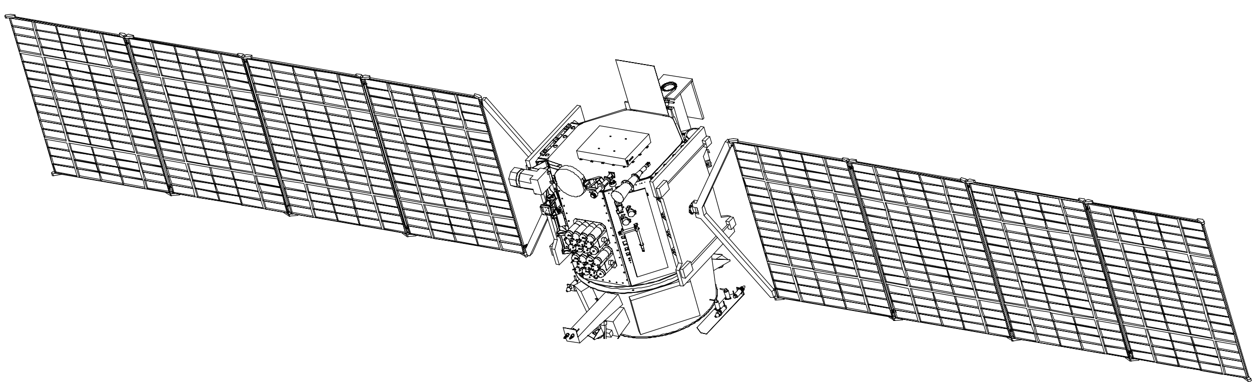
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Deep Space 1 Asteroid Flyby

Press Kit
July 1999



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RELEASE:

DEEP SPACE 1 SET TO FLY BY ASTEROID 9969 BRAILLE

With its technology testing objectives almost fully accomplished, NASA's Deep Space 1 mission is about to undergo its most comprehensive challenge: the exotic spacecraft is set to fly within 15 kilometers (10 miles) of the newly named asteroid 9969 Braille on July 29 (July 28 Pacific Daylight Time), the closest encounter with an asteroid ever attempted.

Deep Space 1 will rely on its experimental autonomous navigation system, or AutoNav, to guide the spacecraft past the mysterious, little-known space rock at 04:46 a.m. Universal Time July 29 (9:46 p.m. July 28 Pacific Daylight Time) at a relative speed of nearly 56,000 kilometers per hour (35,000 miles per hour).

"Testing advanced technologies for the benefit of future missions is the purpose of Deep Space 1, so we view the flyby and its science return as a bonus," said Dr. Marc Rayman, Deep Space 1's chief mission engineer and deputy mission manager. "This ambitious encounter is a high-risk endeavor whose success is by no means guaranteed. But should there be significant data return, the findings will be of great interest to the science community."

Asteroid Braille was previously known by its temporary designation of 1992 KD. The new name was announced today by the Planetary Society, Pasadena, CA, as the result of a naming contest focused on inventor themes which drew more than 500 entries from around the world.

The winning entry was submitted by Kerry Babcock of Port Orange, FL. Eleanor Helin, who co-discovered the asteroid with fellow astronomer Kenneth Lawrence, made the final decision on the name. Helin and Lawrence are astronomers at NASA's Jet Propulsion Laboratory, Pasadena, CA, which also manages Deep Space 1.

During the encounter, Deep Space 1 will be in the ecliptic plane (the plane in which Earth and most other planets orbit the Sun), moving more slowly than the asteroid, which will be progressing up through the ecliptic plane from below. Thus it may well be more apt to say that the asteroid will zoom by Deep Space 1 than the reverse.

The flyby will allow final testing of AutoNav, which enables the spacecraft to use images of distant stars and asteroids within our solar system to keep track of its location in space and to guide trajectory changes it needs to remain on course. Deep Space 1 has successfully completed testing of its 11 other new technologies.

The asteroid and the space environment surrounding it make scientifically interesting targets for two advanced, highly integrated science instruments aboard Deep Space 1. During the flyby, an integrated spectrometer and imaging instrument is scheduled to send back black-and-white photographs as well as images taken in infrared light, while a second instrument that studies the three-dimensional distribution of ions and electrons, or plasma, will conduct several investigations.

In addition to their value for engineering future space missions, images and other data returned from this encounter will greatly assist scientists in their understanding of the fundamental properties of asteroids. Although scientists believe its diameter is approximately 1 to 5 kilometers (0.6 to 3 miles), they know little else about the object. With this flyby, they can learn more about its shape, size, surface composition, mineralogy and terrain.

Launched on October 24, 1998, from Cape Canaveral Air Station, FL, Deep Space 1 is the first mission under NASA's New Millennium Program, which tests new technologies for future space and Earth-observing missions. The technologies that have been tested on Deep Space 1 will help make future science spacecraft smaller, less expensive, more autonomous and capable of more independent decision-making so that they rely less on tracking and intervention by ground controllers.

The mission has exceeded almost all of its technology testing requirements by conducting more extensive tests than had been planned. As one dramatic example, the spacecraft's experimental xenon ion engine, which was required to thrust for a minimum of 200 hours, has been operated for more than 1,800 hours to date.

Deep Space 1 is budgeted at $152 million, including design, development, launch and operations. The mission is managed for NASA's Office of Space Science by the Jet Propulsion Laboratory, Pasadena, CA. JPL is a division of the California Institute of Technology.

[End of General Release]

Media Services Information

NASA Television Transmission

NASA Television is broadcast on the satellite GE-2, transponder 9C, C band, 85 degrees west longitude, frequency 3880.0 MHz, vertical polarization, audio monaural at 6.8 MHz. A schedule of programming is available on the Internet at **http://www.nasa.gov/ntv** .

Status Reports

Status reports on mission activities for Deep Space 1 are issued by the Jet Propulsion Laboratory's Media Relations Office as events dictate. They may be accessed online as noted below. Audio status reports from the Deep Space 1 project are available by calling (800) 391-6654 or (818) 354-2410.

Briefing

An overview of results from the asteroid flyby will be presented in a news briefing broadcast on NASA Television originating from NASA's Jet Propulsion Laboratory, Pasadena, CA, on August 3, 1999, at 10 a.m. PDT.

Internet Information

Extensive information on Deep Space 1, including an electronic copy of this press kit, press releases, fact sheets, status reports and images, is available at **http://www.jpl.nasa.gov/ds1news** . The Deep Space 1 mission also maintains a home page at **http://nmp.jpl.nasa.gov/ds1/** .

Quick Facts

Spacecraft
Dimensions: Core bus 1.1 meters deep by 1.1 meters wide by 1.5 meters high (3.6 by 3.6 by 4.9 feet); with all instruments and blankets attached, 2.1 by 1.7 by 2.5 meters (6.9 by 5.6 by 8.2 feet); with solar panels deployed, overall width 11.8 meters (38.6 feet)
Weight: 486 kilograms (1,071 pounds) total, composed of a 373-kg (822-pound) dry spacecraft plus 31 kg (68 pounds) hydrazine fuel and 82 kg (181 pounds) xenon
Power: 2,500 watts from two solar array wings

Advanced Technologies
1. Ion Propulsion System; 2. Solar Concentrator Arrays
Autonomy:
3. Autonomous Navigation; 4. Remote Agent; 5. Beacon Monitor
Science instruments:
6. Miniature Integrated Camera Spectrometer; 7. Plasma Experiment for Planetary Exploration
Telecommunications:
8. Small Deep-Space Transponder; 9. Ka-Band Solid-State Power Amplifier
Microelectronics:
10. Low-Power Electronics; 11. Multifunctional Structure; 12. Power Actuation and Switching Module

Mission
Launch: October 24, 1998, at 8:08 a.m. Eastern Daylight Time from Cape Canaveral Air Station, FL
Launch vehicle: Delta II, Model 7326
Primary technology testing: October-December 1998
End of prime mission: September 18, 1999

Asteroid
Object: Asteroid 9969 Braille (formerly temporarily designated as 1992 KD)
Discovered: May 27, 1992 by Eleanor Helin and Kenneth Lawrence
Estimated diameter: 1 to 5 kilometers (0.6 to 3 miles)
Time for asteroid to orbit once around Sun: 1,308.3 days (3.58 years)
Time for asteroid to rotate once: 9.4 days
Asteroid's closest approach to Sun: 198 million km (123 million miles)
Asteroid's farthest distance from Sun: 502 million km (312 million miles)

Asteroid Flyby
Closest approach: July 29, 1999 at 04:46 Universal Time (July 28 at 9:46 p.m. Pacific Daylight Time)
Flyby distance: 15 km (9.3 miles)
Flyby speed: 56,000 km/hr (35,000 mph)
Distance from Earth at time of flyby: 188 million km (117 million miles)
One-way speed of light time from spacecraft to Earth during flyby: 10 minutes, 28 seconds
Distance from Sun at time of flyby: 199 million km (124 million miles)

Program
Cost of mission: $94.8M pre-launch development; $10.3M mission operations; $3.7M science; total $108.8 million (not including launch service)

The New Millennium Program

NASA has an ambitious plan for space exploration in the next century. The agency foresees launching frequent, affordable missions with spacecraft boasting revolutionary new capabilities compared to those of today. Spacecraft are envisioned as flying in formation, or featuring artificial intelligence to provide the kind of capability that can answer the more detailed level of questions that scientists have about the universe.

The goal of the New Millennium Program is to identify and test advanced technologies that will provide spacecraft with the capabilities they need in order to achieve NASA's vision. Technologies such as ion propulsion and artificial intelligence promise a great leap forward in terms of future spacecraft capability, but they also present a risk to missions that use them for the first time.

