FROM THE PROJECT MANAGER

Despite rumors to the contrary, it apparently never was the intent of the Office of Management and Budget (OMB) or the Presidential Science Advisor, Dr. George Keyworth, to cancel the Galileo Project. Dr. Keyworth explained this to me following his talk to the National Space Club in Washington, D.C. on February 24. In an article published in the Washington Post on December 2, 1981, Dr. Keyworth was quoted as recommending a halt to all new planetary space missions for at least the next decade. But, Dr. Keyworth explained, he never intended this statement to include halting Galileo — or the Venus Orbiting Imaging Radar (VOIR) project either, for that matter. Nor does he feel that all future planetary programs should be halted. Apparently, what Dr. Keyworth intended was that, for the next decade at least, we should suspend new starts of large, i.e., $500 million to $1 billion programs such as Galileo, Voyager and Viking, while continuing with smaller scaled missions in the $200 million to $300 million category. Dr. Keyworth is advocating a balanced program of space science missions, that is, a proper balance between planetary exploration, astrophysics, and the other fields of space science.

Further testimony to the continuing support of Galileo by the White House and the OMB is reflected by the substantial increase in funding for Galileo submitted by the President in his FY’83 budget message to Congress. This increase, of course, was a necessary consequence of switching from the NASA Centaur upper stage to the Air Force two-stage IUS (Inertial Upper Stage), which requires a third stage to be developed for use with the IUS and the use of the ΔV-EGA trajectory type.

JPL has been given responsibility for developing the new stage to be used for both Galileo and the International Solar Polar Mission (ISPM) at an estimated cost of $50 million to be borne equally by both projects. Galileo will be the developing agent responsible for the design and implementation of the stage.

Galileo’s share of the stage, plus the cost of modifying the spacecraft for the ΔV-EGA mission, the new launch vehicle integration work, and the cost increases associated with the ΔV-EGA mission, are expected to add a total of almost an additional $170 million to the Project, bringing the total cost to $864 million. The very fact that such a large increase in Galileo funding was supported speaks to the very strong support the project enjoys within this Administration.

— John R. Casani

ΔV-EGA MISSION

Galileo’s baseline mission has changed from the 1985 launch on a direct trajectory to Jupiter to a 1985 launch on a longer trajectory that will make an initial orbit around the sun and come near Earth again before heading to Jupiter. This mission, known as ΔV-EGA, will require the addition of an injection module, lengthen the cruise phase by about two years, and decrease the number of obtainable encounters with Jupiter’s Galilean satellites.

The decision to fly the ΔV-EGA mission derives from the loss of funds for the modified Centaur upper stage that was to have boosted the spacecraft out of Earth orbit and onto a direct trajectory to Jupiter. The replacement upper stage will be the Air Force’s two-stage Inertial Upper Stage (IUS). However, a “kick stage” will also be needed to supply enough energy to boost the spacecraft into its initial orbit around the sun.

(The term ΔV-EGA denotes the use of a large propulsive maneuver in deep space in conjunction with a subsequent Earth gravity assist (EGA) to achieve the Jupiter trajectory.)

The scenario for the ΔV-EGA mission starts with launch in May 1985. The combined Orbiter and Probe, mated to the injection module (the “kick stage”) and the two-stage IUS, will be launched to Earth orbit in the space see page 4

MEET THE TEAM

Bill O’Neil

With a strong background in mission design and navigation, Bill O’Neil welcomed the opportunity to become involved with hardware when he became Galileo’s Science and Mission Design Manager. His areas of responsibility include mission design, interfaces with the Galileo scientists, and the Orbiter’s science instrument hardware.

Most of the hardware is now in fabrication, and Bill looks forward to deliveries to JPL beginning late this year. “Now its real,” he says, “and this mission will be executed.” Bill is also encouraged by the fact that Galileo will now have the advantage of using a fully-developed launch system, as both the space shuttle and IUS upper stage will have been fully tested and exercised by the time Galileo launches in 1985.

Bill studied aeronautical engineering, with a B.S. from Purdue and a master’s degree from the University of Southern California. Since joining JPL in 1963, he has worked on the moon lander Surveyor, the Mariner Mars 1971 orbiter, and the Viking Mars landers and orbiters. He was manager of the Mission Design Section before joining Galileo.

