration and program management. In parallel, NASA is performing an independent technical and programmatic assessment, including a joint cost and schedule confidence level analysis of the SLS and EGS programs. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.
- Webb: Cost Estimate includes Construction of Facilities funds.
- EGS: The 80% JCL is inferred from analysis based on FY 2014 President's Budget Request (PBR) including FY 2014 Appropriation changes. JCL analysis was completed prior to the release of the FY 2015 PBR. The ABC is informed by the 80% JCL and adjusted to reflect the FY 2015 PBR budget reduction.
- LCRD: The project will fly as a hosted payload on the U.S. Air Force Space Test Program (STPSat-6) mission. The primary spacecraft bus is co-funded by NASA and the U.S. Air Force. The LCRD project has remained within its cost and schedule baseline for payload development and has completed payload integration and testing. The re-plan incorporating the U.S. Air Force managed spacecraft bus and schedule problems was completed in April 2019. The table below reflects the LCRD proposed rebaselined cost and schedule as provided in the 2019 Congressional notification.

COST AND SCHEDULE PERFORMANCE SUMMARY

Additional information on the projects shown in the table below can be found in their individual program and project pages. This report includes data as of March 31, 2021 and does not match mission data in CJ sections in all cases.

Figure 1: MPAR Summary and Confidence Levels

Project	Base Year	JCL (%)	Development Cost Estimate ($M)		Cost Change (%)	Key Milestone Event	Key Milestone Date		Schedule Change (months)
			Baseline	FY 2021			Baseline	FY 2021	
DART	2019	70	258.3	258.3	0%	LRD	Feb 2022	Feb 2022	0
EGS*	2015	80	2,438.4	2,496.4	2%	LR for Artemis I	Nov 2021	Nov 2021	0
Europa Clipper+	2020	N/A	2,412.8	2,393.8	-1%	LRD	Sep 2025	Sep 2025	0
Landsat-9	2018	70	634.2	587.7	-7%	LRD	Nov 2021	Nov 2021	0
LBFD	2019	70	467.7	532.2	14%	First Flight	Jan 2022	Jun 2022	5
LCRD**	2020	70	128.6	128.6	0%	LRD	Jan 2021	Jun 2021	5
Lucy	2019	70	622.2	614.2	-1%	LRD	Nov 2021	Nov 2021	0
NISAR	2017	70	661.0	774.3	17%	LRD	Sep 2022	Sep 2023	12
Orion***	2016	70	6,768.4	7,656.0	13%	LR for Artemis II	Apr 2023	Sep 2023	5
OSAM-1	2021	70	974.4	974.4	0%	LRD	Sep 2025	Sep 2025	0
PACE	2020	70	558.0	572.2	3%	LRD	Jan 2024	Jan 2024	0
Psyche	2020	70	681.9	646.1	-5%	LRD	Aug 2022	Aug 2022	0
Roman	2021	70	2,898.1	2,922.9	1%	LRD	Oct 2026	Oct 2026	0
Sentinel-6	2017	70	465.9	402.3	-14%	LRD	Nov 2021	Nov 2021	0
SEP*****	2020	70	155.9	156.4	0%	AEPS Life Qual Test Report	Dec 2024	Dec 2024	0
SLS	2015	70	9,108.3	9,108.3	0%	LR for Artemis I	Nov 2021	Nov 2021	0
SPHEREx	2021	70	367.8	367.8	0%	LRD	Apr 2025	Apr 2025	0

COST AND SCHEDULE PERFORMANCE SUMMARY

Project	Base Year	JCL (%)	Development Cost Estimate ($M)		Cost Change (%)	Key Milestone Event	Key Milestone Date		Schedule Change (months)
			Baseline	FY 2021			Baseline	FY 2021	
SWOT	2017	80	571.5	572.0	0%	LRD	Apr 2022	Apr 2022	0
VIPER	2021	70	336.2	336.2	0%	IOC	Nov 2023	Nov 2023	0
Webb****	2012	70	7,002.6	7,002.1	0%	LRD	Mar 2021	Oct 2021	7

** The 80% JCL is inferred from analysis based on FY 2014 President's Budget Request (PBR) including FY 2014 Appropriation changes. JCL analysis was completed prior to the release of the FY 2015 PBR. The ABC is informed by the 80% JCL and adjusted to reflect the FY 2015 PBR budget reduction.*

*** The table reflects the LCRD proposed rebaselined cost and schedule as provided in the 2019 Congressional notification.*

**** Approximately -2% of this amount reflects a transfer of funding to formulation costs and does not represent a reduction in the life cycle cost estimates.*

***** Based on the Consolidated Appropriations Act, 2019 the Webb project has a new reporting baseline. Compared to the prior baseline of $6,197.9, the mission has been delayed 29 months and increased by $804.7 million.*

****** Aerojet Electric Propulsion String Qual Test: The test demonstrates continuous long-term operation of the system sufficient to characterize and predict the capability and lifetime of the system. The report tells us what the capability is based on the results of the test.*

+ The Budget proposes to launch the Europa Clipper on a commercial launch vehicle as early as 2024. The launch date in Figure 1 assumes current law, which requires launch on an SLS rocket in 2025. Launching the Europa Clipper on a commercial launch vehicle would save over $1.5 billion compared to using an SLS rocket

Launch Readiness (LR) Launch Readiness Date (LRD) Aerojet Electric Propulsion String (AEPS)

FY 2022 Proposed Appropriations Language

Deep Space Exploration Systems

For necessary expenses, not otherwise provided for, in the conduct and support of exploration research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $6,880,400,000, to remain available until September 30, 2023. (Science Appropriations Act, 2021.)

Exploration Technology

For necessary expenses, not otherwise provided for, in the conduct and support of space technology research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $1,425,000,000, to remain available until September 30, 2023. (Science Appropriations Act, 2021.)

Space Operations

For necessary expenses, not otherwise provided for, in the conduct and support of space operations research and development activities, including research, development, operations, support and services; space flight, spacecraft control, and communications activities, including operations, production, and services; maintenance and repair, facility planning and design; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $4,017,400,000, to remain available until September 30, 2023. (Science Appropriations Act, 2021.)

Science

For necessary expenses, not otherwise provided for, in the conduct and support of science research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $7,931,400,000, to remain available until September 30, 2023. (Science Appropriations Act, 2021.)

