From the Project Manager

NASA Administrator James Beggs has agreed to add an asteroid option to the Galileo mission and to change the Jupiter arrival date from August 29, 1988 to December 10, 1988. The option will permit a later decision to fly by the asteroid 29 Amphitrite in December 1986.

The approval follows two years of study by numerous scientific groups, mission designers, and program officials to devise a means to include this option. If the option is elected — a decision to be made after launch — it would add a significant scientific “first” to the Galileo mission.

The National Academy of Sciences, as well as the Solar System Exploration Committee (SSEC), has identified the investigation of the asteroids by spacecraft as an essential element of a balanced planetary exploration program.

The flyby has the unanimous endorsement of the Galileo Project Science Group and the Small Bodies Working Group of the SSEC.

The asteroid flyby will be treated as an add-on, not a primary mission objective, and will not be permitted to compromise the basic mission objectives or to add any risk to the Jupiter mission.

A decision on whether or not to exercise the flyby option will be made about two months after launch, based on an assessment at that time of the health of the spacecraft, particularly the attitude control system and the mission operations system.

A new trajectory containing both Amphitrite and Jupiter, constrained by the launch vehicle energy and existing launch window, has been developed. The trajectory will result in a delay in the Jupiter arrival date from August 1988 to December 1988. No mission operations work or added software capability related to the flyby will be accomplished prior to launch other than that required to plan the primary mission based on the asteroid flyby trajectory.

If the flyby option is exercised, the asteroid flyby distance will be determined by spacecraft safety considerations. A special hazards workshop concluded that with a 10,000 to 20,000 kilometer flyby distance, the hazard to the Galileo spacecraft is no greater than merely flying through the asteroid belt. (The asteroid belt is located between the orbits of Mars and Jupiter.)

At that distance, significant scientific data can be obtained, including images with a resolution of 200 to 300 meters, high quality infrared spectral mapping to determine the asteroid’s mineral composition, and a good mass determination. The scan platform would be pointed in a sequence of pre-determined fixed directions, letting the asteroid drift through the instruments’ field of view before moving to the next position.

Amphitrite is a large, main belt asteroid about 200 kilometers in diameter; from Earth it appears as the twelfth brightest asteroid. As such, it is an outstanding candidate for exploration. Amphitrite lies in a part of the asteroid belt subject to gravitational perturbations by Jupiter and might be a source of some of the meteorites that impact Earth.

The effect on the Jupiter mission will be minor. Since the flyby requires added expenditure of propellant in the early mission phase, the number of tour orbits of Jupiter would be decreased from 11 to 10. Consequently, the length of the tour has been extended from 20 months to 22 months to permit the achievement of all the major objectives previously encompassed by the 11-orbit tour.

There will be no near-term cost impact due to the incorporation of the flyby option. Major added costs, estimated at $20-25 million, are attributable to a five-month mission extension due to the delayed arrival date and increased tour time.

— J. R. Casani
Centaur G’

The Space Shuttle will lift the Galileo spacecraft to Earth orbit, but it will take a powerful upper stage rocket to boost the 2-1/2 ton spacecraft out of Earth orbit and on toward Jupiter.

The expendable high energy upper stage for Galileo is the Centaur G-Prime (G’), a new version of the Centaur stage that has launched all of the United States’ planetary missions since 1962. The combination of Centaur with the Titan booster launched the Helios, Viking, and Voyager spacecraft. The Atlas/Centaur combination boosted a series of Surveyors (7) to soft landings on the moon starting in 1966, and Atlas/Centaur continue to boost Earth orbiting communications satellites and various Earth-orbiting and planetary scientific satellites.

Galileo’s Centaur is being built in San Diego, California at General Dynamics Convair Division, under contract to NASA/Lewis Research Center, Cleveland, Ohio.

