Ida Ho!

This mosaic of Ida consists of five image frames acquired by Galileo’s Solid-State Imaging System at ranges of 3057 to 3821 kilometers on August 28, 1993, about 2-1/2 minutes before closest approach. Galileo flew about 2400 kilometers (1500 miles) from Ida at a relative velocity of 12.4 km/sec (28,000 mph). Asteroid and spacecraft were 441 million kilometers (274 million miles) from the Sun.

Ida is the second asteroid ever encountered by a spacecraft. It appears to be about 52 kilometers (32 miles) in length, more than twice as large as Gaspra, the first asteroid observed by Galileo in October 1991. Ida is an irregularly shaped asteroid, believed to be like stony or stony-iron meteorites, and is a member of the Koronis family, fragments left from the breakup of a larger asteroid in a catastrophic collision.

This view shows numerous craters, including many degraded craters larger than any seen on Gaspra. The extensive cratering seems to dispel theories about Ida’s surface being geologically youthful. This view also seems to rule out the idea that Ida is a double body. The south pole is believed to be in the dark side near the middle of the asteroid.

The camera’s clear filter was used to produce this extremely sharp picture. Spatial resolution is 31 to 38 meters (roughly 100 feet) per pixel. Playback of the remaining images is planned for April through June 1994. (P-42964)

From the Project Manager

Galileo’s Ida encounter was a spectacular success. It was a lot tougher than it looked. A pair of spurious Command and Data Subsystem (CDS) bus resets occurred in June, after this phenomenon had been dormant for two years. Spin Bearing Assembly (SBA) brush lifts in the presence of otherwise benign brush debris cause these random resets. Resets result in spacecraft safing, which terminates the spacecraft sequence. The Flight Team must then send and monitor the response of each of a half-dozen command packages to re-establish dual string (redundant) operation of the CDS and they must also build and uplink a new spacecraft sequence.

When a second pair of resets on July 10 and 12 precluded the first of five planned Ida optical navigation images, we began massive contingency efforts. Without at least two navigation images, the most important Ida observations might be missed due to degraded navigation. And, if a reset occurred within a few days of Ida, the whole encounter would be lost because spacecraft safing would terminate the sequence.

OpNav #2 was obtained without incident. Then, a fifth bus reset on August 11 precluded OpNav #3. The Flight Team had already very aggressively streamlined the recovery process. The Team quickly recovered the CDS, uplinked a prerequisite attitude maneuver, and executed the Ida -15 day TCM-20 exactly on schedule August 13—just two days after the reset!

At Ida -7 days, August 21, communication with the Mars Observer (MO) spacecraft was lost. Galileo and MO...
were only 10 deg apart in the sky. Thus, maximum efforts to recover MO, requiring the 70-m DSN antenna at each complex, restricted Galileo tracking to a few hours a day during station view-period overlaps. OpNav #4 had been acquired without incident. The MO problem occurred 10 hours after OpNav #5 was shuttered, so only one-fourth of the image was returned.

The final navigation estimate, including OpNavs #4 and the partial #5, indicated Galileo was just 0.7 see early and 10 km high—encounter would be at 16:51:59.0 UTC at 2410 km from Ida without performing TCM-21. Accordingly, at Ida —5 days, TCM-21 and contingency pointing updates were cancelled. The outstanding power and quality of OpNav #2 had enabled TCM-20 to hit the bull's-eye.

The Flight Team continued streamlining the recovery process for the Ida encounter and ultimately could have recovered from a reset as late as Ida —21 hours. Because a bus reset recovery was no longer possible, the last 21 hours were a period of anxiety to the max! At Ida —4 hours 16 minutes, a totally unrelated problem occurred. The spacecraft autonomously turned off its gyros and switched to cruise mode. The attitude control engineers quickly confirmed the the encounter would be satisfactorily performed in cruise mode—scan-platform pointing controlled using only the encoders in the actuators. However, the mode change stowed the platform. A precisely timed ground command was sent at Ida —3 hours 18 minutes to restore proper pointing. Additional real-time commanding was required after closest approach to restore the configuration for subsequent sequence events. Gratefully, no bus resets occurred during the encounter—in fact, none have occurred since August 11. We have been operating Galileo in all-spin mode as much as possible since July 16 to minimize the reset threat, but the spacecraft had to be in dual-spin mode for the OpNav images, maneuvers, and the Ida encounter observing sequence.

