December 1995 Sky & Telescope

Arrival at Jupiter

If you catch a glimpse of Jupiter after sunset these days, you might imagine the tiny specks of two robotic spacecraft very close to it. On the 7th of this month, one of them will become the first earthly object to enter a gas giant's atmosphere. Withstanding 300 G's and stellar temperatures as it decelerates from 170,000 kilometers per hour down to a speed suitable for deploying its parachute, Galileo's instrumented atmospheric Probe will transmit data up to the second spacecraft, the Galileo Orbiter, which has been carefully orchestrated to be in position, ready to capture the precious data.

The Probe separated from the Orbiter last July. Both were on target for impact with Jupiter, when on-board commands set the Probe to internal battery power, then shut down all its equipment except a countdown timer, to preserve the battery until entry. After engineers checked the timer, they commanded the spin-stabilized Orbiter to go ahead with the remaining Probe release activities.

First a pyre-activated guillotine sliced the umbilical. Then the combined spacecraft turned to the attitude optimum for the Probe's entry ordeal, and increased its rotational speed to 10.5 RPM, ensuring the Probe's stability. A bank of capacitors charged, then discharged suddenly to fire three explosive nuts, and titanium springs nudged the Probe away. The Orbiter then maneuvered back and slowed its rotation to a more normal 3 RPM.

After radio signals had 38 minutes to span the distance, some delighted engineers saw the Doppler signature change just as expected, indicating the Orbiter's reaction to the Probe's pushoff, measured in millimeters per second. Later on, as the telemetry bits were processed, it was confirmed that the microswitches had opened: the Probe was indeed a separate spacecraft. Ballistics alone would carry it to Jovian entry, whereas the Orbiter would have opportunities to make fine trajectory adjustments.

The Probe's departure was crucial for the Orbiter; in place, the Probe was situated right at the business end of the Orbiter's 400-Newton main engine. Two weeks after the Probe was gone, Galileo fired the engine successfully for an orbiter deflection maneuver, re-targeting itself for orbital entry rather than atmospheric entry.

The road to Jupiter has been long and rocky. Galileo's launch configuration was re-engineered during the Space Transportation System's initial development, and again after Challenger's accident. It finally left Earth in October 1989 aboard the Atlantis, and made a name for itself during encounters with Venus, Earth, Gaspara, and Ida, and again when it observed Comet SL-9's impact with Jupiter.

While many scientific observations have been planned to be carried out as Galileo makes its final approach and closely encounters Europa, Io, and Jupiter, two events are far more critical: Probe relay and the Jupiter orbit insertion maneuver (JOI). As the Probe negotiates the atmosphere, its signals will be too weak to receive on Earth. They depend on the Orbiter's ability to keep a small dish-shaped relay antenna pointed to the entry site, receiving the Probe's transmission and storing its scientific data for later transmission to Earth. And there will be no second chance for JOI. Were the spacecraft not to fire its main engine at the right time, in the correct attitude, it would sail past Jupiter and spend the rest of its days in a comet-like solar orbit.

To maximize the chances that these two events will succeed, Galileo's Command and Data System computer (CDS) will operate in "critical mode," issuing commands redundantly. Should anything go awry deep within a Jovian radiation field strong enough to kill a human, the Orbiter will respond autonomously by terminating all non-essential activities, including the science observations - there'll be no time to wait for orders from Earth - and it will concentrate on executing its two critical tasks.

The mechanics of JOI will be aided by a close flyby of Io. As the Orbiter passes somewhat in front of Io in its Jovian orbit, mutual gravitational attraction will slow the spacecraft significantly, accelerating Io in trade by an infinitesimal amount. The main engine will do the rest, decelerating Galileo enough to be captured into Jovian orbit.

The sequence of commands for Galileo's arrival took control of the spacecraft October 9. Over the next few days, science observations began: global imaging of Jupiter, observations of the plasma torus by the UV spectrometer, and dust-detector and magnetometer sampling of the outer Jovian environment. Starting in late October, and continuing in November, a series of three optical navigation images were taken, in which targets were seen against a background of known stars. They were analyzed on Earth to determine how best to fine-tune Galileo's trajectory. By November 16th, the CDS was configured to critical mode.

Zero hours UTC on December 7 finds all the optical instruments - IR, UV, and visual - trained on the Probe's entry site (6.5 degrees north of the equator) to remotely characterize the patch of atmosphere soon to be sampled in situ. A color image is taken of Io just before 06:00 hours UTC, followed by a measurement of the site in Jupiter's atmosphere through which Galileo's radio signal will pass later, during the spacecraft's occultation of Earth. Closest approach to Europa, at 33,000 km, follows at about 13:00 amid a series of optical exposures. At the same time, the fields and particles instruments begin their in-situ sampling of the torus and inner magnetosphere. These will continue past JOI. By 15:00, the suite of optical instruments has begun remote sensing of Io, and, at 17:45, Galileo careens within 1000 km of its erupting volcanoes. Perijove sneaks by just before 22:00, with the spacecraft only three Jupiter radii away from the planet.