Development of the Centaur stage for use with the Shuttle began in July 1981. Colloquially known as the “wide-body” Centaur, the original rocket configuration has been widened to provide increased propellant capacity while accommodating longer payload length. The first use of the wide-body will be in May 1986, when Ulysses (formerly the International Solar Polar Mission) will be boosted toward Jupiter on the initial phase of its journey over the poles of the Sun. The Galileo launch will follow about ten days later.

The Shuttle will carry the mated Centaur/Galileo combination to low Earth orbit, about 130 nautical miles. About six hours after liftoff, on about the fourth orbit, the Galileo/Centaur combination will be prepared for release from the Shuttle bay. The Centaur integrated support structure (CISS) will erect the rocket to about 45 degrees and then springs will gently push it away from the Shuttle at about one foot per second. The Centaur burn will begin about 45 minutes after separation from the Shuttle.

Centaur’s thin stainless steel tanks will hold about 21,000 kilograms of propellants, in a 5:1 ratio of oxygen to hydrogen. This is an increase of about 50 percent in propellant load from the Atlas/Centaur. Two Pratt and Whitney engines will develop about 16,500 pounds of thrust each. At the end of the 9-1/2 minute Centaur burn, Galileo will be traveling over 50,000 mph.

After Centaur main engine cutoff, Galileo will unfurl its antenna, deploy its instrumented booms, and fire pyrotechnic devices to sever the joint holding it to the Centaur. After separation, the Centaur will maneuver away to avoid a collision with and/or contamination of the spacecraft. Centaur’s guidance and control electronics are provided by Honeywell and Teledyne Systems Corporation.

The major weld of the tank structure of the Centaur G’ designated for Galileo was completed in October 1984, and the innards—propellant loading probes, vent pipes, etc.—are now being installed. Completion of final assembly is scheduled for March 1985. After a three-month checkout, the Centaur will be shipped via airplane to Cape Canaveral in July 1985. Tanking tests will be conducted in October 1985 at Complex 36, and in February 1986 a “wet” (propellants loaded) Centaur countdown demonstration test will be performed using the Shuttle, Centaur, and the development test model of the Galileo spacecraft.

Joan Sherley, liaison between Convair and JPL for Galileo, notes that interface activity for the Galileo mission is more complex than for previous planetary missions, since use of the high energy upper stage in the Shuttle is brand new.

Both Galileo and Ulysses carry radio-isotopic thermoelectric generators (RTGs) to provide internal electrical power. Prior to launch, the RTGs must be cooled, and one challenge has been designing the system to run cool water lines from the Shuttle, along the CISS and Centaur stage, to the field joint on Galileo’s spacecraft adapter, and then to run the hot water lines back down.

Plumbing lines for gaseous nitrogen must also run to the Galileo orbiter’s science instruments to avoid contamination prior to separation from the Shuttle. General Dynamics is integrating the JPL-provided airborne purification equipment box into the CISS and running the plumbing lines.

“The launch opportunity (a ten-day period in May 1986) gives a big lever arm,” says Marty Winkler, Director of the Shuttle/Centaur Program at Convair. “It can’t be late, and it has to be built right. Motivation in the plant here is very high for those reasons. When you think through the complexity of everything that has to go right, it’s monumental!”
Solid State Imaging

Building on the experience of the Pioneer and Voyager programs, Galileo will obtain about 40,000 images containing useful scientific information about the jovian system—the planet Jupiter, its atmosphere, rings, satellites, and magnetosphere.

The Galileo orbiter will carry a 1500-mm narrow angle telescope inherited from Voyager. Along with an image sensor and electronics, this forms the solid state imaging subsystem (SSI).

"Galileo's 22-month tour of the jovian system will allow long-term studies of Io's active volcanoes and Jupiter's atmosphere. The satellites will be mapped at a wide range of angles and lighting conditions and at very high resolution, utilizing satellite flybys that are as much as 20 to 100 times closer than ever achieved before," notes imaging team leader Michael Belton of the National Optical Astronomy Observatories.