Through a series of deep space and Earth-observing flights, the New Millennium Program will demonstrate these promising but risky technologies in space in order to "validate" them — that is, to prove that they work, or to determine what problems may crop up. Once validated, the technologies pose less of a risk to mission teams that would like to use them to achieve their scientific objectives.

The testing of advanced technologies is the basic requirement for these missions. As a bonus, the missions can also collect science data as the advanced technologies are put through their paces. Science, however, is secondary to the technology testing on New Millennium's missions.

Created in 1994, the New Millennium Program forms partnerships among organizations in government, private industry, academia and the nonprofit sector so that the expertise and know-how of scientists, engineers, and managers can be pooled and used as a resource to meet the program's goals.

New Millennium's solicitation of advanced technologies for its missions will also stimulate the development of technologies around the nation and will strengthen the nation's technological infrastructure, making it more competitive in the global market. Many technologies will also have commercial spinoffs that will benefit the public in their daily lives.

Integrated Product Development Teams

The concept of integrated product development teams was developed in the commercial sector by the aircraft and automotive industries. Such teams bring together members of different departments within an organization, such as sales, manufacturing and design, to work together to develop a product. This kind of concurrent decision-making team has made it possible for industries to manufacture products of better quality and competitive costs for their customers.

The New Millennium Program has taken this intra-organizational team concept to a higher level and used it to bring together diverse organizations. For the development of Deep Space 1 and Deep Space 2, it created six integrated product development teams that include technologists from government, private industry, academic and nonprofit sectors across the nation. In effect, they represent the U.S. technology development community.

The teams were formed to develop technologies and concepts for six key areas of space flight:

❑ **Autonomy.** If spacecraft are capable of making more decisions on their own, they require less frequent tracking and intervention by ground controllers.

❑ **Telecommunications.** These technologies improve the communications link between the spacecraft and Earth.

❑ **Microelectronics.** New chips and circuits allow engineers to shrink down science instruments and other spacecraft subsystems, saving size and mass.

❑ **"In Situ" Instruments and Microelectromechanical Systems**. "In situ" instruments study a celestial body directly rather than at a distance.

❑ **Instrument Technologies and Architectures.** This team develops new technologies for science instruments such as cameras and radiometers, as well as seeking entirely different ways of making the same science observations or measurements.

❑ **Modular and Multifunctional Systems.** This team is continuing and accelerating an existing trend toward combining spacecraft's electronics more closely with their mechanical system of trusses, supports, etc.

The technologists were encouraged to search the nation's development programs to find advanced technologies that will provide the capabilities needed to achieve NASA's vision of space exploration in the 21st century.

The membership of each team represents a considerable range of organizations. Technologists come from aerospace companies, small businesses, non-NASA government laboratories, NASA field centers and nonprofit organizations. The diversity of organizations and the resulting interorganizational partnerships capitalize on and effectively take advantage of the nation's overall investment in advanced technology.

Mission Overview

Deep Space 1's mission was most intense during the weeks immediately following its launch in October 1998, when most of the 12 technologies it carries were actively tested. The spacecraft will fly by asteroid 9969 Braille on July 29, 1999 (July 28 Pacific time).

Highlights to Date

Launch. Deep Space 1 was launched October 24, 1998, at 8:08 a.m. Eastern Daylight Time from Cape Canaveral Air Station, FL on a variant of the Delta II launch vehicle known as a Delta 7326, the first use of this new and lower-cost model. The launch took place from Space Launch Complex 17A at Cape Canaveral Air Station, FL.

The Delta 7326 is a liquid-fuel rocket augmented by three solid rocket motors. The second stage was restartable, and performed two separate burns during Deep Space 1's launch to place the spacecraft in Earth orbit. A third burn was executed to finalize the orbit for the Delta's secondary payload, a student-built satellite called SEDSat-1 developed by Students for the Exploration and Development of Space. At 49 minutes after launch, the third and final stage of the Delta — a Thiokol Star 37FM solid-fuel booster — fired to send Deep Space 1 into orbit around the Sun.

Early cruise. On its way out of Earth's orbit of the Sun into a wider orbit between Earth and Mars, Deep Space 1 tested all 12 of its new technologies. Final testing of the autonomous navigation experiment, or AutoNav, will take place during the asteroid flyby.

Highlights have included thrusting the ion engine for more than 1,800 hours; progressively increasing AutoNav's autonomy; and observing the Remote Agent software play doctor to self-diagnose a minor glitch that could have otherwise cut short its experimental lifetime.

Asteroid Flyby

Deep Space 1 will fly past asteroid 9969 Braille on July 29, 1999 at 04:46 Universal Time (July 28 at 9:46 p.m. Pacific Daylight Time). The flyby will allow the spacecraft to test its autonomous navigation system, or AutoNav, and will also provide its two science instruments with an interesting target. The encounter is not required for the testing of Deep Space 1's technologies, but will allow engineers an extra chance to observe the performance of the technologies under conditions similar to what would be experienced on future science missions.

The asteroid. Mission planners considered more than 100 possible asteroids or comets to target before settling on asteroid 9969 Braille, previously known by its temporary designation of 1992 KD. The asteroid was discovered May 27, 1992, by astronomers Eleanor Helin and Kenneth Lawrence of NASA's Jet Propulsion Laboratory using the 46-centimeter (18-inch) Schmidt telescope at Palomar Observatory while scanning the skies as part of the Palomar Planet-Crossing Asteroid Survey. At the time it was discovered, asteroid Braille appeared as a streak traveling north-northeast in the constellation Libra with a magnitude of 15.5, much too dim to see with the unaided eye. At the time, the asteroid was about 38.4 million kilometers (23.9 million miles) from Earth.

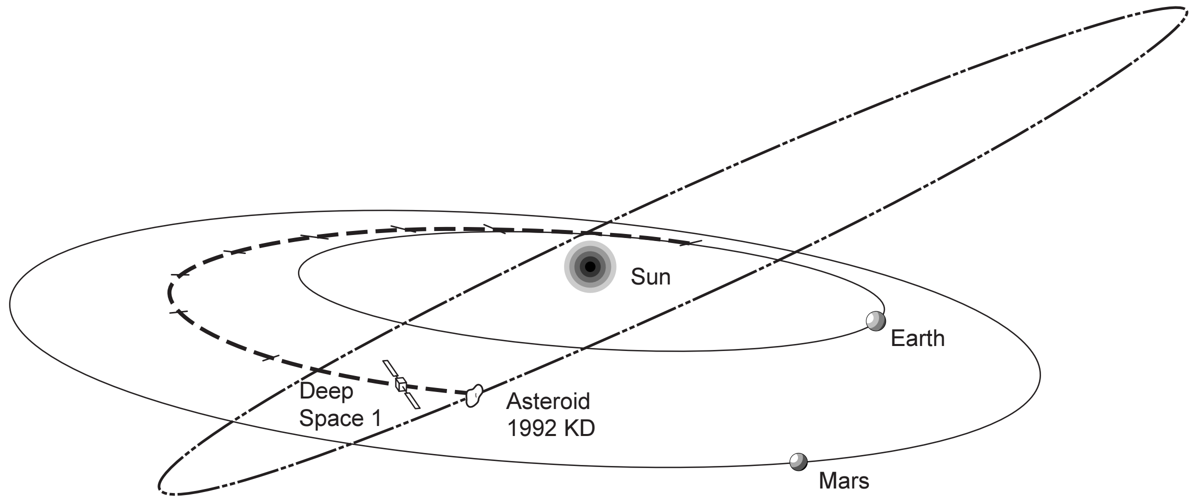
In 1999, the Planetary Society sponsored a contest inviting the public to propose names for the asteroid, based on a theme of inventors. The society forwarded 10 finalists to the asteroid's co-discoverer, Eleanor Helin, who selected the name Braille submitted by Kerry Babcock of Port Orange, FL, a software engineer who works as a contractor at NASA's Kennedy Space Center. The name honors Louis Braille (1809-1852), the blind French educator who developed the system of printing and writing named for him that is extensively used by the blind. The number 9969 in the asteroid's formal name indicates that it is the 9,969th asteroid to be numbered since the first asteroid, Ceres, was discovered in 1801. The name 9969 Braille was accepted by the International Astronomical Union's Small Bodies Naming Committee just a few days before Deep Space 1's flyby.

Asteroid Braille orbits the Sun outside of the main asteroid belt between Mars and Jupiter. Astronomers calculated that its orbit is highly elliptical, or shaped like a big loop. The closest it gets to the Sun (called its "periapsis") is a point midway between Earth and Mars, while at its most distant point (its "apoapsis") it is more than three times further from the Sun than Earth, or more than halfway out to the giant planet Jupiter. Much of the time, the asteroid is a considerable distance above or below the ecliptic plane, the plane in which Earth and most other planets orbit the Sun.

The asteroid's speed changes as it moves through its orbit. When it is close to the Sun, it moves at 31 kilometers per second (69,480 miles per hour) relative to the Sun, whereas at its most distant it slows down to 12.2 kilometers per second (27,360 miles per hour) relative to the Sun. One loop around the Sun takes 1,308.3 days, or 3.58 years. At the time of Deep Space 1's flyby, when asteroid Braille will be 6.3 days past its closest approach to the Sun, the asteroid's velocity will be 30.9 kilometers per second (68,400 miles per hour) relative to the Sun. Its diameter is estimated as approximately 1 to 5 kilometers (0.6 to 3 miles). Scientists know that the asteroid is elongated, but they don't know if it's one large chunk or a rubble pile.