Completing a 5-month freefall, the Probe slams into Jupiter's atmosphere at 22:05, decelerating rapidly. Before two minutes are up, its main parachute has deployed, and the Orbiter has begun its critical Probe relay activity. No other observations are in progress aboard the Orbiter. Galileo is preoccupied capturing data transmitted from instruments descending within the Jovian atmosphere. The Orbiter's fields and particles measurements start up again at 23:22, when the Probe relay is complete. Having served its mission, the trusty Probe will soon be crushed by the Jovian atmosphere. There's hardly a breather, though; Galileo's second critical activity, JOI, begins at 00:27, now December 8 UTC. The main engine burns for the best part of an hour. Nominally, the exact time for engine cutoff is determined by on--board processing of input from accelerometers. When it does stop, Galileo becomes the first spacecraft to be in orbit at a giant outer planet.

Fields and particles measurements finish up just before 03:00. While engineers monitoring Galileo's activities begin to see a slump in their high-pressure workload, the radio science team is just beginning to gear up, working with the DSN, which forms part of their instrument. The other part of their instrument, the Orbiter's radio transmitter, will be passing behind Jupiter. At about 09:30, the radio occultation experiment begins, digitally sampling and recording the received signal at a high rate. Earth is occulted at 10:30, causing loss of realtime telemetry from the spacecraft; it is too weak to receive through a gas giant. But for a time, enough of a radio signal is refracted through the atmosphere and received by the radio science team to yield a ton of data about Jupiter's atmosphere, the Jovian environment, even Jupiter's mass. They'll concentrate on capturing it now, and then spend months or years processing and teasing out scientific results.

Galileo's telemetry reappears at 14:00, once again giving visibility into the status and condition of all the Orbiter's systems. By 21:30, the CDS has returned to its normal mode of operation, and all that remains is to return the data to Earth. But why should that be easy? Nothing else in Galileo's history has been. Solar conjunction is right on our heels! By the end of the day, the Sun and Earth are separated by only 8 degrees and closing, from Galileo's point of view. The solar corona will soon play havoc with the Orbiter's weak S-band radio signal. Clear communications will not be expected again until after Christmas. Even so, an attempt will be made to return some of the Probe data starting December 10. During January and February, all the Probe data will be played back to Earth, and subsequent months will see the return of the rest of the data collected and stored aboard on tape during encounter. Out at apojove in its initial 7-month orbit, Galileo's main engine will fire to raise perijove, keeping the spacecraft clear of the intense radiation environment on subsequent orbits.

Galileo's prime mission will last two years, executing eleven individually tailored orbits to study the Jovian system. Caltech's Jet Propulsion Laboratory designed and developed the Galileo Orbiter and is operating the mission, under contract to NASA. NASA's Ames Research Center developed the atmospheric Probe, with Hughes Aircraft as prime contractor. The German government is a partner in the mission through its provision of the spacecraft propulsion system and two science instruments. Galileo's science investigations are being carried out by more than 100 scientists from seven nations.

The times called out for Galileo's events represent actual spacecraft time; add 52 minutes for Earth-receive time.

Dave Doody is a member of technical staff in the Advanced Mission Operations Section of Caltech's Jet Propulsion Laboratory.

Sidebar: Compensating for a Failed High-Gain Antenna

It was a major disappointment to discover in 1991 that Galileo's High-Gain Antenna (HGA) wouldn't deploy, despite repeated attempts. Galileo was sentenced to use its low-gain antenna (LGA), normally capable of only one ten-thousandth the HGA's data rate. Contributing to the gloom, the LGA had plumbing only for S-band radio signals. The nominal plan for the HGA was to use the higher frequency X-band transmitter at a low power setting. The high-power S-band would need a good deal more electrical power to be wrangled, Apollo 13-style. Even given the needed electrical power, the LGA's low data rate would be a show-stopper, without major improvements.

Since then, the improvements have indeed been major. The needed 40 Watts of spacecraft power was scrounged by juggling loads. Galileo's S-band transmitter was programmed to modulate the daylights out of its carrier - producing a signal impossible to capture on Earth without specially designed receivers. So the Deep Space Network, DSN, JPL's worldwide tracking system, installed newly designed receivers! On-board error-correction algorithms were improved. Spare processing power was commandeered from the spacecraft's attitude control computer to do high-speed data compression. The DSN installed a special new waveguide system having ultra-low system noise. Arrays were set up to combine several tracking antennas at one DSN complex, while new inter-complex array techniques, spanning the continents, were engineered. The Orbiter's data rates were programmed to vary during tracking passes to optimize performance during rise and set. The uplink signal normally transmitted to the spacecraft is being shut down at selected times to obtain a lower-noise "one-way" tracking operation. These achievements range in character from fine-tuning to major breakthrough. As a result, 100% of the Probe data, and a good 70% of the Orbiter data originally planned to be returned via Galileo's HGA will be recovered using the LGA.

Little tiny sidebar:

Be sure to browse Galileo's www pages to learn the latest news of arrival at Jupiter, starting at http:/ /www.jpl .nasa.gov/ galileo. And if you 're interested in how robotic spacecraft such as Galileo are navigated and commanded, or how gravity assists work, see JPL's "Basics of Space Flight" workbook at http:/ /oel-www.jpl.nasa.gov/ basics.