"The design of the SSI was dictated by a combination of goals and constraints," explains SSI science coordinator Ken Klaasen. "The need to study both atmospheric motion and geologic formations dictates a high-resolution large-format camera, while the need to study the composition of satellite surfaces and the vertical structure of features in Jupiter's atmosphere dictates the use of several spectral filters within the range 400 to 1100 nanometers. Accurate mapping and atmospheric velocity measurements require a camera with excellent geometric fidelity, while precise photometric requirements necessitate a linear detector, stable calibration, and adequate data encoding. Low lighting situations, such as observations of the auroras, lightning, and ring system, require a detector of very high sensitivity and an optical system with low scattered light. Constraints on the design included limitations on the available telemetry rate, potential image smearing caused by residual motions in the scan platform, use of large amounts of shielding to protect the instrument from Jupiter's harsh radiation environment, limited electrical power and mass, and protection from contamination during launch and from propellant byproducts in flight."

For the Galilean satellites Io, Europa, Ganymede, and Callisto, the imaging investigators hope to determine the form and structure of at least 50 percent of the satellite surfaces at a scale of 1 kilometer or better. In many images, features as small as 100 meters will be distinguishable. In the very best pictures, the smallest distinguishable features will be 20 meters. Volcanic Io is of prime interest, and in addition to geological studies, the imaging team will try to detect Io's atmosphere and map the source of sodium emissions that connect it with Io's torus.

Since the SSI's wavelength range extends from the visible into the near-infrared, the experimenters will be able to map variations in the satellites' color and albedo (reflectivity) that show differences in the composition of surface materials.

Imaging data will also pinpoint the location of each satellite's spin axis, their rotation rates, and their shapes and dimensions with high precision.

As opportunities arise, the camera will also turn toward Jupiter's smaller and more distant satellites to obtain information on the form and structure of their surfaces, colors, and albedoes. This information will aid in determining the origin of these small satellites which were captured by Jupiter sometime after its formation. New small satellites may be found in or near Jupiter's rings.

Images of features such as the Great Red Spot, "barges," and white ovals will yield new information on their physical structure and will aid in distinguishing between mass motion and wave motion. Relative motion among clouds at various altitudes will be tracked to learn how local wind flows maintain themselves. A detailed, long-term study of Jupiter's largest atmospheric motions will show how the planet transports energy from the equator to the poles and maintains its equilibrium. The SSI's near-infrared filters will allow us to "see" at different levels in the atmosphere to study relationships among vertical structure, color, and morphology.

The imaging instrument is mounted with three other optical instruments on a movable platform bolted to the non-spinning portion of the Galileo orbiter. This scan platform can be slewed up, down or sideways to point the instruments. The optical axes of the instruments—the SSI, the near infrared map-

The SSI's optical sensor is shielded to protect it from radiation damage.
Meet the Team

A sign above the door of Torrence Johnson’s office reads: “Self-Guided Tour Interest Point 36A: Typical Scientist’s Office”. A peek inside reveals a landslide of papers, wallboards charting Congressional processes and the resolution of Galileo’s images of the jovian satellites, a tiny figure of Yoda sitting atop a desktop computer, and a sign from Star Wars: “The Force is With Us.”

As Galileo’s Project Scientist, Torrence is the principal science advisor to the project, the principal science interface between the project and the principal investigators on Galileo’s science experiments, an ex-officio member of all of Galileo’s science teams and working groups, and chair of the Project Science Group.

Torrence’s involvement with Galileo goes back to the mid-70’s when he was part of the Mariner Jupiter Uranus planning group and then the Jupiter Orbiter Probe science working group, the group that developed the science rationale for Galileo and “sold” the mission to the science community and to Congress.