FY 2022 PROPOSED APPROPRIATIONS LANGUAGE

AERONAUTICS

For necessary expenses, not otherwise provided for, in the conduct and support of aeronautics research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $914,800,000, to remain available until September 30, 2023. (Science Appropriations Act, 2021.)

SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS ENGAGEMENT

For necessary expenses, not otherwise provided for, in the conduct and support of aerospace and aeronautical education research and development activities, including research, development, operations, support, and services; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $147,000,000, to remain available until September 30, 2023. (Science Appropriations Act, 2021.)

SAFETY, SECURITY, AND MISSION SERVICES

For necessary expenses, not otherwise provided for, in the conduct and support of science, aeronautics, space technology, exploration, space operations and education research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; not to exceed $63,000 for official reception and representation expenses; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $3,049,200,000, to remain available until September 30, 2023. (Science Appropriations Act, 2021.)

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

For necessary expenses for construction of facilities including repair, rehabilitation, revitalization, and modification of facilities, construction of new facilities and additions to existing facilities, facility planning and design, and restoration, and acquisition or condemnation of real property, as authorized by law, and environmental compliance and restoration, $390,300,000, to remain available until September 30, 2027: Provided, That proceeds from leases deposited into this account shall be available for a period of 5 years to the extent and in amounts as provided in annual appropriations Acts: Provided further, That such proceeds referred to in the preceding proviso shall be available for obligation for fiscal year 2022 in an amount not to exceed $20,000,000: Provided further, That each annual budget request shall include an annual estimate of gross receipts and collections and proposed use of all funds collected pursuant to section 20145 of title 51, United States Code. (Science Appropriations Act, 2021.)

INSPECTOR GENERAL

For necessary expenses of the Office of Inspector General in carrying out the Inspector General Act of 1978, $46,000,000, to remain available until September 30, 2023. (Science Appropriations Act, 2021.)

FY 2022 PROPOSED APPROPRIATIONS LANGUAGE

ADMINISTRATIVE PROVISIONS

Funds for any announced prize otherwise authorized shall remain available, without fiscal year limitation, until a prize is claimed or the offer is withdrawn.

Not to exceed 5 percent of any appropriation made available for the current fiscal year for the National Aeronautics and Space Administration in this Act may be transferred between such appropriations, but no such appropriation, except as otherwise specifically provided, shall be increased by more than 10 percent by any such transfers. Any funds transferred to "Construction and Environmental Compliance and Restoration" for construction activities shall not increase that account by more than 20 percent. Balances so transferred shall be merged with and available for the same purposes and the same time period as the appropriations to which transferred. Any transfer pursuant to this provision shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

Not to exceed 5 percent of any appropriation provided for the National Aeronautics and Space Administration under previous appropriations Acts that remains available for obligation or expenditure in fiscal year 2022 may be transferred between such appropriations, but no such appropriation, except as otherwise specifically provided, shall be increased by more than 10 percent by any such transfers. Any transfer pursuant to this provision shall retain its original availability and shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

The spending plan required by this Act shall be provided by the National Aeronautics and Space Administration at the theme, and program level. The spending plan, as well as any subsequent change of an amount established in that spending plan that meets the notification requirements of section 504 of this Act, shall be treated as a reprogramming under section 504 of this Act and shall not be available for obligation or expenditure except in compliance with the procedures set forth in that section.

Not more than 20 percent or $25,000,000, whichever is less, of the amounts made available in the current-year CECR appropriation may be applied to CECR projects funded under previous years' CECR appropriation Acts. Use of current-year funds under this provision shall be treated as a reprogramming of funds under section 504 of this act and shall not be available for obligation except in compliance with the procedures set forth in that section. (Science Appropriations Act, 2021.)

ACRONYMS AND ABBREVIATIONS

AA	Ascent Abort
AAM	Advanced Air Mobility
AAO	Agency Applications Office
AATT	Advanced Air Transport Technology
AAVP	Advanced Air Vehicles Program
ABC	Agency Baseline Commitment
ACCESS	Advancing Collaborative Connections for Earth System Science
ACE	Advanced Composition Explorer
ACF	Analytic Center Framework
ACME	Advanced Combustion via Microgravity Experiments
ACO	Announcement of Collaborative Opportunity
ACSC	Advanced Cislunar and Surface Capabilities
ACT	Advanced Component Technology
ACTIVATE	Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment
ADAP	Astrophysics Data Analysis Program
ADCAR	Astrophysics Data Curation and Archival Research
ADP	Advanced Developments Projects
ADS	Astrophysics Data System
AEPS	Advanced Electric Propulsion Systems
AES	Advanced Exploration Systems
AETC	Aeronautics Evaluation & Testing Capability Project
AFRC	Armstrong Flight Research Center
AFRL	Air Force Research Laboratory
AGN	Active Galactic Nucleus
AI	Artificial Intelligence
AI&T	Assembly, Integration, and Testing
AIM	Aeronomy of Ice in the Mesosphere
AIRS	Atmospheric Infrared Sounder
AIS	Antarctic Ice Sheet
AIST	Advanced Information Systems Technology
AMMOS	Advanced Multi-Mission Operations System
AMR	Advanced Microwave Radiometer
AMS	Alpha Magnetic Spectrometer
ANNH	Alaska Native and Native Hawaiian Institutions
ANZ	Air New Zealand
AO	Announcements of Opportunity
AOSP	Airspace Operations and Safety Program
APL	Applied Physics Laboratory
APMC	Agency Project Management Council
APPEL	Academy of Program/Project and Engineering Leadership
AQ	Air Quality
ARC	Ames Research Center