Bill and his wife Diane live in Arcadia and have three adult children. Although they enjoy travel and downhill skiing, on many weekends Bill can be found looking after their real estate investments — painting and fixing plumbing in their “mom and pop” apartments.
As the Galileo Probe enters Jupiter's atmosphere and rapidly descends through the cloud layers, its signal will be tracked by the relay radio hardware (RRH) onboard the Orbiter. This relay link is a crucial element of the Probe's mission, for otherwise there would be no way to transmit the Probe's data to Earth.

The RRH consists of a dish antenna, two receivers, and two ultra-stable oscillators. The 1.1-meter diameter antenna will be mounted on a moveable support boom attached to the non-spinning (or "despun") portion of the Orbiter. The antenna will remain in a stowed position until the Probe separates from the Orbiter about 150 days before arrival at Jupiter. After Probe separation, the antenna will be deployed. During the Probe's entry into Jupiter's atmosphere, the RRH antenna will be repointed to receive the Probe's signal. Use of this smaller, side-mounted antenna will allow the Orbiter's 5-meter antenna to remain Earth-pointed for tracking and communications.

Although the concept is simple, the Probe data relay presents special challenges that the hardware and firmware must meet. The acquisition, tracking, and transfer of Probe data to the Orbiter must occur autonomously. The receiver must automatically acquire and "lock" onto the Probe's signal within 50 seconds from the start of data transmission from the Probe. It must maintain lock for as long as the Probe survives in the increasingly hostile environment of Jupiter's atmosphere.

The first task of the Orbiter RRH will be to find the Probe's signal. It will be faint — approximately 1000 times less than the human audible level — and its frequency and signal strength will vary due to the Probe's rapid descent as well as turbulence and chemical effects in the atmosphere. During this important phase of the mission, the RRH antenna will be receiving the Probe's signal from a distance of over 200,000 kilometers, with a narrow (15°) beamwidth.

To ensure that the relay link is not jeopardized due to equipment failure, the RRH design is "redundant" — it has two receivers and two ultrastable oscillators, and the antenna is designed to simultaneously receive two channels of Probe data that are differentiated by frequency and polarization. The two receivers are physically and electrically identical except that each is tuned to its respective channel of Probe data transmission and each has a unique address for command and data transactions with the Orbiter's command and data subsystem computers. Both receive the same real-time data from the Probe. Each receiver uses an ultrastable oscillator as a reference to extract Doppler information from the Probe's signal. During the search and track modes, each receiver consumes 23 watts of power.

The RRH is controlled by a complex, permanently fixed computer sequence. Because events will occur rapidly, the Probe data acquisition, tracking, and transfer to the Orbiter must occur automatically.

The search for the Probe signal begins when power is applied to the receivers. In 16 seconds or less, the receivers will search the entire 70 kiloHertz bandwidth several times to find the Probe signal with a high probability. At the end of 40 seconds, the signal frequency and rate are estimated, and the receiver "locks" onto the signal phase within another 8 seconds. The Probe is expected to transmit for about one hour before it is silenced by the intense heat and crushing pressure.

The receiver breadboard tests and software are complete, and the qualification and flight units and unit tester are being assembled. Parts procurement is complete except for a recent change in the random access memory to provide better radiation hardness. The spacecraft will experience the most intense radiation during its close flyby of Jupiter as it relays the Probe's signal. The antenna is in the early stages of design.

Ames Research Center is providing the RRH along with the Probe system. The receivers and antenna are being developed, fabricated, and tested by Hughes Aircraft Company under contract to Ames, and the oscillators are provided by Frequency Electronics Inc. under subcontract to Hughes.

Two reviews this month represent significant milestones in the Galileo development schedule. The Final Mission and Systems Review (FMSR), to be held at JPL on May 17-19, is the culmination of all the Project design reviews. The agenda includes reviews of the mission design, engineering areas that comprise more than one system, and updates in several areas since the critical design reviews. In addition, the FMSR will cover all changes, both in requirements and design, resulting from the change to the Δv-EGA trajectory.

On May 20, the On-Board Software Implementation Review (OBSIR) at JPL will assess the implementation plans of the various on-board software packages, including the attitude and articulation control subsystem (AACS), command and data subsystem (CDS), Probe firmware, and science instrument software and firmware for both the Orbiter and Probe. (Firmware is computer programming that cannot be changed after launch.) Topics to be discussed include current software status, remaining development schedule, test approach and plans, configuration management plan, software maturity, and any schedule concerns.