As for Gaspra, the high resolution Ida image on the front page was obtained by copying about 150 lines of an imaging frame at a time into CDS memory and then transmitting that memory to the ground at 40 bps—the so-called DMSMRO. It takes about six DMSMROs to return a full frame. As luck would have it, Ida's location in the 30-frame-high resolution mosaic caused it to straddle 5 frames. Thus, nearly all of the available 35 DMSMROs in the September 40-bps playback opportunity were required to return this one image. The playback was further complicated when the Canberra 70-m antenna was down for six days due to a totally unprecedented transformer failure. Five unanticipated mini-mini-sequences had to be designed and uplinked to work around the outage.

In summary, the Ida encounter took much, much more Flight Team effort than originally planned. The Flight Team, Deep Space Network, and Multimission Operations Systems Office did an outstanding job in the face of major difficulties. It was well worth it. The rest of the data will be returned next spring when the Earth's orbital position will again allow 40 bps.

For five days beginning October 4, Galileo will execute its largest 10-N maneuver. TCM-22 will impart 38.6 m/sec to Galileo to target the atmospheric-entry Probe to its entry corridor. It is noteworthy that this marks the first time the Galileo spacecraft has been targeted to Jupiter.

Excellent progress is being made developing the new capabilities for Jupiter. The Phase 1 software that provides a redundant Probe data path is already in test. The Phase 2 Orbital Operations requirements have been agreed upon with the Project Science Group (PSG) and the Flight Team, and the Preliminary Design Review (PDR) is on schedule for next month.

I am extremely proud of the achievements of the Galileo Project Team to date and confident they will perform an absolutely outstanding mission at Jupiter.

Bill O'Neil
Project Manager
The Galileo Mission Control Team (MCT) members, highly professional, dedicated individuals, bring unique talents and skills to the complex task of mission plan execution. This combination of talents and skills provides a synergistic effect that benefits the Project. Functional interdependence and enthusiasm to get the operations job done right are the unique ingredients that make the MCT work.

The MCT is divided into two functional areas: real-time operations conducted by the Mission Controllers and real-time support under the auspices of the Ground Operations Engineer.

Real-time operations are conducted by four Mission Controllers (ACEs) (Gene Brower, Steve Hillabrand, Herlen Reed, Jr., and Ron Sharp) and a Data Technician (Kathy Fimbres), who are “on-line” whenever the spacecraft is being tracked, sometimes 24 hours a day, by the Deep Space Network (DSN). The ACEs’ primary functions are to monitor spacecraft activities to ensure proper execution of planned events, to operate the Ground Command System and radiate commands to the spacecraft, and to ensure the receipt of the highest possible percentage of science, engineering, and navigation data. The Data Technician assists the ACEs in distributing products and maintaining Mission Support Area equipment.

Most of the ACEs’ time is spent monitoring the 2000 channels of telemetry radiated from the spacecraft to ensure that the spacecraft is operating as planned. The telemetry includes engineering data on the spacecraft as well as memory readouts from the science instruments. This task has been further complicated for Galileo with the loss of the high-gain antenna. Because the low-gain omni-antenna can provide a data rate of only 40 bits per second (bps), which drops to 10 bps as the cruise to Jupiter takes the spacecraft farther from Earth, it takes much longer to receive enough telemetry to verify the spacecraft’s performance. At the 40 bps data rate, it takes 30 minutes to receive a full commutation of spacecraft telemetry. At 10 bps, two hours pass before the final bit of commutated data reaches the ground. If an anomaly occurs any time after a specific channel is received at the 10 bps rate, two hours pass before the alarm is confirmed.

The ACE is the first to learn of an alarm event. Alarms are identified when tolerances set by the analysts for each subsystem are exceeded. These alarms are displayed on a digital television alarm page and are routed to line
printouts and on video displays. To use these data, the ACE needs a working knowledge of the spacecraft and ground telemetry systems. In-depth analysis of the data, however, is handled by engineering specialists called subsystem analysts, who are members of the Orbiter Engineering Team.