ACRONYMS AND ABBREVIATIONS

ARCSIX	Arctic Radiation-Cloud-Aerosol-Surface-Interaction Experiment
ARIEL	Atmospheric Remote-sensing Infrared Exoplanet Large-survey
ARMD	Aeronautics Research Mission Directorate
ARRM	Asteroid Redirect Robotic Mission
ARSET	Applied Remote Sensing Training
ARTEMIS	Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun
ASAP	Aerospace Safety Advisory Panel
ASCAN	Astronaut Candidate
ASHI	A Lightweight All Sky Imager for Future NASA Heliospheric Missions
ASIC	Application-Specific Integrated Circuit
ASM	Acquisition Strategy Meeting
AST	Architecture Study Team
ASU	Arizona State University
ATA	Agency Technical Authority
ATD	Air Traffic Management Technology Demonstration-1
ATLAS	Advanced Topographic Laser Altimeter System
ATLO	Assembly, Test, and Launch Operations
ATM	Air Traffic Management
ATM-X	Air Traffic Management - eXploration
AU	Astronomical Units
AURA	Association of Universities for Research in Astronomy
AVA	Affordable Vehicle Avionics
AWE	Atmospheric Waves Experiment
BAA	Broad Agency Announcement
BCDU	Battery Charge/Discharge Unit
BCT	Blue Canyon Technologies
BDPA	Breakthrough Distributed Power Architecture
BFF	Booster Fabrication Facility
BI	Business Intelligence
BLAST-TNG	Balloon-borne Large Aperture Submillimeter Telescope
BMGG	The Bulk Metallic Glass Gears
BOLE	Booster Obsolescence and Life Extension
BPA	Brine Processor Assembly
BPS	Biological and Physical Sciences
BTC	Budget to Complete
BWG	Beam Wave Guide
CADRE	Cooperative Autonomous Distributed Robotic Explores
CAL	Cold Atom Laboratory
CALET	Calorimetric Electron Telescope
CALIOP	Cloud-Aerosol LIdar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation

ACRONYMS AND ABBREVIATIONS

Caltech	California Institute of Technology
CAN	Cooperative Agreement Notice
CAPSTONE	Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment
CARES	Coronavirus Aid, Relief, and Economic Security
CAS	Convergent Aeronautics Solutions
CASE	Contribution to ARIEL Spectroscopy of Exoplanets
CASIS	Center for the Advancement of Science in Space
CBM	condition-based maintenance
CCDev	Commercial Crew Development
CCDev2	Commercial Crew Development Round 2
CCiCap	Commercial Crew Integrated Capability
CCP	Commercial Crew Program
CCRPP	Civilian Commercialization Readiness Pilot Program
CCRS	Capture, Containment, and Return System
CCSDS	Consultative Committee for Space Data Systems
CCSFS	Cape Canaveral Space Force Station
CCtCap	Commercial Crew Transportation Capability
CDISS	Commercial Destinations for ISS
CDL	Construction Debris Landfill
CDM	Continuous Diagnostic Mitigation
CDR	Critical Design Reviews
CE	Continuous Evaluation
CECR	Construction and Environmental Compliance and Restoration
CERCLA	Comprehensive Environmental Response, Compensation, Liability Act
CERES	Compact Radiation Belt Explorer
CESAS	Committee on Earth Science and Applications from Space
CESO	Center Engineering, Safety, and Operations
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
CFT	Crewed Flight Test
CHIPS	Chemical Heat Integrated Power Source
CHS	Crew Health and Safety
CIF	Center Innovation Fund
CIR	Critical Integration Review
CIS	Commercialization, Innovation, and Synergies
CL	Confidence Level
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CLICK	CubeSat Laser Infrared Crosslink
CLIN	Contract Line Item Number
CLPS	Commercial Lunar Payload Services
CLV	Commercial Launch Vehicles

ACRONYMS AND ABBREVIATIONS

CM	Crew Module
CMA	Crew Module Adapter
CME	Coronal Mass Ejections
CMV	Co-Manifested Vehicle
CNES	Centre National d'Etudes' Spatiales
CoF	Construction of Facilities
COMPETES	Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science
COR	Cosmic Origins
CoSTEM	Committee on Science, Technology, Engineering, and Mathematics
COTS	Commercial Orbital Transportation Services
COVID-19	Coronavirus Disease 2019
CPC	Certification Products Contract
CPF	CLARREO Pathfinder
CRISM	Compact Reconnaissance Imaging Spectrometer for Mars
CRP	Commercialization Readiness Program
CRS	Commercial Resupply Services
CSA	Canadian Space Agency
CSDA	Commercial SmallSat Data Acquisition
CSESP	Citizen Science for Earth Systems Program
CSI	Calorimeter Spectrometer Insert
CSLI	CubeSat Launch Initiative
CSM	Crew and Service Module
CSP	Communications Services Program
CST	Commercial Supersonic Transport
CT	Computerized Tomography
CTE	Composite Technology for Exploration
CTX	Context Camera
CUI	Controlled Unclassified Information
CY	Calendar Year
CYGNSS	Cyclone Global Navigation Satellite System
DAA	Detect and Avoid
DAAC	Distributed Active Archive Center
DAEP	DSN Aperture Enhancement Project
DALI	Development and Advancement of Lunar Instrumentation
DARPA	Defense Advanced Research Projects Agency
DART	Double Asteroid Redirection Test
DATA	Digital Accountability and Transparency Act
DCOTSS	Dynamics and Chemistry of the Summer Stratosphere
DCR	Design Certification Review
DDL	Deorbit Descent and Landing
DDT&E	design, development, test, and evaluation

ACRONYMS AND ABBREVIATIONS

DE&I	Diversity, Equity, and Inclusion
DEAP	Deep Space Network Aperture Enhancement Project
DEUCE	Dual-Channel Extreme Ultraviolet Continuum Experiment
DFO	Designated Federal Official
DHS	Department of Homeland Security
DLC	Descent Landing Computer
DLEU	DSN Lunar Exploration Upgrades
DLR	German Aerospace Center
DM	Demo
DNA	Deoxyribonucleic Acid
DO	Designated Observable
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOJ	Department of Justice
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DPMC	Directorate Program Management Council
DPR	Dual-frequency Precipitation Radar
DRACO	Didymos Reconnaissance and Asteroid Camera for OpNav
DraGMet	Dragonfly Geophysics and Meteorology Package
DraGNS	Dragonfly Gamma-Ray and Neutron Spectrometer
DRIVE	Diversify, Realize, Integrate, Venture, Educate
DRPS	Dynamic RPS
DSA	Distributed Spacecraft Autonomy
DSAC	Deep Space Atomic Clock
DSCOVR	Deep Space Observatory
DSE	Data System Evolution
DSI	Deutsches SOFIA Institute
DSL	Deep Space Logistics services
DSN	Deep Space Network
DSOC	Deep Space Optical Communication
DSS	Deep Space Station
DTN	Delay Tolerant Networking
DTU	Technical University of Denmark
DUST	Determining Unknown yet Significant Traits
DYNAMIC	Dynamical Neutral Atmosphere-Ionosphere Coupling
EAP	Electric Aircraft Propulsion
ECI	Early Career Initiative
ECIPA	Europa Clipper Integrated Pump Assembly
ECLSS	Environmental Control and Life Support Systems
ECOSTRESS	Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station
ECR	Environmental Compliance and Restoration