Astronomers know little else with certainty about asteroid Braille; it is the least-studied asteroid that has ever been the target of a spacecraft flyby. It is very dim, making it difficult to observe. In late 1998, a team of astronomers led by Drs. Michael D. Hicks and Bonnie Buratti of the Jet Propulsion Laboratory used a number of telescopes equipped with special filters and detectors to study the asteroid. Scientists scrutinize the colors of light given off by celestial objects to look for clues called absorption lines that reveal what the object is made out of. In the 1998 observations, Braille exhibited colors that suggest it is may contain the greenish mineral olivine and/or pyroxene, a group of minerals that vary from white to dark green or black. This would suggest that Braille is more similar in makeup to the stony meteorites that fall to Earth than most asteroids in the main asteroid belt are.

Some astronomers theorize that asteroid Braille may have been knocked off of Vesta. Discovered in 1807, Vesta is the brightest asteroid (though not the largest), sometimes visible to



Primary mission trajectory

the unaided eye; it is about 390 kilometers (240 miles) in diameter, circling the Sun in the main asteroid belt. One theory holds that a hole was knocked into Vesta when it collided with another body, and that the debris from this collision provides the raw materials for most of the meteorites that fall to Earth.

The fact that Braille's orbit is tilted so much relative to the solar system's ecliptic plane shows that it must have been disrupted at some point. If it was in fact knocked off an asteroid in the main belt like Vesta, it would have joined other debris or particles from that larger body that spewed off in all directions. Astronomers determined in June 1999 — only a month and a half before Deep Space 1's flyby — that Braille rotates at a relatively slow rate of once every 9.4 days. Some scientists think that the fact that it rotates this slowly suggests it is a young object, lending more evidence to the theory that it was knocked off a larger body relatively recently in terms of the age of the solar system. Most asteroids rotate once every 6 to 9 hours; if one is found to spin much faster or slower, astronomers assume that it must have been sped up or slowed down by a relatively recent collision.

With the Deep Space 1 flyby, space scientists will be able to learn more about asteroid Braille's shape, size, surface composition, terrain and, perhaps, how it interacts with the solar wind, a flow of charged particles constantly streaming away from the Sun. The spacecraft's two science instruments will be used to gather images and other data on the asteroid and its environment.

Approach sequence. In the final 30 days of the spacecraft's approach to the asteroid, Deep Space 1's AutoNav experiment has been taking more frequent pictures of so-called "beacon" asteroids to help it navigate. Most of these are objects in the main asteroid belt that are bright enough to be seen in the camera and whose positions are sufficiently well-known to be useful for navigation. Asteroid Braille itself is too dim to be seen by the spacecraft until perhaps a day before the closest approach. During this month, the spacecraft has also been firing its thrusters in a series of increasingly frequent trajectory correction maneuvers to control the targeting of the final encounter.

Deep Space 1 will send its final session of data to Earth about seven hours before closest approach. During this transmission, the dish-shaped high-gain antenna must be pointed toward Earth. Following this session, the spacecraft will turn to point its camera toward the asteroid. Six minor trajectory correction maneuvers are scheduled as needed in the 48 hours preceding the flyby, when the spacecraft is likely to see the asteroid for the first time.

The last opportunity for a trajectory correction maneuver will be three hours before closest approach. During the final approach, the spacecraft's camera will both take navigation pictures for AutoNav and collect images and spectra for scientific purposes. The late navigation images will contain information that AutoNav needs to provide rapid updates to its estimates of the distance to the asteroid, critical for keeping the asteroid in the camera's field of view. The camera may be able to obtain pictures of the asteroid's surface with resolutions as high as about 30 to 50 meters (100 to 150 feet) per pixel.

Although the spacecraft will not linger as it flashes past the asteroid, there will be opportunities for it to take scientifically interesting pictures during the last five minutes as it approaches asteroid Braille. As the asteroid and spacecraft close in on each other, Deep Space 1's autonomous navigation system will change the spacecraft's orientation in the last five minutes before the encounter by approximately 2 to 3.5 degrees to keep its camera oriented toward the quickly approaching body.

In planning the encounter, scientists had to select tradeoffs between observations by the spacecraft's camera and plasma instrument. In order to take pictures, the spacecraft must keep its camera pointed at the asteroid by frequently firing its onboard thrusters. The plasma instrument, however, cannot collect high-quality data when the thrusters are fired often. Scientists decided to take pictures as the spacecraft approaches the asteroid, and then switch to collecting plasma data at the closest moments of the flyby. At this point, pictures would very probably be blurry, while this is the only time that the plasma instrument would be able to detect any faint magnetic field at the asteroid, if any exists.

With that in mind, the camera will stop taking photos and the spacecraft will reduce the frequency of its thruster firings about 20 to 25 seconds before closest approach, when the spacecraft is about 350 kilometers (220 miles) from the asteroid. The plasma instrument will then collect data as Deep Space 1 sails past the asteroid.

Flyby geometry. At the time of the flyby, the spacecraft will be in the ecliptic plane, the plane in which Earth and most of the other planets orbit the Sun. The spacecraft will be moving more slowly than the asteroid, which, in broad terms, will be progressing up through the ecliptic plane from below. Thus in some ways it may be more apt to say that the asteroid will zoom by Deep Space 1 than the other way around.

Once the asteroid has passed by, the spacecraft will take about 15 minutes to execute a complex 180-degree turn to watch and record the asteroid as it moves away, sailing above the ecliptic plane. This maneuver gives the spacecraft the opportunity to study the opposite side of the asteroid.

The asteroid has far too little gravity to cause the spacecraft's flight path to turn or bend in any measurable way, as other spacecraft do when they execute "gravity assist" flybys of planets. Although scientists are unsure of Braille's surface gravity, it is estimated to be in the range of 1/10,000 that of Earth.

During the encounter, Deep Space 1's autonomous navigation experiment will attempt to guide the spacecraft to within 15 kilometers (about 10 miles) of the asteroid's center, making it the closest flyby of a solar system body ever attempted. During the flyby, the spacecraft will be moving at a velocity of about 24.2 kilometers per second (54,000 miles per hour) relative to the Sun and 15.5 kilometers per second (34,560 miles per hour) relative to the asteroid.

Deep Space 1 will fly past the dark side of the asteroid facing away from the Sun, passing through its shadow or umbra. Much as the asteroid has an optical shadow, it also casts a "shadow" marked by an absence of the charged particles that make up the solar wind constantly streaming outward from the Sun. The spacecraft will sample this area as it flies by.

Post-encounter period. The spacecraft is expected to take two to three days to transmit to Earth all of its technology testing and science data from the flyby. Starting a day and a half after the flyby, the spacecraft will start thrusting with its ion engine while keeping its dish-shaped high-gain antenna pointed at Earth. Twelve days after the flyby, the spacecraft will turn to a new orientation so that thrusting from the ion engine will shape its flight path for a possible comet flyby in 2001 if NASA elects to extend the spacecraft's mission.

End of Prime Mission

Deep Space 1's prime mission will conclude September 18, 1999. By this time, all of the technology testing will have been accomplished.

If the spacecraft is healthy and NASA chooses to continue the mission, an extended mission may be conducted. At the end of the primary mission, Deep Space 1 will be on a trajectory that could result in two scientifically interesting flybys within the following two years. One would be of an object known as comet Wilson-Harrington; this body is believed to be either a dormant comet or a "transition object" that is in the process of changing from a comet to an asteroid. Wilson-Harrington, which Deep Space 1 could fly by in January 2001, has not been observed to behave like a comet — spewing gas with a coma and tail — since 1949; it is very unusual for a comet to exhibit this type of change in behavior.

The second possible flyby target of an extended mission, comet Borrelly, is one of the most active comets that regularly visit the inner solar system. Deep Space 1 could fly by Borrelly in September 2001.

Deep Space Network and Ground Support

Communication with Deep Space 1 is enabled by two major systems on the ground: the Deep Space Network and the Advanced Multimission Operations System.

The Deep Space Network provides the vital two-way communications link that both controls the spacecraft and receives telemetry. The network consists of three complexes located approximately 120 degrees of longitude apart around the world: at Goldstone in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. This spacing insures that one antenna is always within view of a spacecraft as Earth rotates. The stations feature precision-pointed, high-gain, parabolic reflector antennas; some of these giant dishes are 34 meters (112 feet) in diameter, while the most sensitive are 70 meters (230 feet) in diameter. They work together with high-power transmitters and ultra-low-noise amplifiers to optimize the communication link with spacecraft millions of kilometers (miles) away. All data gathered by antennas at the three complexes are communicated directly to the control center at the Jet Propulsion Laboratory, the operations hub for the network. Voice and data traffic between various locations is sent via land lines, submarine cable, microwave links or communications satellites.

The Advanced Multimission Operations System is an integrated ground system at JPL which provides a common set of mission operations services and tools to space projects. These allow engineers to carry out mission planning and analysis, develop pre-planned sets of commands to be sent to the spacecraft, perform trajectory calculations to check the autonomous navigation system on the spacecraft, and process data transmitted to Earth from the spacecraft. The system also provides capabilities to display and analyze key measurements from the spacecraft, such as readings of temperature, pressure and power. Other mission operations services include simulation of telemetry and command data, data management and retrieval of all data types. Deep Space 1 is the first mission to rely heavily on the operations system's multimission capability for mission operations.

Compared to some other solar system spacecraft, Deep Space 1 has made many decisions on its own and has required relatively infrequent intervention from ground controllers. For long periods of the mission, Deep Space 1 will be tracked only once per week for normal telemetry dumps and command loads during non-prime hours. This ability to use tracking passes as available will help reduce competition between spacecraft projects for antenna time on the Deep Space Network system.

Deep Space Network engineers are also very interested in Deep Space 1's successful tests of its small deep space transponder and Ka-band solid-state power amplifier, technologies that will improve telecommunications for future spacecraft missions.