To properly carry out their responsibilities, the ACEs need products provided by the real-time support function, the other half of the MCT. The real-time support function blazes an operations trail in establishing spacecraft tracking schedules, prioritizing and allocating Galileo’s use of DSN antennas, providing spaceflight operations schedules, performing spacecraft command planning, conducting Project command conferences, and providing the sequence of events documents used by the ACEs to “fly” the spacecraft. This is the realm of the Ground Operations Engineer (GOE), Belinda Arroyo, who reports to Team Chief Jack Nash.

The GOE acts as the focal point internally between the real-time activities and real-time support functions and externally between the MCT and the other Galileo Project teams. The GOE coordinates the delivery of the real-time support function products, interfaces and assists with the timeline, command, sequence, and scheduling engineers, and presents the integrated MCT point of view to the Project when issues need resolution in a broader forum. The GOE leads the Project’s effort to establish the weekly operations schedule, regularly coordinates with Division 37’s Operation Engineering Laboratory on software changes and upgrades that affect the sequence generation, and monitors and supports the resource allocation negotiation process. In addition, the GOE maintains and assists in updating team operation procedures and interface agreements and is cognizant of Project mission and flight rule applicability for the team.

The weekly negotiations for the DSN long-range tracking antenna allocations can cover periods from 8 weeks to 5 years in the future. These long-range allocations are critical to the mission design because they provide the baseline footprint needed to assure that the required data are collected. If the

Leading the Mission Control Team

The MCT functions under the watchful eye of Team Chief John (Jack) C. Nash. Jack has a solid operations background, with 24 years at JPL in some form of operations support. His first 12 years on Lab were in Division 38, researching and developing solid propellants and polymer bindings. When the Lab transferred work on these materials to Edwards Air Force Base, Jack chose to work in operations. He joined the DSN as an Operations Chief, to handle both the MCCC and DSN operations. After 4 years, he became Network Operations Planning Engineer with Office 400, where he worked on the Viking, Voyager, Pioneer, Helios, Venus Balloon, and International Solar Polar Mission (Ulysses) Projects. From there he moved to Flight Projects’ operations in Division 37, where he worked on the AMPTE, Voyager, and Galileo Projects.

“Most people on the outside of a project say they would find mission operations to be boring,” says Jack, “but the reality is that the operations needed to capture new science, to recover a sequence, or reconfigure an anomalous spacecraft, when performed by the right mix of talented people, is exciting. Their skill assures the job will get done and done right. Project Galileo has such people in its MCT.”
Up To Date

Operations Activity Summary

During this update time period (January 29–September 16, 1993), the spacecraft performed many operations, including attitude maintenance turn maneuvers (SITURNs), 10-N thruster flushes, two trajectory correction maneuvers, numerous power management activities, a radio-relay antenna (RRA) characterization test, several telecommunications tests, and a 10.5-rpm spin-up–down demonstration. Additionally, significant Command and Data Subsystem (CDS) flight software changes were loaded.

Attitude Control

Eight SITURNs were performed. Several of these SITURNs were in support of the high-gain antenna (HGA) X-band uplink and downlink tests. The spacecraft performance throughout these turn activities was normal.

The first post-Earth-2 flyby Trajectory Correction Maneuver, TCM-19, was performed on March 9 using the Z thrusters to impart a total delta velocity of 2.1 m/s. On August 13, TCM-20 was performed, consisting of one axial and one lateral segment imparting a total delta velocity of approximately 0.62 m/s. Preliminary radio navigation data indicated a 0.1 percent overrun in the axial segment. All Retropulsion Module (RPM) pressures and temperatures and attitude control indicators were as expected.

Seven periodic RPM 10-N thruster maintenance flushing activities were completed. For these activities, all 12 thrusters were exercised, and spacecraft performance was normal.

The first 10.5-rpm spin-up–down activity was performed March 10–12 using a special mini-sequence. The spin activity used the new Attitude and Articulation Control Subsystem (AACS) phase 12.0 software, which was loaded on the spacecraft in late January. The entire spin activity was performed superbly with attitude control operation and RPM thruster counts near predicted values. The spacecraft achieved a spin rate of 10.49 rpm and remained at that rate for nearly 48 hours before spinning down and returning to dual-spin mode.