ACRONYMS AND ABBREVIATIONS

eCryo	Evolvable Cryogenics
ECS	Environmental Control System
EDL	Entry, Descent, and Landing
EDS	Electrodynamic Dust Shield
EES	Emergency Egress Systems
EEV	Earth Entry Vehicle
EGS	Exploration Ground Systems
EIA	Equatorial Ionization Anomaly
EHRI	Enterprise HR Integration
EIR	Enterprise Integration Review
EIS	Europa Imaging System
EM	Exploration Mission
EMIT	Earth Surface Mineral Dust Source Investigation
EONS	Engagement Opportunities in NASA STEM
EOS	Earth Observation Systems
EOSDIS	Earth Observing System Data and Information System
EPA	Environmental Protection Agency
EPFD	Electrified Powertrain Flight Demonstration
EPIC	Earth Poly-Chromatic Imaging Camera
EPSCoR	Established Program to Stimulate Competitive Research
ERB	Earth Radiation Budget
ERBS	Earth Radiation Budget Science
ERD	Exploration Research and Development
ERO	Earth Return Orbiter
EROS	Earth Resources Observation and Science
ESA	European Space Agency
EscaPADE	Escape and Plasma Acceleration and Dynamics Explorers
ESD	Exploration Systems Development
ESDIS	Earth Science Data and Information System
ESDS	Earth Science Data Systems
ESM	European Service Module
ESO	Engineering, Safety, and Operations
ESPRIT	European Systems Providing Refueling, Infrastructure, and Telecommunications
ESSP	Earth System Science Pathfinder
ESTP	Earth Science Technology Program
ETA	Engineering Technical Authority
EUL	Enhanced Use Lease
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUS	Exploration Upper Stage
EUV	Extreme UV
EUVST	Extreme Ultraviolet High-Throughput Spectroscopic Telescope
EVA	Extravehicular Activity

ACRONYMS AND ABBREVIATIONS

EVC	Earth Venture Continuity
EVI	Earth Venture Instruments
EVM	Earth Venture small Missions
EVS	Earth Venture Suborbital
EWC	External Wireless Coverage
EXCOM	Executive Committee
EZIE	Electrojet Zeeman Imaging Explorer
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
FAST	Fellows Advancing in Science and Technology
FBCE	Flow Boiling and Condensation Experiment
FDC	Flight Demonstrations and Capabilities
FFATA	Federal Funding Accountability and Transparency Act
FGDC	Federal Geographic Data Committee
FIRST	For Inspiration and Recognition of Science and Technology
FO	Follow-On
FOR	Flight Operations Review
FPKI	Federal Public Key Infrastructure
FRR	Flight Readiness Review
FSH	Foundation Surface Habitat
FSP	Fission Surface Power
FSR	Formulation Synchronization Review
FTE	Full-Time Equivalent
FY	Fiscal Year
GAO	Government Accountability Office
GDC	Geospace Dynamics Constellation
GDMS	General Dynamic Mission Systems
GE	General Electric
GEDI	Global Ecosystem Dynamics Investigation Lidar
GEER	Glenn Extreme Environment Rig
GEO	Geostationary Earth Orbit
GeoCarb	Geostationary Carbon Cycle Observatory
GFE	Government Furnished Equipment
GHG	Greenhouse Gases
GLIDE	Global Lyman-alpha Imagers of the Dynamic Exosphere
GLIMR	Geosynchronous Littoral Imaging and Monitoring Radiometer
GLOBE	Global Learning and Observations to Benefit the Environment
GNSS	Global Navigation Satellite System
GO	Guest Observers
GOES	Geostationary Operational Environmental Satellite
GOLD	Global-scale Observations of the Limb and Disk
GPHS-RTG	General Purpose Heat Source - Radioisotope Thermoelectric Generator

ACRONYMS AND ABBREVIATIONS

GPIM	Green Propellant Infusion Mission
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GPSP	Global Positioning System-Payload
GRACE	Gravity Recovery and Climate Experiment
GRC	Glenn Research Center
GS	General Schedule
GSA	General Services Administration
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GSI	Ground Systems Implementation
GSSR	Goldstone Solar System Radar
GT	Ground Terminal
GUSTO	Galactic/Extragalactic Ultralong duration balloon Spectroscopic Terahertz Observatory
HALO	Hydrogen Albedo Lunar Orbiter
HARP	Hyper-Angular Rainbow Polarimeter
HBCU	Historically Black Colleges and Universities
HDL	Hazard Detection LIDAR
HEASARC	High Energy Astrophysics Science Archive Center
HECC	High End Computing Capability
HEOMD	Human Exploration and Operations Mission Directorate
HERA	Human Exploration Research Analog
HERMES	Heliophysics Environmental and Radiation Measurement Experiment
HERO	Human Exploration Research Opportunity
HESTO	Heliophysics Strategic Technology Office
HFOS	Heliophysics Flight Opportunities Studies
HFOTM	Heliophysics Flight Opportunities for Technology Maturation
HHS	Department of Health and Human Services
HiRISE	High-Resolution Imaging Science Experiment
HLS	Harmonized Landsat/Sentinel
HMP	Habitable Mobility Platform
HMTA	Health and Medical Technical Authority
HOTTech	Hot Operating Temperature Technology
HPSC	High Performance Spaceflight Computing
HQ	Headquarters
HR	Human Resources
HRP	Human Research Program
HSFO	Human Space Flight Operations
HSI	Human Systems Integration
HSO	Heliophysics System Observatory
HT	Hypersonic Technology
HTIDeS	Heliophysics Technology and Instrument Development for Science