Student Involvement

Boys & Girls Clubs. In an effort to reach children who traditionally have not had much access to the marvels of space exploration, the Deep Space 1 mission has sponsored a "Picture Yourself in the New Millennium" activity with the Boys & Girls Clubs of America.

The 1,800 clubs nationwide have a membership of 2.6 million children from inner city, underprivileged backgrounds.

Based on a discussion of what a millennium means, the progress of technology in the past century, and how dramatically they expect life to change because of technology in the next century, youths in the program have created drawings and written poems about life in the new millennium. Approximately 1,000 entries and the names of all the children participating were scanned onto a CD-ROM that is flying on Deep Space 1. Spectrum Astro Inc. designed certificates to acknowledge the children's contributions. Deep Space 1 and the New Millennium Program will be sponsoring more activities with the clubs in the future.

ITEA. The International Technology Education Association (ITEA), the nation's largest professional education association devoted to technology education in kindergarten through 12th grade, has formed an educational partnership with JPL. Among the joint projects resulting from this alliance is a web site, "The Space Place," designed to introduce students and their teachers to some of the latest, most advanced technologies being tested on New Millennium Program missions for use on space missions of the future. The Space Place is accessible at **http://spaceplace.jpl.nasa.gov** . The Deep Space 1 project team has developed several curriculum supplements which have been published in ITEA's publication Technology Teacher. These include "Ion-Drive Your Way Through Space" and "We've Got Algo-Rhythm."

In the summer of 1998, both the Boys and Girls Clubs of America and ITEA participating in a Deep Space 1 "National Countdown" activity, through which thousands of school children took part in a three-tiered exercise: setting goals, identifying ways of achieving them and, finally, pledging to take action to turn these goals into reality. Youths from four Boys and Girls Clubs from the area near Cape Canaveral, FL, participated in a pre-launch event at Kennedy Space Center. The kids shared their goals with several NASA scientists and then packed a time capsule to be opened in the year 2048.

Science Objectives

Unlike most solar system missions, Deep Space 1's main purpose is to test new technologies rather than visit or make observations of celestial objects. Even so, the spacecraft's science instruments will collect valuable data, particularly during the asteroid flyby. This encounter will allow engineers an extra chance to observe the performance of the technologies under conditions similar to what would be experienced on future science missions.

Among the 12 new technologies that Deep Space 1 has been testing are two advanced science instruments that will collect information during the flyby. One, the Miniature Integrated Camera Spectrometer (MICAS), is a package that combines two cameras with spectrometers that analyze ultraviolet and infrared energy thrown off by celestial objects. The other experiment, called the Plasma Experiment for Planetary Exploration (PEPE), combines multiple instruments that study space plasma, or ions and electrons that flow outward from the Sun and elsewhere in space. Detailed information on the hardware of these experiment packages is found in the section on technologies on pages 27-28.

The Camera-Spectrometer Team

Pictures taken by Deep Space 1's advanced camera will allow scientists to study the asteroid's general physical characteristics, such as its dimensions, shape, surface texture, brightness and diversity, and to make estimates of its mass, volume and density. High-resolution images will be particularly useful for studying the size, number and distribution of craters.

The teams using the camera-spectrometer have the following goals:

❑ Understand the asteroid's composition. Scientists will use the instrument's infrared spectrometer to look for the spectral signatures of the minerals that make up the asteroid. The instrument will allow them to do this at a much higher resolution than possible from ground-based telescopes. They hope that this analysis will allow them to pinpoint similarities between the asteroid and meteorites that fall to Earth. By studying how light is reflected from the asteroid, scientists will also try to form conclusions about its surface texture.

❑ Understand how Braille's spectral signatures correspond to those of asteroids in the main asteroid belt, based on observations with the infrared spectrometer.

❑ Determine whether Braille contains any "pre-biotic" materials — meaning any precursors for life such as carbon, oxygen, hydrogen or nitrogen — again using the infrared channel.

❑ Understand the asteroid's "morphology" — which is to say, its dimensions, form and surface relief — using both of the experiment's optical cameras, the active pixel sensor and charge-coupled device.

These investigations are designed to answer questions that fall into two key categories:

❑ What is the overall structure, or “morphology,” of this asteroid? Is it a solid chunk, or a rubble pile? Perhaps Braille and similar near-Earth asteroids are chips off of large asteroids in the main belt that have somehow drifted closer to Earth. Once the mystery of the asteroid's structure has been solved, scientists may be able to answer questions about how asteroids are formed and what kinds of events, such as collisions, lead to their transport from the asteroid belt to Earth.

❑ What is the asteroid's composition? There is evidence that the asteroid is unusually bright, indicating that the surface is fresher and younger than other asteroids. Its color suggests it may be closer in composition to terrestrial meteorites than to main-belt asteroids.

The Plasma Team

Electrically charged ions and electrons constantly flow through the solar system. Many of them stream outward from the Sun in a flow called the solar wind. Some gather in the powerful magnetic fields of giant planets such as Jupiter and Saturn. Still others are believed to enter the solar system from regions beyond in the galaxy at large.

Deep Space 1’s plasma experiment will study whether any charged particles are thrown off from the asteroid’s surface as it interacts with sunlight or the solar wind. The team will also investigate the composition of any such particles that may be expelled by the asteroid. Knowing the composition of such materials would reveal information about the composition of the asteroid itself. If successful, this will be the first time that material of any kind has been

Deep Space 1 Science Team

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directly measured coming off an asteroid. This information can be directly compared with other information about the composition of the asteroid's surface obtained from the infrared channel on Deep Space 1's camera-spectrometer.

Scientists will also attempt to measure any effects that the asteroid might have on the solar wind. This might be caused, for example, if the asteroid has a magnetic field — considered unlikely — or if it gives off a sufficient amount of charged particles. Scientists would detect such an effect if the instrument's count of electrons in the solar wind varies as the spacecraft passes the asteroid.

The 12 Technologies

The technologies that have been tested on Deep Space 1 will contribute to spacecraft of the future in several ways. A number of the technologies are designed to help make future spacecraft smaller and less expensive. Others make spacecraft less dependent on tracking by NASA's Deep Space Network and intervention from ground controllers.

Ion Engine

Ion propulsion has been a technology favored by science fiction writers for decades. As imagined in television's "Star Trek" or the "Star Wars" movie series, ion drives are highly advanced devices delivering an extremely powerful thrust allowing spaceships to outrun routine vessels of the future.

The reality of ion propulsion, at least today, is very different. The ion drive on Deep Space 1 combines a gas found in photo flash units with some of the technologies that make television picture tubes work to deliver a thrust only as powerful as the pressure of a sheet of paper resting on the palm of a hand. Despite the almost imperceptible level of thrust, however, over the long haul Deep Space 1's ion engine can deliver up to 10 times more thrust than a conventional liquid or solid fuel rocket for a given amount of fuel.

This year, Deep Space 1's ion propulsion system and the team that developed it have been honored with awards from both Popular Science and Discover magazines.

Ion propulsion basics. The fuel used in Deep Space 1's ion engine is xenon, a colorless, odorless and tasteless gas more than 4-1/2 times heavier than air. Xenon was discovered in 1898 by British chemists Sir William Ramsay and Morris W. Travers when they were distilling krypton, another noble gas that had been discovered only six weeks earlier. Xenon occurs naturally in air, but only accounts for 1 part in 10 million of Earth's atmosphere by volume. The gas is used commercially in products such as photo flash units and some lasers. The Deep Space 1 system carried a total of 82 kilograms (181 pounds) of xenon at launch.

When the ion engine is running, electrons are emitted from a hollow bar called a cathode into a chamber ringed by magnets, much like the cathode in a TV picture tube or computer monitor. The electrons strike atoms of xenon, knocking away one of the 54 electrons orbiting each atom's nucleus. This leaves each atom one electron short, giving it a net positive charge — making the atom what is known as an ion.

At the rear of the chamber are a pair of metal grids, one of which is charged positively and the other charged negatively, with up to 1,280 volts of electric potential. The force of this electric charge exerts a strong "electrostatic" pull on the xenon ions — much like the way that bits of lint are pulled to a pocket comb that has been given a static electricity charge by rubbing it on wool on a dry day. The electrostatic force in the ion engine's chamber, however, is much more powerful — causing the xenon ions to shoot past at a speed of more than 100,000 kilometers per hour (62,000 miles per hour), continuing right on out the back of the engine and into space. In order to keep the xenon ions from being attracted back into the engine's chamber, an electrode at the very rear of the engine emits electrons which rejoin with many of the xenon atoms speeding past to neutralize their electrical charge.