Galileo Mission Summary*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance From The Earth</td>
<td>581,852,100 km (3.89 AU)</td>
</tr>
<tr>
<td>Distance From The Sun</td>
<td>460,733,100 km (3.08 AU)</td>
</tr>
<tr>
<td>Distance From Jupiter</td>
<td>380,705,300 km</td>
</tr>
<tr>
<td>Round-Trip Light Time</td>
<td>64 min, 46 s</td>
</tr>
<tr>
<td>Velocity Relative to the Sun</td>
<td>61,600 km/h</td>
</tr>
<tr>
<td>Spacecraft–Sun Angle</td>
<td>8 deg off Sun</td>
</tr>
<tr>
<td>Spacecraft Spin Rate</td>
<td>2.89 rpm</td>
</tr>
<tr>
<td>Spin Configuration</td>
<td>All spin</td>
</tr>
<tr>
<td>Downlink Telemetry Rate</td>
<td>40 bits/s (coded), LGA 1</td>
</tr>
<tr>
<td>Powered Science Instruments</td>
<td>Dust Detector Subsystem,</td>
</tr>
<tr>
<td></td>
<td>Energetic Particles</td>
</tr>
<tr>
<td></td>
<td>Detector, Extreme</td>
</tr>
<tr>
<td></td>
<td>Ultraviolet Spectrometer,</td>
</tr>
<tr>
<td></td>
<td>Heavy Ion Counter,</td>
</tr>
<tr>
<td></td>
<td>Magnetometer, Plasma Wave,</td>
</tr>
<tr>
<td></td>
<td>Ultraviolet Spectrometer</td>
</tr>
<tr>
<td>General Thermal Control</td>
<td>All temperatures within</td>
</tr>
<tr>
<td></td>
<td>acceptable ranges</td>
</tr>
<tr>
<td>RTG Power Output</td>
<td>512.6 W</td>
</tr>
<tr>
<td>Real-Time Commands Sent</td>
<td>72,410 commands</td>
</tr>
</tbody>
</table>

*As of September 16, 1993.

Calibration and Characterization Activities

Several AACS calibration activities were performed, covering the inertial and celestial sensors, spin-bearing assembly, and the scan platform actuator. The first inflight over-travel test was performed to verify that the platform could be safely slewed to cone angles between 153 and 209.6 deg. Performance and friction data were collected, and no unexpected events were observed.

In support of the Galileo mission with the low-gain antenna (LGA), two telemetry performance tests were conducted in late April and early May to characterize the link performance improvement with a suppressed carrier modulation technique using the DSN ARX advanced receiver. Data collected from both Deep Space Stations 14 and 15 at Goldstone, California, showed that performance improvement was near predicted theoretical levels.

The first RRA slew characterization test was performed during late April and early May. The RRA was incrementally slewed from its 4-deg off-stow position out to 53 deg and then incrementally back to about 6 deg off stow. Preliminary data analysis indicated that RRA control and monitor hardware are functioning properly and the antenna slew rate was within expected values.

HGA Activities

Two HGA X-band radio frequency (RF) tests were performed to determine if the asymmetric, partially deployed HGA has a usable RF gain lobe. An X-band uplink (7167-MHz) test, performed
in mid-March, was similar to the test performed in May 1991. RF data analysis indicated the possible presence of a gain lobe, about 4 to 6 dB better than that of the LGA, located about 1 deg off boresight.

In mid-June, the first HGA downlink test was performed. The test was conducted using the X-band (8420-MHz) transmitter flight equipment. This test was the first operation of the X-band transmitter in nearly 4 years. All X-band hardware engineering telemetry data were within predicted levels. The downlink test was conducted with the X-band transmitter in the low-power mode simultaneously with the S-band in the high-power mode, radiating via the LGA. The HGA signal was coarsely mapped to about ±20 deg off boresight, and finely mapped every 0.25 deg within 4 deg of boresight. Preliminary analysis indicates no useful gain lobe exists.