ACRONYMS AND ABBREVIATIONS

HTV	H-II Transfer Vehicle
HVAC	Heating, Ventilating, and Air Conditioning
I&T	Integration & Test
I&TC	Infrastructure & Technical Capabilities
IA	Independent Assessment
IAE	Integrated Award Environment
IASP	Integrated Aviation Systems Program
IBC	Interior Business Center
IBEX	Interstellar Boundary Explorer
IBR	Integrated Baseline Review
ICE	Instrument Control Electronics
ICEMAG	Interior Characterization of Europa Using Magnetometry
ICESat	Ice, Cloud, and Land Elevation Satellite
ICF	Industrial Crystallization Facility
ICON	Ionospheric Connection Explorer
ICPS	Interim Cryogenic Propulsion Stage
IDF	Instrument Development Facility
IDIQ	Indefinite-Delivery-Indefinite-Quantity
IEIs	Informal Education Institutions
IIP	Instrument Incubator Program
ILLUMA-T	Integrated LCRD Low-Earth Orbit User Modem and Amplifier Terminal
IM	Information Management
IMAP	Interstellar Mapping and Acceleration Probe
IMC	International Mission Contributions
IMERG	Integrated Multi-satellite Retrievals for GPM
IMPACT	Interagency Implementation and Advance Concepts Team
IMPACTS	Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Storms
IMPALA	Information Management Platform for Data Analytics and Aggregation
INL	Idaho National Lab
InSAR	Interferometric Synthetic Aperture Radar
InSight	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport
InVEST	In-Space Validation of Earth Science Technologies
IOAG	Interagency Operations Advisory Group
IOC	Initial Operation's Capability
IPAC	The Infrared Processing and Analysis Center
IPM	Integrated Payload Module
IR	Infrared
IRAD	Independent Research and Development Projects
IRB	Independent Review Board
IRIS	Interface Region Imaging Spectrograph
IRSA	Infrared Science Archive
IRT	Independent Review Team

ACRONYMS AND ABBREVIATIONS

IRTF	Infrared Telescope Facility
ISAAC	Integrated System for Autonomous and Adaptive Caretaking
ISM	In-Space Manufacturing
ISPF	In-Space Propulsion Facility
ISRO	Indian Space Research Organisation
ISRU	In-Situ Resource Utilization
ISS	International Space Station
ISSNL	International Space Station National Laboratory
IT	Information Technology
ITL	Integrated Test Lab
ITM	Ionosphere-Thermosphere-Mesosphere
ITT	Instrument Technology Transition
IV&V	Independent Verification and Validation
IViS-TP	In-space Navigation Vision System Tipping Point
IVM	Ion Velocity Meter
IVR	Intra-Vehicle
IXPE	Imaging X-Ray Polarimetry Explore
JAXA	Japanese Aerospace Exploration Agency
JCL	Joint Confidence Level
JHU	Johns Hopkins University
JHU/APL	John Hopkins University/Applied Physics Laboratory
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSC	Johnson Space Center
JUICE	Jupiter Icy Moons Explorer
KaRIn	Ka-band Radar Interferometer
KASI	Korea Astronomy and Space Science Institute
KDP	Key Decision Point
KOA	Keck Observatory Archive
KSC	Kennedy Space Center
LANCE	Land, Atmosphere Near real-time Capability for EOS
LANL	Los Alamos National Laboratory
LaRC	Langley Research Center
LAS	Launch Abort System
LASCO	Large Angle and Spectrometric Coronagraph
LASP	Laboratory for Atmospheric and Space Physics
LBFD	Low Boom Flight Demonstrator
LBNP	lower body negative pressure
LC	Launch Complex
LCC	Life Cycle Cost
LCPSO	Land Cover Project Science Office
LCRD	Laser Communications Relay Demo

ACRONYMS AND ABBREVIATIONS

LDEP	Lunar Discovery and Exploration Program
LEGS	Lunar Exploration Ground System
LEO	Low Earth Orbit
LETS	Lunar Exploration Transportation Services
LH2	Liquid Hydrogen
LIDAR	Light Detection and Ranging
LIS	Lightning Imaging Sensor
LISA	Laser Interferometer Space Antenna
LISA-T	Lightweight Integrated Solar Array and Transceiver
LISM	Local Interstellar Medium
LLAMA	Long-Life Additive Manufacturing Assembly
LLC	Limited Liability Company
LLISSE	Long-Lived In-Situ Solar System Explorer
L'LORRI	High-Resolution Visible Imager
LMOC	LCRD Mission Operations Center
LoB	Line of Business
LOFTID	LEO-based Flight Test of Inflatable Decelerator
LOX	Liquid Oxygen
LP	Limb Profiler
LRA	Laser Retro-reflector Assembly
LRD	Launch Readiness Date
LRO	Lunar Reconnaissance Orbiter
LRR	Launch Readiness Review
LSIC	Lunar Surface Innovation Consortium
LSII	Lunar Surface Innovation Initiative
LSITP	Lunar Surface Instrument and Technology Payload
LSP	Launch Services Program
L'TES	Thermal Emission Spectrometer
LTV	Lunar Terrain Vehicle
LunIR	Lunar Infrared imaging
LuSTR	Lunar Surface Technology Research
LVS	Lander Vision System
LVSA	Launch Vehicle Stage Adapter
LWS	Living With a Star
M&MA	Moon and Mars Architecture
MAF	Michoud Assembly Facility
MAGIC	MAGnetometers for Innovation and Capability
MAIA	Multi-Angle Imager for Aerosols
MAIANSE	MUREP’s American Indian and Alaska Native STEM Engagement
MARCI	Mars Color Imager
MASPEX	The Mass Spectrometer for Planetary Exploration/Europa
MAV	Mars Ascent Vehicle