“All of this planning was done before Voyager was even launched,” noted Torrence. “When the Voyager results began coming in, we had to change the emphasis in a few areas, but it’s still basically the same mission in concept that we started with. It’s been exciting to have an active mission – Voyager – while we plan Galileo. It gave us something to look forward to when things looked darkest,” he said, referring to the many attempts to kill the project due to launch vehicle delays and budget cuts.

“Galileo was viewed as the baseline for the planetary program. If we had lost Galileo we would have lost the whole planetary program. Networking efforts at high levels by the scientific and industrial communities saved Galileo, and also opened the door for new missions such as the Mars Observer,” he reflected.

“The scientists involved have a big stake in Galileo – at least 12 years of thinking and planning, and 5 to 10 years of hard work building instruments and writing software. As scientists, we are very lucky to have the opportunity to be involved in the operational phase of the mission and I get a lot of personal fulfillment from that as the results come in,” he concluded.

Torrence earned his undergraduate degree in physics from Washington University, St. Louis, Missouri, graduating with honors, before doing his doctoral work at Caltech on the albedo and spectral reflectivity of Jupiter’s Galilean satellites. He was a research associate at MIT for several years before returning to Pasadena and JPL. He is currently a member of the Voyager imaging science team, a co-investigator for Galileo’s near infrared mapping spectrometer, a guest investigator for the Hale Observatories, and recently spent two years as a visiting associate professor of planetary sciences at Caltech.

Torrence is a fellow of the Explorers Club and the American Association for the Advancement of Science, a founding member of The Planetary Society, and a member of numerous other professional organizations.

As his job has thrust him into the public eye, Torrence has become a sought-after public speaker for both technical and non-technical audiences. In January 1985 he will present a Watson lecture at Caltech on Jupiter’s satellite Io.

Torrence and his wife Mary Eleanor live in Altadena with their children Aaron and Eleanor, and enjoy scuba diving and cooking.

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Imaging...

ping spectrometer, the ultraviolet spectrometer, and the photopolarimeter-radiometer – are aligned so they are looking at the same areas, and their data will be correlated. For example, the use of Voyager’s imaging and infrared data confirmed the possibility and extent of lava lakes on Io.

“The SSI uses a Cassegrain telescope with a 176.5-mm aperture, and a fixed relative aperture of f/8.5,” explains instrument manager Maurice Clary. “It is focussed on infinity. Light from a scene is collected on an 800 line by 800 column solid state silicon image sensor array called a charge-coupled device (CCD). Charge is transferred by rapidly cycling the voltage level applied to the 640,000 gates in this integrated circuit. Analog video data from the CCD are converted to digital bits, sent to the telemetry system, and relayed to Earth. There, the bit stream is delayed from the tracking stations to image reconstruction equipment at JPL.”

An eight-position filter wheel is stepped on command to obtain images of scenes through several different filters which may then be combined electronically at Earth to produce color images. There are 28 selectable exposure times between 0.004 and 51.2 seconds. Galileo’s spectral range is three times that of Voyager, and its field of view is 8.13 x 8.13 milliradians. The resolution is about 34 line pairs (of the 800 x 800 sensor array) per millimeter.

Since high levels of neutrons emitted by Galileo’s onboard power sources could degrade the image quality the camera’s CCD is cooled to -110° C to eliminate the problem. The CCD is protected from Jupiter’s natural radiation by a 1-cm thick tantalum shield. While transient radiation-induced effects may be seen when the spacecraft is in the heaviest radiation environment near Jupiter, no damage is expected up to a total radiation dose of 100,000 rads.

The SSI was designed and assembled at JPL. It weighs 29.7 kilograms (65 pounds) and draws 15 watts. Texas Instruments provided the virtual phase CCD. The SSI uses RCA 1802 microprocessors and contains 600 integrated circuits. The telescope, shutter, and filters were inherited from Voyager but have been improved to better reject off-axis scattered light. The collimator used for pre-launch testing was inherited from Mariner 10. The electronics chassis was fabricated on a numerically-controlled machine at JPL.