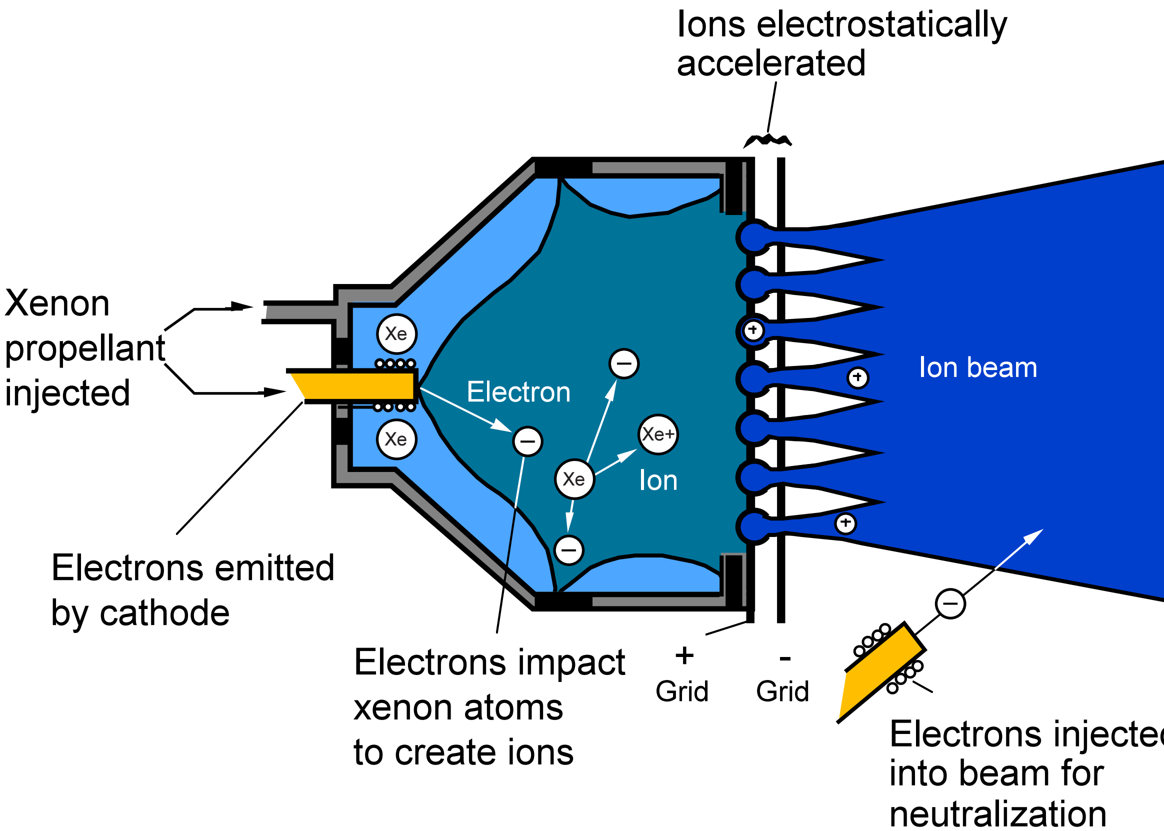
At full throttle, the ion engine would consume about 2,500 watts of electrical power and put out 90 millinewtons (1/50th of a pound) of thrust. This is comparable to the force exerted by a single sheet of paper resting on the palm of a hand. At the minimum possible throttling level, the engine uses 500 watts of power and puts out about 20 millinewtons (1/200th of a pound) of thrust. Deep Space 1's solar arrays can supply a maximum of 2,500 watts of power, not enough to cover both the engine at full throttle in addition to the nearly 400 watts that the spacecraft consumes, so the ion engine will not be run at full thrust during the mission.

The engine's magic, however, lies in its staying power. Such a minute force could never be used to launch a spacecraft from Earth's surface, but it is ideal for the cruise segment of interplanetary journeys lasting months or years. With constant operation over time, an ion engine can provide substantial thrust to a spacecraft. Over the life of the primary mission, the ion engine on Deep Space 1 will change the spacecraft's speed by a total of nearly 13,000 kilometers per hour (more than 8,000 miles per hour). Even more significantly, the ion engine can deliver more than 10 times more thrust than a conventional liquid or solid fuel motor for a given amount of fuel. The ion engine on Deep Space 1 is 30 centimeters (12 inches) in diameter.

Development history. Ion propulsion — also known as solar electric propulsion because of its dependence on electricity from solar panels — has been under development since the 1950s. Dr. Harold Kaufman, a now-retired engineer at NASA's Glenn Research Center (formerly the Lewis Research Center), Cleveland, OH, built the first ion engine in 1959.

In 1964, a pair of NASA Lewis Research Center ion engines were launched on a Scout rocket from Wallops Island, VA, under the name Space Electric Rocket Test 1 (SERT 1); one of the two thrusters onboard did not work, but the other operated for 31 minutes. A follow-up mission, SERT 2, was launched in 1970 on a Thor Agena rocket from Vandenberg Air Force Base, CA. SERT 2 carried two ion thrusters, one operating for more than five months and the other for nearly three months.

Many early ion engines used mercury or cesium instead of xenon. SERT 1 carried one mercury and one cesium engine, while SERT 2 had two mercury engines. Apart from the fuel, these ion drives were similar to Deep Space 1's; the mercury or cesium would be turned into a gas, bombarded with electrons to ionize it, then electrostatically accelerated out the rear of the engine. But mercury and cesium proved to be difficult to work with. At room temperature, mercury is a liquid and cesium is a solid; both must be heated to turn them into gases. After exiting the ion engine, many mercury or cesium atoms would cool and condense on the exterior of the spacecraft. Eventually researchers turned to xenon as a cleaner and simpler fuel for ion engines.



Ion propulsion system

Beginning in the 1960s, the Hughes Research Laboratories, Malibu, CA, conducted development work on ion engines. The first xenon ion drive ever flown was a Hughes engine launched in 1979 on the Air Force Geophysics Laboratory's Spacecraft Charging at High Altitude (SCATHA) satellite. In August 1997, Hughes launched the first commercial use of a xenon ion engine on PanAmSat 5 (PAS-5), a communications satellite launched on a Russian Proton rocket from the Baikonur Cosmodrome in Kazakhstan. This ion engine is used to maintain the position of the communications satellite in its proper orbit and orientation. Ion engines for such purposes are smaller than systems like Deep Space 1's, which is designed for long-term interplanetary thrusting.

In the early 1990s, JPL and NASA Lewis partnered on an effort called the NASA Solar Electric Propulsion Technology Application Readiness (NSTAR) project. The purpose of NSTAR was to develop xenon ion engines for deep space missions. In June 1996, a prototype engine built by NASA Lewis began a long-duration test in a vacuum chamber at JPL simulating the conditions of outer space. The test concluded in September 1997 after the engine successfully logged more than 8,000 hours of operation. Results of the NSTAR tests were used to define the design of flight hardware.

Testing on Deep Space 1. After an initial problem attempting to start the ion engine on

November 10, 1998, the system was successfully fired up two weeks later on November 24, and continued thrusting for two weeks uninterrupted. With this, Deep Space 1 had already operated its thruster for a much longer uninterrupted time than any deep space probe using any other propulsion system.

From November 24 through November 30, throttle levels were commanded up from level 6 to 90, the maximum being 111, in order to gauge power consumption at various levels. At throttle level 90, it appeared that the spacecraft was near its limit for providing power to the ion propulsion system, drawing approximately 2.4 kilowatts of power.

The engine was turned off on December 8. By running the ion engine for more than the required 200 hours and successfully testing the spacecraft's solar array and transponder, the team achieved the minimum criteria that NASA established for overall mission success.

The engine was turned back on on December 11, when the team determined that the highest throttle level that could be supported was approximately 83 at the spacecraft's distance from the Sun at that time (the solar array's capabilities change as the spacecraft recedes from the Sun); at level 85, it became necessary for the spacecraft's batteries to supplement solar array power.

On January 5, 1999, the autonomous navigation system turned off the ion engine, completing the first thrust segment of the Deep Space 1 mission. During that period, the engine accumulated more than 850 operating hours and experienced 59 recycles, which are momentary automatic interruptions, or shutoffs, of the system, primarily for the system to protect itself from damage due to drifting particulates. By contrast, in the first 850 hours of ground testing of the flight-spare ion engine, approximately 240 recycles were experienced. The lower number of recycles in flight suggests that in-space operation of an ion thruster is more benign than operation in a vacuum chamber.

On April 27, Deep Space 1 completed a six-week period of thrusting with its ion propulsion system. It took less than 5 kilograms (under 11 pounds) of xenon to provide the steady push for the six weeks of thrusting that ended on April 27, during which the spacecraft's speed was increased by nearly 300 meters per second (about 650 miles per hour). If the spacecraft had expended the same amount of standard rocket propellant instead of using ion propulsion, the speed would have changed by a mere 80 kilometers per hour (50 miles per hour). Deep Space 1 has now completed a total of more than 75 days of thrusting.

Partners. The xenon ion flight engine was built for Deep Space 1 by Hughes Electron Dynamics Division, Torrance, CA, and Spectrum Astro Inc., Gilbert, AZ. Other partners in the development of the flight engine included Moog Inc., East Aurora, NY, and Physical Science Inc., Andover, MA. Development of the xenon ion propulsion system was supported by NASA's Office of Space Science and Office of Aeronautics and Space Transportation Technology, Washington, DC. A portion of the NSTAR program was supported by the Advanced Space Transportation Program, managed by NASA's Marshall Space Flight Center, Huntsville, AL.

Solar Concentrator Arrays

Because of the ion engine's power requirements, Deep Space 1 requires a high-power solar array. Designers met this need by combining high-performance solar cells with lenses designed to focus sunlight on them.

The spacecraft is equipped with two solar wings, each of which is composed of four panels measuring about 113 by 160 centimeters (44 by 63 inches). At launch, the wings were folded up so that the spacecraft fit into the launch vehicle's fairing; when fully extended, the wings measure 11.8 meters (38.6 feet) from tip to tip. A total of 720 cylindrical Fresnel lenses made of silicone concentrate sunlight onto 3,600 solar cells made of a combination of gallium indium phosphide, gallium arsenide and germanium.

The arrays produce 15 to 20 percent more power than most modern solar arrays of the same size — about 2,500 watts at the beginning of the mission (declining over the life of the mission as the array ages and the spacecraft recedes from the Sun) with a voltage of 100 volts.

An earlier version the solar array was included as a test on a satellite on the unsuccessful launch of the Conestoga launch vehicle in October 1995, so it was never tested in space.