ACRONYMS AND ABBREVIATIONS

MAVEN	Mars Atmosphere & Volatile Evolution
MCL	Metrology and Calibration Laboratory
MCR	Mission Concept Review
MCS	Mars Climate Sounder
MDAO	Multi-disciplinary Design, Analyses, and Optimization
MDR	Mission Design Review
MDSCC	Madrid Deep Space Communications Complex
MEaSUREs	Making Earth System Data Records for Use in Research Environments
MEDA	Mars Environmental Dynamics Analyzer
MEDLI2	Mars Entry Descent and Landing Instrument 2
MEGA	Mars-Earth Gravity Assist
MEGANE	Mars-moon Exploration with Gamma rays and Neutrons
MES	Mission Enabling Services
MESSENGER	Mercury Surface, Space Environment, Geochemistry, and Ranging
MeV	Mega electron-Volt
MEVV	Multi-Element Validation and Verification
MFA	Multi-Factor Authentication
MIDEX	Medium-Class Explorers
MIE	Museum and Informal Education
MIGHTI	Michelson Interferometer for Global High-Resolution Thermospheric Imaging
MIR	Mission Integration Review
MIRI	Mid-Infrared Instrument
MIRO	MUREP Institutional Research Opportunity
MISE	Mapping Imaging Spectrometer for Europa
MISR	Multi-angle Imaging SpectroRadiometer
MISSE	Materials International Space Station Experiment
MIT	Massachusetts Institute of Technology
ML	Mobile Launcher
MLS	Microwave Limb Sounder
MMA	Main Mission Antenna
MMPACT	Moon-to-Mars Planetary Autonomous Construction Technology
MMRTG	Multi-mission Radioisotope Thermoelectric Generator
MMS	Magnetospheric Multiscale
MMX	Martian Moons Exploration
MO	Missions of Opportunity
MODIS	Moderate Resolution Imaging Spectroradiometer
MOMA	Mars Organic Molecule Analyzer
MOMA-MS	MOMA Mass Spectrometer
MOSB	Main Optical Sub-Bench
MOU	Memorandum of Understanding
MOXIE	Mars Oxygen ISRU Experiment
MPAR	Major Program Annual Report

ACRONYMS AND ABBREVIATIONS

MPIA	Max Planck Institute for Astronomy
MRO	Mars Reconnaissance Orbiter
MS	Mass Spectrometer
MSD	Mission Support Directorate
MSFC	Marshall Space Flight Center
MSI	Minority-Serving Institutions
MSL	Measurement Systems Laboratory
MSolo	Mass Spectrometer observing lunar operations
MSR	Mars Sample Return
MTB	Multirotor Test Bed
MUREP	Minority University Research and Education Program
MUSS	Multi User Systems and Support
MW	Megawatt
NAC	National Agency Check
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications
NASEM	National Academies of Science, Engineering, and Mathematics
NASS	National Agricultural Statistics Survey
NAVO	NASA Astronomical Virtual Observatories
NCCIPS	National Center for Critical Information Processing and Storage
NCRP	National Council on Radiation Protection
NDL	Navigation Doppler Lidar
NEA	Near Earth Asteroid
NEAT	NASA Electric Aircraft Testbed
NED	NASA/IPAC Extragalactic Database
NEK	Nezemnyy Eksperimental’nyy Kompleks
NEN	Near Earth Network
NEO	Near-Earth objects
NEOO	Near-Earth Object Observations
NEOWISE	Near Earth Objects Wide-field Infrared Survey Explorer
NEPA	National Environmental Policy Act
NESC	NASA Engineering and Safety Center
NET	No Earlier Than
NEXT-C	NASA Evolutionary Xenon Thruster – Commercial
NextSTEP	Next Space Technologies for Exploration Partnerships
NG	Northrop Grumman
NGAS	Northrop Grumman Aerospace Systems
NGIS	Northrop Grumman Innovation Systems
NGSS	Northrop Grumman Space Systems
NHPA	National Historic Preservation Act
NIAC	NASA Innovative Advanced Concepts

ACRONYMS AND ABBREVIATIONS

NICER	Neutron star Interior Composition Explorer
NIH	National Institutes of Health
NIP	New Investigator Program
NIRCam	Near-Infrared Camera
NIRSpec	Near-Infrared Spectrograph
NIRVSS	Near InfraRed Volatiles Spectrometer System
NISAR	NASA-ISRO Synthetic Aperture Radar
NIST	National Institute of Standards and Technology
NISTAR	National Institute of Standards and Technology Advances Radiometer
NLS	NASA Launch Services
NN-EXPLORE	NASA-National Science Foundation Exoplanet Observational Research
NOAA	National Oceanographic and Atmospheric Administration
NOS	New Observing Strategies
NPLP	NASA-Provided Lunar Payload
NPP	National Polar-orbiting Partnership
NPR	NASA Procedural Requirements
NRA	NASA Research Announcement
NRHO	Near Rectilinear Halo Orbit
NRPTA	National Rocket Propulsion Test Alliance
NSC	NASA Safety Center
NSF	National Science Foundation
NSN	Near Space Network
NSP	National Space Policy
NSpC	National Space Council
NSPIRES	NASA Solicitation and Proposal Integrated Review and Evaluation System
NSS	National Security Systems
NSSC	NASA Shared Services Center
NuSTAR	Nuclear Spectroscopic Telescope Array
O&M	Operations and Maintenance
O&TM	Operations and Test Management
O2O	Optical to Orion
OA	Office of Audits
OCE	Office of the Chief Engineer
OCEAN	Ocean Biology and Biogeochemistry
OCFO	Office of the Chief Financial Officer
OCHCO	Office of Chief Human Capital Officer
OCHMO	Office of Chief Health Medical Officer
OCI	Ocean Color Instrument
OCIO	Office of the Chief Information Officer
OCO	Orbiting Carbon Observatory
OCOMM	Office of Communications
OCT	Office of the Chief Technologist

ACRONYMS AND ABBREVIATIONS

ODEO	Office of Diversity and Equal Opportunity
OFT	Orbital Flight Test
OGC	Office of General Counsel
OI	Office of Investigations
OIG	Office of Inspector General
OIIR	Office of International and Interagency Relations
OLI	Operational Land Imager
OMB	Office of Management and Budget
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
OMS	Orbital Maneuvering System
ONERA	French Office National d'Etudes et Recherches Aérospatiales
OPF	Orbiter Processing Facility
OPM	Office of Personnel Management
OPOC	Orion Production Operation Contract
OPR	Operating Pressure Ratio
OPS	Office of Protective Services
ORR	Operational Readiness Review
OSAM	On-Orbit Servicing, Assembly, and Manufacturing
OSBP	Office of Small Business Programs
OSC	Orbital Sciences Corporation
OSIRIS-Rex	Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer
OSMA	Office of Safety and Mission Assurance
OSS	Open Sourced Science
OSST	Ocean Salinity Science Team
OSTEM	Office of STEM Engagement
OSTP	Office of Science and Technology Policy
OSTST	Ocean Surface Topography Science Team
OTE	Optical Telescope Element
PAC	Planetary Science Advisory Committee
PACE	Payload Accelerator for CubeSat Endeavors
PASS	Precision Assembled Space Structure
PB	President's Budget
PBS	Plum Brook Station
PCA	Physicians' Comparability Allowance
PCM	Post Certification Mission
PCOS	Physics of the Cosmos
PDCO	Planetary Defense Coordination Office
PDP	Plasma Diagnostics Package
PDR	Preliminary Design Review
PDS	Planetary Data System
PEP	Particle Environment Package