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Jupiter's magnetosphere is the largest structure in the solar system. It is millions of miles across and tens of millions of miles long. If it were visible to us, it would appear in the night sky bigger than the moon.

The magnetometer instruments on-board the Galileo Orbiter will measure magnetic fields throughout Jupiter's enormous magnetosphere, from its boundaries where interactions with the solar wind will be studied, to the inner regions where properties of the planet itself will be investigated.

Planets having large magnetic fields, including the Earth, are surrounded by magnetospheres - "bubbles" in the solar wind in which the planet's magnetic field dominates and controls the behavior of charged particles. As the solar wind streams around this area, a magnetic tail is formed on the far side of the planet. Jupiter's magnetosphere can be visualized as a giant, tattered wind sock, with a bulbous end toward the sun and an elongated, flapping tail stretched away from the sun. Most of this magnetosphere is filled with gases of charged particles.

The Pioneer and Voyager missions showed that the size, shape, and internal structure of the Jovian magnetosphere changes, but they remained near Jupiter too briefly to study the process of change. As it orbits Jupiter for nearly two years, Galileo will record changes in the magnetosphere and help us understand their causes. For example, at Earth, large-scale instabilities that trigger explosive responses throughout the magnetosphere, including ionospheric effects such as aurora and radio noise, are initiated in the tail. The Galileo tour will include a large looping orbit that provides two months in the near-planetary regions of the tail where evidence of similar processes will be sought. (Jupiter's tail may extend as far as Saturn, over 650 million kilometers distant, but Galileo will go only about 11 million kilometers down the tail.)

Jupiter's four largest satellites — Io, Europa, Ganymede, and Callisto — orbit within Jupiter's magnetosphere. As the magnetized planet rotates, it sets the gases in the magnetosphere into rotation. The rotating charged particles interact with the satellites in ways that depend on whether or not a satellite is conducting, magnetized, or has an ionosphere. The Orbiter's tour through the Jupiter system will yield information about the magnetosphere-satellite interactions and about the satellites themselves. For example, measurements will reveal if the satellites have magnetic fields and thus provide critical information about their interiors.

Currents flowing along the magnetic field in the Jovian magnetosphere play a crucial role in coupling the magnetosphere with the upper atmosphere. In recent years such currents have been measured at Earth, but their importance at Jupiter was recognized much earlier. These currents stimulate radio emissions from the ionosphere (both at Jupiter and at Earth) and may play a role in producing auroras much like Earth's Northern and Southern Lights. Neutral atoms coming from Io or other moons are "spun up" to the rotation rate of the surrounding charged particles by forces transmitted from the ionosphere along the magnetic field of the magnetosphere. Exchange of mass and energy between the planet and its magnetosphere may occur along these field lines.

During the long journey to Jupiter, the magnetometer instrument will study the properties of interplanetary fields, including fast streams and interplanetary shocks. Long-term measurements of the solar wind magnetic field at great distances from the sun will be studied to find changes as solar activity increases in the next solar cycle.

The instrument consists of six sensing circuits, data handling circuits, and power circuits. Two clusters of three sensors each are mounted on an 11-meter boom which unfurls from the spinning section of the Orbiter after IUS separation. One set of sensors is mounted at the tip of the boom, while the other is about 6.7 meters from the spacecraft spin axis. The sensors must be placed at some distance from the main body of the spacecraft to minimize magnetic effects from the spacecraft. On the spacecraft, the sensed magnetic field is converted from an analog voltage to a digital signal. Data indicating the orientation of the spacecraft is added and the measurements are analyzed by the instrument's data processor. Effects caused by spacecraft-generated fields or the electronics circuits can be identified, measured, and separated during the data analysis so that only physically useful data need be transmitted to Earth. The challenge associated with pushing the on-board data processing capability of the instrument to its limit has been met successfully in the magnetometer design.

The basic magnetic measuring device, the ring-core sensor, was fabricated by the Naval Surface Weapons Center, White Oak, Silver Spring, MD. The entire assembly and associated electronics were designed by the University of California, Los Angeles, and fabricated by the Westinghouse Electric Company. An RCA microprocessor is used. The instrument is now at UCLA where it is undergoing tests and calibration.