Because power from the arrays were needed almost immediately, the arrays were tested within just two hours of launch. Telemetry was received from the spacecraft through NASA's Deep Space Network at 1 hour, 37 minutes after launch, and 3 minutes later it was determined that the spacecraft's arrays had been deployed.

On October 31, 1998, one day ahead of schedule, the operations team measured the arrays' electrical characteristics, particularly eight modules comprised of five solar cells each that are specially instrumented for measuring current and voltage. The following day, a more complex test was executed successfully in a 10-hour activity. The intricate choreography included rotations of the pair of solar arrays and turns of the spacecraft to vary the angle of the sunlight incident upon the arrays, all designed to determine the best angle to maximize collection of sunlight.

When the ion engine was powered on beginning November 24, the team gathered additional test data on the arrays. This marked the first opportunity that the arrays had to provide high power, since the propulsion system has the greatest power requirements of any unit onboard.

To test exactly how much power the array could generate, the operations team needed to draw as much power from the array as it could deliver. On January 22, 1999, the ion engine was powered on and raised to a high throttle level. The data that were generated contributed to understanding this advanced technology's detailed performance.

The solar concentrator array was developed by AEC-Able Engineering Inc., Goleta, CA;

Entech, Keller, TX; NASA's Glenn Research Center, Cleveland, OH; and JPL. Technology development was sponsored by the Ballistic Missile Defense Organization, Washington, DC.

Autonomy Technologies

As more planetary spacecraft are launched into the solar system more frequently in NASA's era of smaller and more rapidly developed missions, competition increases for tracking time on the giant dish antennas of the agency's Deep Space Network. Several new technologies on Deep Space 1 are designed to make spacecraft more self-reliant, depending less on tracking and the intervention of ground controllers. Autonomy also helps when spacecraft are too far away from Earth for rapid assistance from ground controllers.

❑ **Autonomous Navigation** (AutoNav). In a traditional solar system mission, ground controllers track the radio signal from a spacecraft to determine its position in space. They may also periodically command the spacecraft's camera to take pictures of the target planet, asteroid or comet to check the position of the craft in space. Based on these measurements, engineers command the spacecraft to execute thruster firings to fine-tune its flight path. Deep Space 1 has dramatically improved this process by allowing the spacecraft to take over the parts of the navigation job formerly carried out by ground controllers.

Deep Space 1 has been finding its location in the solar system by taking images of known asteroids and comparing their positions to background stars. The orbits of 42 asteroids and the positions of 250,000 stars were stored in computer memory at launch. Using the positions of the asteroids and stars, the actual spacecraft location can be determined.

In most cases, the trajectory changes for which AutoNav called were implemented through changes in the ion engine's thrust profile. In some cases, small maneuvers were achieved with dedicated firings of the ion engine or by firings of the spacecraft's separate hydrazine thrusters.

One of many challenges in the use of AutoNav was its reliance on another new technology, ion propulsion, to achieve the thrusting necessary to fulfill its navigation decisions. Because of this uncertainty, the onboard navigator was designed to be able to cope with a wide range of propulsion performance.

Engineers consider AutoNav to be 95 percent validated, with the final test taking place with the flyby, when this new technology will be called upon to locate asteroid Braille and to navigate the spacecraft to within 15 kilometers (10 miles) of the asteroid's center.

Test activities began in mid-November, when AutoNav first turned the spacecraft to point the spacecraft's camera to take pictures of various asteroids. The flight team watched as AutoNav took the spacecraft to several different orientations to collect its data.

AutoNav transitioned into further spacecraft control on December 18, 1998, when it directed the ion propulsion system to pressurize its xenon tanks for thrusting, commanding the spacecraft's attitude control system to turn the spacecraft to thrust in the direction that AutoNav desired and, finally, starting the thruster.

When the ion propulsion system is thrusting, AutoNav updates both the direction and the throttle level for the thrusting every 12 hours in order to follow the flight profile stored on board. So far, the AutoNav system has operated flawlessly.

On December 21, thrusting was suspended for a few hours, during which AutoNav commanded the spacecraft to turn to point its camera at asteroids and stars and take images of them. The images taken allowed AutoNav's designers to improve onboard computer routines for processing such pictures. Previously, all they had was prelaunch predictions of the camera's performance; now, with actual images, the routines could be updated.

During the week of February 1, 1999, AutoNav's weekly optical navigation imaging session was different than usual: for the first time, the operations team allowed the session to proceed without monitoring it. In addition, much of the normal, careful ground testing that precedes most spacecraft activities was avoided.

Until April 12, AutoNav controlled the ion engine without using its full autonomy potential, as it was merely following a plan generated by the mission team. Starting on April 12, however, AutoNav was allowed to use its own calculations to change that plan for the first time ever. It began autonomously commanding the ion engine to thrust as needed — an important further step toward thorough testing of this autonomy technology.

On May 4, the mission team successfully conducted further AutoNav tests and has conducted intermittent experiments ever since.

AutoNav was developed by JPL.

❑ **Remote Agent**. This experiment takes an even bigger step toward spacecraft autonomy with onboard computer software designed to make a wider variety of decisions. It is capable of planning and executing many onboard activities with only general direction from the ground.

The software is an autonomous "remote agent" of ground controllers in the sense that they rely on the agent to achieve particular goals. Ground controllers do not tell the agent exactly what to do at each instant; rather, they assign it more generalized tasks.

The software package includes a "planner/scheduler" that generates a set of time-based and event-based activities, known as tokens, that are delivered to an "executive" that is also a part of the software system. The executive makes decisions by taking into account knowledge of the spacecraft state, constraints on spacecraft operations and the high-level goals provided by the ground. The executive expands the tokens to a sequence of commands that are issued directly to the appropriate subsystems on the spacecraft. The executive monitors responses to these commands, and reissues or modifies them if the response is not what was planned.

Remote Agent's design is flexible enough to handle a variety of unexpected situations onboard. Because of its access to a much more complete description of the spacecraft state than would be available to ground controllers in a traditional operations concept, it can make better use of onboard resources.

Remote Agent software was not designed to control Deep Space 1 throughout the mission; software was transmitted to the spacecraft after launch to control the ion engine and selected other systems during a 48-hour test period starting on the morning of May 17, 1999. On the morning of May 18, however, the experiment team detected an anomaly that interrupted execution of the experiment. The first indication occurred when Remote Agent did not command the spacecraft's ion propulsion system to shut down as expected. While some portions of the Remote Agent software continued to operate, the component that issues commands had suspended operation.

The spacecraft was determined to be safe and healthy. The experiment software appeared active and was allowed to continue processing while the experiment team and Deep Space 1 flight team analyzed the problem. After retrieving diagnostic data from the spacecraft, a ground command was issued that afternoon that halted the experiment.

By the time it was halted, the experiment had already achieved about 70 percent of its test objectives. A small bug in the very complex software was identified as the probable cause of the suspension, with the significant assistance of Remote Agent's own self-diagnostic software.

A successful follow-up experiment on May 21 completed the remaining objectives for the Remote Agent test. Presented with three simulated failures on the spacecraft, the experimental software correctly handled each event. The simulations included: a failed electronics unit, which Remote Agent fixed by reactivating the unit; a failed sensor providing false information, which Remote Agent recognized as unreliable and therefore correctly ignored; and a thruster stuck in the "off" position, which Remote Agent detected and for which it compensated by switching to a mode that did not depend on that thruster.

Remote Agent was developed by NASA's Ames Research Center, Moffett Field, CA; JPL; and Carnegie Mellon University, Pittsburgh, PA.

❑ **Beacon Monitor Operations Experiment**. This experiment simplifies the way that the spacecraft communicates information about its condition to ground controllers. In a traditional planetary mission, spacecraft send information to Earth as part of telemetry transmitted as digital information in radio signals. Such digital signals are relatively demanding for the antennas of NASA's Deep Space Network to receive and process.

The Beacon Monitor experiment, by contrast, translates overall spacecraft health and status into one of four general states. The monitor then radios one of four tones to Earth to notify ground controllers of the spacecraft's state. A so-called "green" tone indicates that the spacecraft is operating within acceptable conditions. An "orange" tone indicates that an anomaly was resolved by the spacecraft but conditions are acceptable. A "yellow" tone indicates a desire to send data to the ground or to request help with a problem that may escalate to jeopardize the mission. Finally, a "red" tone indicates that the spacecraft has a critical anomaly it cannot resolve and requires urgent assistance from the ground. A substantial portion of the system is the onboard artificial-intelligence software that allows it to summarize the spacecraft's condition succinctly.

The beacon monitor makes communication with spacecraft easier in two ways. First, the beacon's tones are much simpler to receive and understand than traditional complex, encoded digital telemetry. Instead of requiring one of the mammoth 70-meter (230-foot) antennas of the Deep Space Network to track a spacecraft, a mission might get by with an antenna only 3 to 10 meters (10 to 30 feet) in diameter. Second, a ground station can receive the beacon monitor's tone, understand it and move on to another spacecraft much more quickly than it could receive digital telemetry. A spacecraft might go for weeks or months without sending digital telemetry, instead broadcasting only pre-arranged simple beacon status checks.

During Deep Space 1's primary mission, mission managers haven't relied on the beacon monitor continuously, instead using it during selected test periods. In February 1999, for instance, it successfully transmitted four different beacon signals, allowing engineers to verify predictions of how well experimental instruments could detect them.

The Beacon Monitor Operations Experiment was developed by JPL.

Science Instruments

❑ **Miniature Integrated Camera Spectrometer** (MICAS). This package is one of two next-generation science instruments being flown on Deep Space 1. MICAS includes several imaging systems within a single 12-kilogram (26-pound) package.