ACRONYMS AND ABBREVIATIONS

PEP-Hi	Particle Environment Package suite of instruments
PFAS	Per- and Polyfluoroalkyl Substances
PI	Principal Investigator
PIMS	Plasma Instrument for Magnetic Sounding
PIR	Program Implementation Review
PIV	Personal Identity Verification
PLA	Payload Adapter
PMCs	Polar mesospheric clouds
PMPO	Planetary Missions Program Office
PMT	Program Management Team
PNT	Positioning, Navigation, and Timing
POWER	Protecting Our Workers and Ensuring Reemployment
PPE	Power and Propulsion Element
PPF	Payload Processing Facility
PREFIRE	Polar Radiant Energy In The Far Infrared Experiment
PRIME	Polar Resources Ice Mining Experiment
PRISM	Payloads and Research Investigations on the Surface of the Moon
PROSWIFT	Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow
PSD	Planetary Science Division
PSI	Physical Sciences Informatics
PSM	Procurement Strategy Meeting
PSP	Parker Solar Probe
PSR	Pre-Ship Review
PTD	Pathfinder Technology Demonstrator
PUFFER	Pop-Up Flat Folding Explorer Robot
PUNCH	Polarimeter to Unify the Corona and Heliosphere
QC	Quality Control
QueSST	Quiet Supersonic Technology
R&A	Research and Analysis
R&D	Research and Development
R&T	Research and Technology
R3	Rapid Response Research
RAC	Regolith Adherence Characterization
RAMPT	Rapid Analysis and Manufacturing Propulsion Technology
RAP	Robotics Alliance Project
REASON	Radar for Europa Assessment and Sounding: Ocean to Near-surface
RF	Radio Frequency
RFC	Regenerative Fuel Cell
RFI	Request for Information
RFP	Request for Proposal
RFU	Radio Frequency Unit

ACRONYMS AND ABBREVIATIONS

RHU	Radioisotope Heater Unit
RID	Research Infrastructure Development
RIME	Radar for Icy Moons Exploration
RO	Radio Occultation
ROD	Record of Decision
RORR	Remote Opportunity Rapid Response
ROSA	Roll Out Solar Array
ROSES	Research Opportunities in Space and Earth Sciences
RPA	Robotic Process Automation
RPOD	Rendezvous and Proximity Operations Demonstration
RPS	Radioisotope Power Systems
RPSF	Rotation, Processing, and Surge Facility
RPT	Rocket Propulsion Testing
RRNES	Rapid Response and Novel Research in Earth Science
RS	Reflected Solar
RSD	Ring-Sheared Drop
RTCA	Radio Technical Commission for Aeronautics
RTG	Radioisotope Thermoelectric Generator
RV	Radial Velocity
RVLT	Revolutionary Vertical Lift Technology
SAAs	Space Act Agreements
SAC	Super-lightweight Aerospace Composites
SAGE	Stratospheric Aerosol and Gas Experiment
SAM	Sample Analysis at Mars
SANS	Spaceflight Associated Neuro-ocular Syndrome
SAR	Synthetic Aperture Radar
SAT	Strategic Astrophysics Technology
SATCOM	Satellite Communications
SBA	Small Business Administration
SBIR	Small Business Innovation Research
SCALPSS	Stereo CAmeras for Lunar Plume Surface Studies
SCaN	Space Communications and Navigation
SDG	Sustainable Development Goal
SDO	Solar Dynamics Observatory
SDR	System Design Review
SE&I	Systems Engineering and Integration
SEAP	STEM Education and Accountability Project
SEDAC	Socio-economic Data and Applications Center
SEIS	Seismic Experiment for Interior Structure
SEP	Solar Electric Propulsion
SERFE	Spacesuit Evaporation Rejection Flight Experiment
SET	Space Environment Testbeds

ACRONYMS AND ABBREVIATIONS

SEWP	Solutions for Enterprise-Wide Procurement
SFCO	Space Flight Crew Operations
SFD	Sustainable Flight Demonstrator
SFNP	Sustainable Flight National Partnership
SFO	Suborbital Flight Opportunities
SFS	Space and Flight Support
SGP	Space Geodesy project
SGSS	Space Network Ground Segment Sustainment
SIF	Solar Induced Chlorophyll Fluorescence
SIM	Spectral Irradiance Monitor
SIMPLEx	Small Innovative Missions for Planetary Exploration
SIO	Systems Integration and Operationalization
SIPS	Science Investigator-led Processing Systems
SIR	System Integration Review
SIRIUS	Scientific International Research in Unique Terrestrial Station
SISTINE	Suborbital Imaging Spectrograph for Transition region Irradiance from Nearby Exoplanet
SLC	Space Launch Complex
SLI	Sustainable Land Imaging
SLS	Space Launch System
SM	Service Module
SMA	Safety and Mission Assurance
SMAP	Soil Moisture Active/Passive
SMARTNav	Small-body Maneuvering Autonomous Real-Time Navigation
SMD	Science Mission Directorate
SMEX	Small Explorers
S-MODE	Sub-Mesoscale Ocean Dynamics and Vertical Transport
SMR	System Maturation Reviews
SN	Space Network
SNC	Sierra Nevada Corporation
SNT	Space Nuclear Technologies
SNWG	Satellite Needs Working Group
SOC	Solar Orbiter Collaboration
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
SOI	Statement of Intent
SoloHI	Solar Orbiter Heliospheric Imager
SOMA	Science Office for Mission Assessments
SORCE	Solar Radiation and Climate Experiment
SOST	Subcommittee on Ocean Science and Technology
SpaceX	Space Exploration Technologies Inc.
SPD	Space Policy Directive
SPEC	Stages Production Evolution Contract