**Sun-Shade Retraction**

On March 4, the Energetic Particle Detector’s (EPD’s) pyro-activated protective sun shade was retracted using the spun pyro-switching unit. All CDS and pyro telemetry data indicated proper activation. Within hours, as predicted, EPD detector temperatures increased, confirming sun-shade retraction. This was the final, planned pyro event prior to Probe release activities in July 1995.

**Anomaly Status**

**AC/DC Imbalance**

The ac/dc bus imbalance measurements continue to fluctuate. The ac imbalance measurement exhibited changes of a few data numbers (DNs), varying from about 3.6 to 4.8 V. The dc measurement, however, changed abruptly within a 24-hour period, from about 16 to 4 V, and then returned to nearly 16 V. The large fluctuations occurred during spacecraft quiescent periods in dual-spin cruise mode. Subsequently, the dc imbalance measurement stabilized and then gradually increased to its present level of about 18.8 V.

**Spacecraft Safing**

The spacecraft entered safing five times during this update period because of CDS transient power on reset (POR) events. After 692 days without a transient CDS bus reset POR, CDS “A” bus reset events occurred on June 10 and 17, July 10 and 11, and August 11. Recovery from the bus reset PORs was accomplished expeditiously using off-the-shelf contingency command files developed, approved, and tested months before. The CDS returned to the fully redundant mode in about 30 hours for June events and in about 12 hours for the July 11 event. During the recovery process from the July 10 bus reset, another bus reset occurred on July 11. The cause of these POR anomalies is believed to be slip-ring brush-wear debris, which builds up and forms conductive paths among spin-bearing assembly electrical interfaces. The unwanted circuit paths, in conjunction with simultaneous brush lifts, produce a transient POR signal, which is detected by the despun CDS electronics.

**Scan Platform Slew**

During the AACS phase 12.0 memory load and verification activity—just after the “A” memory swap event with the 12.0 software loaded—the scan platform unexpectedly slewed at the high rate and hit the mechanical stop before returning to the 153-deg cone-angle safe position. The cause of the anomaly was a software timing flaw that existed before launch. An AACS software patch was sent to the spacecraft to preclude this anomaly in case of a future memory swap. A tiger team analysis effort was formed to assess the integrity of all the scan-platform-mounted hardware, including science instruments, gyros, accelerometers, and structural elements. Slew-induced, analytical loads were compared with prelaunch test-loads, and gyro and accelerometer flight tests were performed. Worst-case analyzed loads showed significant margins for all equipment. Gyro and accelerometer flight test data showed no perceptible change from earlier baseline data, strongly suggesting no hardware damage or misalignments.

**Ground Data Systems**

Galileo participated in the DSN Ground Communications Facility 1.5 upgrade data-flow tests in February and March. These tests demonstrated a new Galileo telemetry data-flow path through the DSN Space Flight Operations Center gateway to the Multimission Command Mission Control and Computing Center (MCCC) and Multimission Ground Data System (MGDS).

The IBM 3090/200 to ES/9000 transition certification testing activities began on February 22. No significant problems occurred and no errors were reported. Galileo made the transition from the IBM 3090/200 to the new IBM ES/9000-6121/610 on April 3.

In March, Multimission Operation System Office (MOSO) system tests for Galileo MGDS tested the integrity of the version 18 command system with the DSN. In May, Galileo participated in additional MOSO system tests using DSS 1, 3, and 42. The tests demonstrated Galileo MGDS compatibility with the MOSO database’s ability to transmit to the Command Processor Assembly and radiate command files. Successful MGDS tests for version 18.1 were conducted in June and July. Galileo has started parallel operations with version 18.1 command system and plans to decommit MCCC in October.

A Galileo mission verification test was performed on June 8 using DSS 15 to evaluate the ability of the new type-A telemetry group controller (TGC) and telemetry channel assemblies (TCA) to support
Galileo. This test demonstrated the telemetry and monitor functions for Galileo on both MCCC and version 18.1 MGDS. The type-A TGC/TCA went into soak operations on June 18.