The instrument has a total of four sensors that share a single 10-centimeter-diameter (4-inch) telescope. Two are black-and-white cameras — one with a conventional charge-coupled device (CCD) detector, and the other with a more exotic device called an active pixel sensor. The active pixel sensor is a next-generation imaging device that combines support electronics that are usually separate in conventional cameras onto the same chip as the detector itself.

The other two systems combined into MICAS are imaging spectrometers; scientists use these to analyze the light reflected by a celestial object in order to determine what it is made of. One of the spectrometers operates in the ultraviolet spectrum, while the other works in the infrared spectrum. Both of the spectrometers work in "push-broom" mode, meaning that the instrument must sweep across the target body to collect data.

In-flight data collection about MICAS's capabilities began on December 11, 1998. In early March 1999, MICAS observed a variety of targets, including Mars and selected stars, and sent back a large volume of data which have helped to evaluate the instrument's performance.

In early May, the mission team successfully completed a calibration of the instrument.

Through these activities, the charge-coupled-device (CCD) and active pixel sensor cameras and the infrared spectrometer have been well exercised. Testing has revealed that the instrument's ultraviolet detector is not functioning properly and is thus unable to return meaningful data. The optical cameras are less sensitive than expected, and pictures exhibit some geometric distortion, but scientists have been able to compensate partly for these problems by developing new software. In addition, stray light has been found in images taken by MICAS, caused partly by how the instrument is mounted on the spacecraft and partly because of its internal design. According to engineers, all of these issues will be easy to correct in future versions of the camera; they consider the debugging process to be a successful example of the flight-testing that Deep Space 1 was designed for.

MICAS was developed by the U.S. Geological Survey, Flagstaff, AZ; SSG Inc., Waltham, MA; the University of Arizona Lunar & Planetary Laboratory, Tucson, AZ; Boston University Center of Space Physics, Boston, MA; Rockwell International Science Center, Thousand Oaks, CA; and JPL.

❑ **Plasma Experiment for Planetary Exploration** (PEPE). The second of Deep Space 1's two advanced science experiments, PEPE combines several instruments that study space plasma — charged particles, most of which flow outward from the Sun — in one compact, 6-kilogram (13-pound) package.

PEPE was powered up for the first time on December 8, 1998. Within two days, the instrument demonstrated the ability to measure both electrons and ions in the solar wind, and, within a few weeks, engineers began using data from PEPE to assess the effect of ion propulsion on the instrument itself.

On January 6, 1999, new software for PEPE was tested. On January 8, PEPE was turned to its highest data rate so that it and a plasma instrument on the Saturn-bound Cassini spacecraft could make simultaneous observations of the solar wind.

On January 22, the operations team tested new software designed to allow the plasma experiment to operate in the presence of the xenon ions produced by the advanced propulsion system. Because this plasma experiment is designed to observe the more tenuous solar wind, it could be overwhelmed by the xenon, but results showed that this versatile instrument can be adjusted to accommodate the ion propulsion system.

The instrument was developed by the Southwest Research Institute, San Antonio, TX, and the Los Alamos National Laboratory, Los Alamos, NM.

Telecommunications Technologies

❑ **Small Deep-Space Transponder**. This is one of two technologies designed to improve spacecraft telecommunications hardware. Deep Space 1's transponder, or radio, combines a number of different functions — receiver, command detector, telemetry modulation, exciters, beacon tone generation and control functions — into one small, 3-kilogram (6.6-pound) package. The unit can receive and transmit in the microwave X band, and transmit in the higher-frequency Ka band. The small size and low mass is enabled by the use of advanced gallium arsenide monolithic microwave integrated-circuit chips, high-density packaging techniques and silicon application-specific integrated-circuit chips.

Because this transponder is used for communications to and from the spacecraft, it was validated within two hours of launch; the first telemetry was received from the spacecraft through NASA's Deep Space Network at 1 hour, 37 minutes after launch.

Key testing took place in December 1998, with some further tests in February 1999; this instrument passed all of its tests perfectly. During these periods, the transponder was used in a successful preliminary test of the beacon monitor experiment. The small deep-space transponder successfully transmitted four different beacon signals, allowing engineers to verify predictions of how well experimental instruments could detect them.

The transponder was developed by the Motorola Government Space Systems Division's Space and Systems Technology Group, Scottsdale, AZ.

❑ **Ka-Band Solid-State Power Amplifier**. This is the second of two technologies concerned with telecommunications hardware. This amplifier allows the spacecraft's radio to transmit in the microwave Ka band.

Engineers are interested in the seldom-used Ka band because it allows the same amount of data to be sent over smaller antennas with less power as compared with missions using lower-frequency transmitters in the X band. The Ka band, however, is more vulnerable to interference from weather on Earth. During the Deep Space 1 mission, engineers have not only tested performance of the amplifier but also have conducted general experiments in Ka-band communications.

The mission's first use of Ka band took place on December 8, 1998, when Deep Space 1 sent data to Earth in the Ka band at a frequency four times higher than that used for most communications with solar system exploration spacecraft today. During these preliminary tests, which have been followed up with further testing throughout the mission, the spacecraft's transponder sent telemetry at 14 different data rates.

On January 10, 1999, Deep Space 1 once again transmitted to the Deep Space Network using Ka band, with regularly scheduled tests having taken place successfully since then.

The Deep Space Network's complex at Goldstone in California's Mojave Desert is the only station equipped to receive Ka-band signals, so all of Deep Space 1's tests have been conducted through Goldstone.

The power amplifier was developed by Lockheed Martin, Valley Forge, PA.

Microelectronics Technologies

These three new technologies were first tested in flight on February 25, 1999, and have been successfully tested intermittently since then.

❑ **Low-Power Electronics**. This is one of three experiments concerned with microelectronics. The experiment involves low-voltage technologies, low-energy architectures and micro-power management. Devices being tested include a ring oscillator and transistors, and are designed to consume very little electrical power.

The low-power electronics experiment was developed by the Massachusetts Institute of Technology's Lincoln Laboratory, Cambridge, MA, and JPL.

❑ **Multifunctional Structure**. The structural, thermal and electronic functions of a spacecraft have traditionally been designed and fabricated into separate elements. These single-function elements are bolted together during the final assembly of a spacecraft. Power distribution and signal transmission between the elements are accomplished by the use of bulky connectors and cable bundles.

On Deep Space 1, however, the multifunctional structure combines thermal management and electronics in one load-bearing structural element. It consists of a composite panel that has copper polyimide patches bonded to one side and embedded heat-transferring devices. The panel's outer surface acts as a thermal radiator. Electrical circuitry are designed in the copper polyimide layer; flex jumpers serve as electrical interconnects for power distribution and data transmission.

The second of three microelectronics experiments on Deep Space 1, the multifunctional structure was developed by the U.S. Air Force's Phillips Laboratory, Kirtland Air Force Base, NM, and Lockheed Martin Astronautics, Denver, CO.

❑ **Power Actuation and Switching Module**. The third of the mission's three microelectronics experiments, this technology is a smart power switch. The module actually consists of a total of eight power switches capable of monitoring a total of four electrical loads. The switches sense voltage and current, and also limit current if necessary.

The module was developed by Lockheed Martin Missiles and Space Inc., Sunnyvale, CA; the Boeing Co., Seattle; and JPL.

Spacecraft

There are not enough advanced technologies on Deep Space 1 to compose an entire spacecraft. Because the focus of the New Millennium Program is on the advanced technologies and not on overall spacecraft design, the remainder of the hardware uses off-the-shelf, low-cost components.

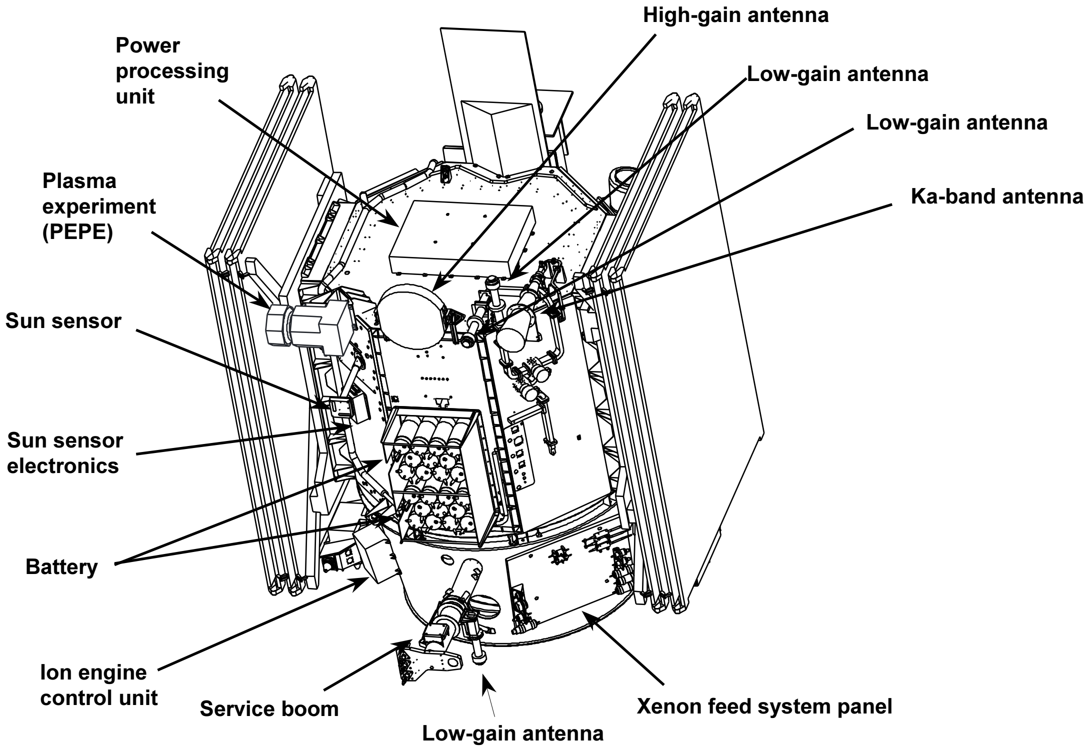
Traditional spacecraft have used redundant systems to lower risk; if an onboard computer or star sensor gives out, the spacecraft can switch to a backup. NASA's philosophy in launching Deep Space 1, however, is to mount a technologically challenging, low-cost mission. Most of the spacecraft therefore is "single-string," with no backup systems or redundancy. The design does include limited internal redundancy in some devices and some functional redundancy at the subsystem level.