ACRONYMS AND ABBREVIATIONS

SPHEREx	Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer
SPICES	Solar wind and Pickup Ion Composition Energy Spectrometer
SPIDER	Space Infrastructure Dexterous Robot
SPLICE	Safe and Precise Landing-Integrated Capabilities Evolution
SPR	Sync Point Review
SR&T	Strategic Research and Technology
SRB	Standing Review Board
SRL	Sample Retrieval Lander
SRON	Netherlands Institute for Space Research
SRR	Systems Requirement Review
SSC	Stennis Space Center
SSFL	Santa Susana Field Laboratory
SSI	Solar Spectral Irradiance
SSM	Surface Soil Moisture
SSMO	Space Science Mission Operations
SSMS	Safety, Security, and Mission Services
SSO	Sun-synchronous Orbit
SST	Small Spacecraft Technologies
STA	Structural Test Article
STAR	Strategic Technology Architecture Round-table
STDT	Science and Technology Definition Team
STEM	Science, Technology, Education, and Mathematics
STEREO	Solar Terrestrial Relations Observatory
STI	Scientific and Technical Information
STMD	Space Technology Mission Directorate
STP	Solar Terrestrial Probes
STPSat	Space Test Program Satellite
STRG	Space Technology Research Grants
STROFIO	Start from a Rotating Field Mass Spectrometer
STScI	Space Telescope Science Institute
STTR	Small Business Technology Transfer
SUDA	Surface Dust Mass Analyzer
SunRISE	Sun Radio Interferometer Space Experiment
SuperTIGER	Trans Iron Galactic Element recorder
SWaP	Size, Weight, and Power
SWAPI	Solar Wind and Pickup Ions
SWE	Snow Water Equivalent
SWFO	Space Weather Follow-On
SWOT	Surface Water Ocean Topography
SWRI	Southwest Research Institute
SWS	System-Wide Safety

ACRONYMS AND ABBREVIATIONS

TA	Technical Authority
TACP	Transformative Aeronautics Concepts Program
TAG	Touch-And-Go
TALOS	Thruster Advancement for Low-Temperature Operations in Space
TAMD	Technology Analysis and Mission Design
TBCC	Turbine-Based Combined Cycle
TBD	To Be Determined
TBIRD	Terabyte Infrared Delivery
TC	Tropical Cyclone
TCI	Thermosphere Climate Index
TDM	Technology Demonstration Missions
TDRS	Tracking and Data Relay Satellite
TEAM II	Teams Engaging Affiliated Museums and Informal Institutions
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TESS	Transiting Exoplanet Survey Satellite
TGO	Trace Gas Orbiter
THEMIS	Time History of Events and Macroscale Interactions during Substorms
TIDES	Thriving In Deep Space
TIM	Total Irradiance Monitor
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics
TIRS	Thermal Infrared Sensor
TLI	Trans-Lunar Injection
TOPEX	Topography Experiment
TP	Tipping Point
TPA	Thruster Probe Assembly
TPS	Thermal Protection System
TRACER	Tracking Aerosol Convection interactions ExpeRiment
TRACERS	Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites
TREAT	To Research, Evaluate, Assess, and Treat
TRIDENT	The Regolith and Ice Drill for Exploring New Terrain
TRISH	Translational Research Institute for Space Health
TRL	Technology Readiness Level
TRMM	Tropical Rainfall Measurement Mission
TRN	Terrain Relative Navigation
TROPICS	Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of SmallSats
TSI	Total Solar Irradiance
TSIS	Total and Spectral Solar Irradiance Sensor
TTBW	Transonic Truss-Braced Wing
TTT	Transformational Tools and Technologies
TUI	Tethers Unlimited Inc.
TWINS	Two Wide-angle Imaging Neutral-atom Spectrometers

ACRONYMS AND ABBREVIATIONS

U.S.	United States
UAG	Users' Advisory Group
UAM	Urban Air Mobility
UAS	Unmanned Aircraft Systems
UFE	Unallocated Future Expenses
UI	University Innovation
UKSA	United Kingdom Space Agency
ULA	United Launch Alliance
ULI	University Leadership Initiative
ULS	United Launch Services
UMBC	University of Maryland Baltimore County
UPS	Uninterruptable Power System
UQ	Uncertainty Quantification
URT	Underway Recovery Test
USA	Universal Stage Adapter
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
USOS	U.S. Operating Segment of ISS
USSF	United States Space Force
UTM	UAS Traffic Management
UV	Ultraviolet
UVOT	Ultraviolet/Optical Telescope
UVS	Ultraviolet Spectrograph
UWMS	Universal Waste Management System
V&V	Verification and Validation
VAB	Vehicle Assembly Building
VADR	Venture-Class Acquisitions of Dedicated and Rideshare
VAFB	Vandenberg Air Force Base
VALUABLES	Valuation of Applications Benefits Linked to Earth Science
VCLS	Venture Class Launch Services
VIIRS	Visible Infrared Imaging Radiometer
VIPER	Volatiles Investigating Polar Exploration Rover
VO	Virtual Observatory
VRT	VIPER Review Team
VSAT	Vertical Solar Array Technology
VTOL	Vertical Take Off and Landing
WAVES	Radio and Plasma Wave
WCF	Working Capital Fund
Webb	James Webb Space Telescope
WFF	Wallops Flight Facility

ACRONYMS AND ABBREVIATIONS

WFIRST	Wide-Field Infrared Survey Telescope
WISE	Wide-field Infrared Survey Explorer
WISPR	Wide-field Imager for Solar Probe
WIT	Water Impact Testing
WIYN	Wisconsin, Indiana, Yale, and NOAO Telescope
WMKO	W.M. Keck Observatory
WOMA	Wide Field Instrument Opto-Mechanical Assembly
WRC	World Radiocommunications Conferences
WSTF	White Sands Test Facility
WWAO	Western Water Applications Office
xEMU	Exploration Extravehicular Mobility Unit
XMM	X-Ray Multi-Mirror Mission
XQC	X-ray Quantum Calorimeter
XRCF	X-Ray Cryogenic Facility
XRISM	X-Ray Imagining and Spectroscopy
ZEV	Zero Emission Vehicle