The principal investigator for the magnetometer experiment is Dr. Margaret Kivelson, professor of space physics in the earth and space sciences department at UCLA. She is supported by four co-investigators from UCLA.
shuttle's payload bay. The shuttle will release the spacecraft and return to Earth. Soon after release from the shuttle, the IUS and injection module engines will fire, sending the spacecraft into an orbit around the sun that will bring it near the Earth again slightly more than two years later, in the summer of 1987. In mid-1986 a large propulsive maneuver of about 500 meters per second will shape the trajectory to obtain the near-Earth geometry required for the Earth gravity assist to Jupiter. The Earth flyby will be at an altitude of about 225 kilometers.

The spacecraft will cruise another two-and-a-half years to Jupiter, arriving in late 1989. Some fields and particles measurements will be made during the Earth-to-Earth and Earth-to-Jupiter cruise phases.

About 150 days before Jupiter encounter, the Probe will separate from the Orbiter and continue its path toward the planet. About three days after Probe release, the Orbiter's flight path will be adjusted to assure that it will be overhead to receive the Probe's radio signal as the module enters Jupiter's atmosphere and sinks through the clouds.

Once the Orbiter and Probe are separated, the Probe will be on its own. It cannot receive commands. Its instructions are pre-programmed into its computer memories, and its entry sequence starts on a timed command. The Probe will hit the atmosphere at a little over 47 kilometers per second — the fastest entry yet attempted in any space mission. After entry, the Probe's protective aeroshell will be jettisoned, and the Probe will descend on a parachute.

During the descent, which may last as long as one hour before the Probe perishes, six different science instruments will take data that characterize the atmosphere of Jupiter. This data will be transmitted to the Orbiter overhead, and the Orbiter will then send the data to Earth.

About four hours before the Probe's mission begins, the Orbiter will fly past the volcanic satellite Io at an altitude of about 500 kilometers. This will be Galileo's only close Io encounter, due to the intense radiation near Jupiter. Repeated exposure to this radiation would damage the spacecraft.

About 30 minutes after the end of the Probe mission, the Orbiter will fire its retro propulsion engines to slow itself and be captured by Jupiter's gravity. The initial orbit of Jupiter will take about 250 days. Midway through this orbit, the engines will fire again to raise periapsis altitude (the closest approach distance to Jupiter) to protect the spacecraft from radiation near the planet.

For the next 24 months, the Orbiter will make a series of looping orbits around Jupiter, providing at least one close satellite encounter on each orbit to study the other three Galilean satellites — Europa, Ganymede, and Callisto. Currently, the estimated number of satellite encounters ranges from seven to ten, depending primarily on the date of launch. The Orbiter will also characterize Jupiter's magnetosphere, make long-term studies of the dynamics of the planet's atmosphere, and investigate Jupiter's tenuous ring.

We have another new mission and a new upper stage...fortunately the launch date is still 1985 and the project appears stable...maybe this will be our last significant programmatic change.

With the demise of all the rest of the planetary programs, Galileo is now the sole surviving descendant of the Mariner, Viking, Voyager line...we carry the tradition and the responsibility...as a result, the pressure on us is perhaps greater than if we were one of many...we must make Galileo a success.

Changes, changes...three planetary old hands have gone or will go to other positions...in addition to Dr. Murray, Tom Young, who was mission director on Viking, has left NASA to join a private firm...and Andy Stofan, past deputy administrator of the Office of Space Science, has left Headquarters...Andy fought some valiant battles for Galileo.

Cosmic rays are made when giant stars die in a supernova blast...they travel across the universe and affect us here on earth, not only by causing mutations but also by causing sophisticated electronic parts to "upset"...in layman's terms, a binary "0" may become a "1" because of a charge deposited in the semiconductor by a cosmic ray...we have been studying this problem for Galileo, trying to figure out how to handle it...in quiet moments I muse about the beauty of knowledge and the universe and this exploration profession...we humans must understand the output from the death throes of an earlier star in order to design miniature computers to help us explore our solar system...this is one facet of a richly rewarding job, to see the delicate interrelationships among all parts of the cosmos.

—Gentry Lee