**Sequence Generation**

Several special mini-sequences were developed in support of spacecraft operations. The TCM-19 sequence memory load was generated and approved for transmission on March 5. The HGA uplink and downlink RF test mini-sequences were generated and approved for transmission on March 13 and June 17, respectively. In late April, the RRA slew test mini-sequence was generated and approved for transmission. In addition to these efforts, the nominally planned Earth–Jupiter (EJ) sequences, EJ-1, EJ-2, and EJ-3A and -3B (Ida encounter), were completed. As a consequence of the bus reset PORs, the EJ-2 Ida approach sequence was regenerated as EJ-2" and EJ-2". Also, several reserve box sequences were developed for the return of Ida data. Cruise plans are also underway for the EJ-4, EJ-5, and EJ-6 sequences, which cover the period through the end of August 1994.

**Software**

Several CDS flight software changes were made in mid-June to incorporate various fault protection updates, the IM-4 anomaly fix, and addition of the new 80-byte memory readout capability, which replaced the 32-byte capability and permits faster return of spacecraft stored data. This new capability was used to return the Ida images.

An AACS 12.0 flight software patch was loaded to preclude recurrence of the scan platform slew anomaly in the event of an AACS memory swap.

Twenty-seven failure reports (FRs) were included in the MIPS version 9.0 deliveries, which provided corrections to support requests (SCRs), was delivered as part of the May 15 E1.1 Mission Build. The E1.2, containing three program sets correcting 65 FRs and implementing 4 SCRs, was delivered on June 11.

The E2.0 software delivery activities will continue through November.

— Matt Landano
Deputy Mission Director
proper resources are not allocated to Galileo on critical dates, unique scientific and engineering data could be lost. Other projects and users vie for the same resources during these weekly long-range allocation meetings so they, too, can take full advantage of their spacecraft’s capabilities. This leads to specific track coverage challenges that have to be resolved before the projects can proceed with their mission designs. Most of the time, satisfactory compromises can be reached; however, relatively small variances of 15 to 30 minutes in the start- and end-of-track allocations can be carried forward to the week before a sequence starts. These minor conflicts are resolved at weekly meetings of a group concerned with real-time changes—the period from the current day to 8 weeks in advance. This scheduling function dovetails with the long-range scheduling function and provides for last-minute changes in equipment and track times.

Once the schedules and resource allocations are set, the MCT real-time support function supplies products to many customers, including the Sequence, Engineering, and Design Teams. These products allow each of the Project’s teams to determine when their tasks need to be completed.

A large part of the Mission Control Team’s real-time support products are generated by the Timeline Engineer (TE), Jennifer Huynh. The TE provides the final profile for station allocations of DSN antenna time for Galileo. In addition, the TE prepares the spaceflight operations schedule (SFOS), which is a day-by-day agenda for Project and team meetings and spacecraft commanding and tracking; the ground events profile, which projects events for the coming month; and the integrated mission operations profile, which covers the Project through the end of its prime mission.

Actual operation of the Galileo spacecraft can result only through the combined integration of ground and spacecraft events, which are presented as a sequence of events (SOE), prepared by the SOE Engineer. The SOE Engineer receives the spacecraft events file from the Sequence Team, and the resource allocations from the MCT scheduling engineers. From the resource allocations, the ground events file is generated. The SOE Engineer then integrates the spacecraft and ground events files to produce the SOE used by the Flight Team to “fly” the spacecraft. This product is the official flight operations document for Project Galileo.

A real-time support interface between the command planning process and the ACE is the Command Engineer (CE), Jim McClure, Jr. The CE’s primary responsibilities are reviewing, constraint checking, scheduling, and presenting real-time command requests to the Galileo Mission Director for approval. Upon approval, these command requests must be prepared for transmittal to the Galileo spacecraft. The CE works with the ACE to ensure that, from each command request, the proper commands are generated and safely transmitted through the DSN to the spacecraft. The CE also provides real-time command information to the Timeline Engineer and the SOE Engineer for inclusion into the SFOS and SOE.

As custodian of the Galileo contingency command library, the CE also plays a significant role in responding to spacecraft anomalies and emergencies. Real-time commanding of the spacecraft has increased because of the high-gain antenna anomaly—over 60,000 real-time commands have been radiated thus far in unsuccessful attempts to free the antenna. Since dedication and attention to detail are required for safe and prompt commanding of the spacecraft, the CE must be knowledgeable about the ground data system and the spacecraft, and always strive for perfection.