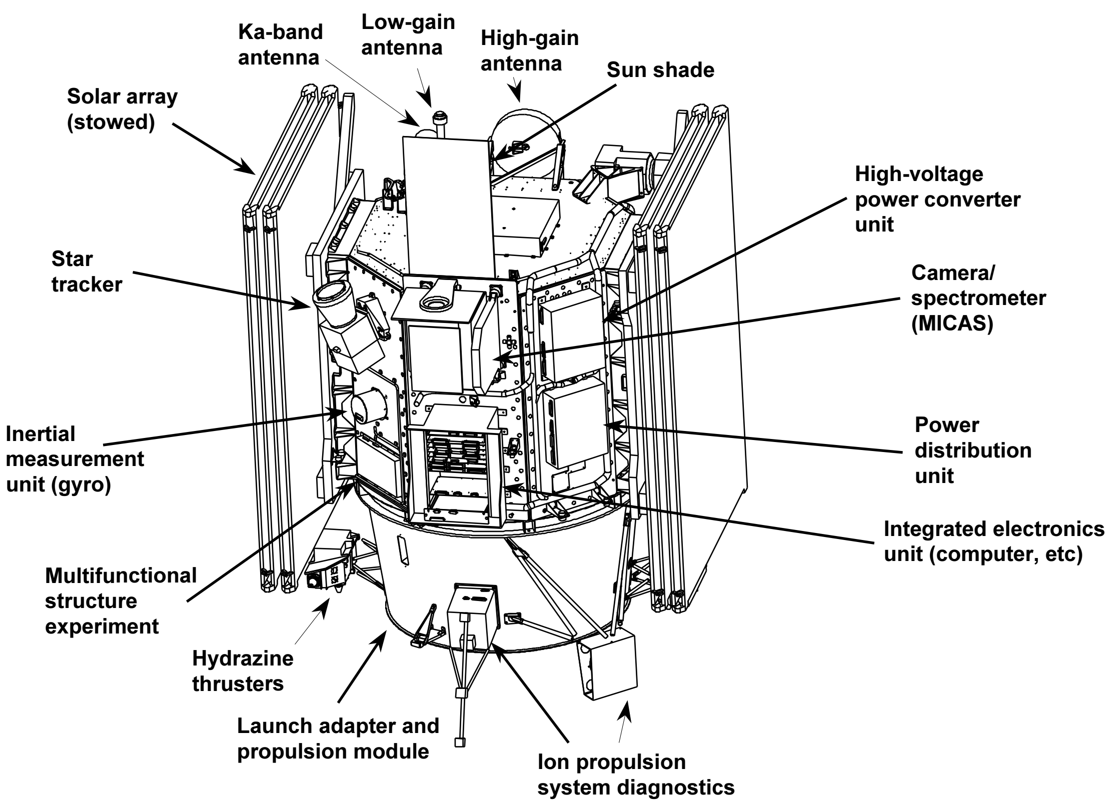
The central spacecraft structure, or "bus," is aluminum. Most components are mounted on the exterior of the bus, making them easy to access and replace during pre-launch integration and testing. A boom is attached to help technicians reach the battery plug and hydrazine, helium and xenon lines when the spacecraft is in the Delta launch vehicle's payload fairing. Thermal control is accomplished with standard multilayer insulation or thermal blanketing, as well as with electrical heaters and radiators.

Sensors used for attitude control — which is to say, control of the spacecraft's orientation — include a star sensor, an inertial measurement unit or gyro, and a Sun sensor. Most of the electronics are enclosed in an integrated electronics module.

Power is provided from the time of launch until the solar arrays are deployed by a 24-amp-hour nickel hydrogen battery provided by the U.S. Air Force's Phillips Laboratory. The battery also supplements the solar array power during ion engine thrusting to cover transients in the spacecraft's power consumption. It will also be used if the geometry of the spacecraft's asteroid flyby requires the solar arrays to be pointed too far away from the Sun for them to collect sufficient energy.

Spectrum Astro Inc., Gilbert, AZ, was JPL's primary industrial partner in spacecraft development.





Deep Space 1 spacecraft

What's Next

Deep Space 1 is the first flight project to be launched under NASA's New Millennium Program. Several more missions to test new technologies are planned in the years ahead.

❑ **Deep Space 2**. Only two and a half months after Deep Space 1's launch, Deep Space 2 departed on a mission to Mars in January 1999. In order to test a variety of new technologies, Deep Space 2 is sending two small probes weighing 2 kilograms (4.5 pounds) each aboard the Mars '98 project's Mars Polar Lander. Shortly before the lander reaches Mars on December 3, 1999, it will release the Deep Space 2 microprobes; each is designed to impact and penetrate the Martian surface up to a depth of about 1 meter (3 feet). The microprobes' technologies include temperature sensors for measuring the thermal properties of the Martian soil, and a sub-surface soil collection and analysis instrument. The microprobes will join instruments on Mars Polar Lander in searching for subsurface water on Mars. Deep Space 2 is managed by JPL.

❑ **Earth Observing 1**. Just as the "Deep Space" series of New Millennium missions tests technologies on spacecraft headed out into the solar system, the program also includes an "Earth Observing" series that will evaluate technologies in local orbit. An advanced, light-weight scientific instrument designed to produce visible and short-wave infrared images of Earth's land surfaces was selected as Earth Observing 1. The mission is scheduled for launch in December 1999.

Earth Observing 1 will serve multiple purposes, including providing remote-sensing measurements of Earth that are consistent with data collected since 1972 by the Landsat series of satellites, which is used by farmers, foresters, geologists and city planners. In addition, it will acquire data with finer spectral resolution, a capability long sought by many scientists, and it will lay the technological groundwork for inexpensive, more compact imagers in the future. Earth Observing 1 is managed by NASA's Goddard Space Flight Center, Greenbelt, MD.

Other NASA Missions to Small Bodies

❑ **Near-Earth Asteroid Rendezvous** (NEAR): The first in NASA's Discovery program of lower-cost, highly focused planetary science missions, NEAR was launched in February 1996. On June 27, 1997, NEAR became the second spacecraft to fly by an asteroid when it encountered 253 Mathilde (the first asteroid flybys were conducted by the Jupiter-bound Galileo in 1991 and 1993). NEAR found Mathilde to be composed of extremely dark material, with numerous large impact craters, including one nearly 10 kilometers (6 miles) deep. A subsequent thruster firing in July 1997 brought NEAR back around Earth for a slingshot gravity assist that put the spacecraft on a trajectory for its main mission: a rendezvous with the Manhattan-sized asteroid 433 Eros. NEAR will arrive at Eros in February 2000 and become the first spacecraft ever to orbit an asteroid, studying Eros from as close as 15 kilometers (9.3 miles). NEAR was built and is managed by Johns Hopkins University's Applied Physics Laboratory, Laurel, MD.

❑ **Stardust**: This technically daring mission under NASA's Discovery program will fly a spacecraft to within 160 kilometers (100 miles) of the nucleus of comet Wild-2 to capture comet dust particles in a material called "aerogel" and return the sample to Earth for analysis. A direct sample of a known comet has been long sought by planetary scientists because comets are thought to be nearly pristine examples of the original material from which the Sun and planets were formed 4.6 billion years ago. The spacecraft launched in February 1999, and the sample will be returned to Earth in 2006. The mission is led by principal investigator Dr. Donald Brownlee of the University of Washington and is managed by JPL.

❑ **Mu Space Engineering Spacecraft C** (MUSES-C): This innovative mission, led by the Japanese space agency ISAS, will use ion propulsion to send a spacecraft to asteroid 4660 Nereus. Although the ion drive is built entirely in Japan, it is functionally the same as — though less powerful than — its Deep Space 1 counterpart. MUSES-C will deliver a NASA nanorover to the asteroid's surface, collect samples of the asteroid and return them to Earth for laboratory analysis. The nanorover, which is being built by JPL, is so small it can be held in the palm of the hand. The mission is scheduled for launch in 2002.

❑ **Comet Nucleus Tour** (CONTOUR): This Discovery program mission will take images and comparative spectral maps of at least three comet nuclei and analyze the dust flowing from them. CONTOUR is scheduled for launch in July 2002, with its first comet flyby to occur in November 2003. This flyby of Comet Encke at a distance of about 60 miles (100 kilometers) will be followed by similar encounters with comet Schwassmann-Wachmann-3 in June 2006 and comet d'Arrest in August 2008. CONTOUR is led by Dr. Joseph Veverka of Cornell University, Ithaca, NY, and is managed by Johns Hopkins University's Applied Physics Laboratory, Laurel, MD.

❑ **Deep Impact**: This mission under NASA's Discovery program will launch in January 2004 toward an explosive July 4, 2005 encounter with Comet P/Tempel 1. The spacecraft will send a 500-kilogram (1,100-pound) copper projectile into the comet, creating a crater as big as a football field and as deep as a seven-story building. A camera and infrared spectrometer on the spacecraft, along with ground-based observatories, will study the resulting icy debris blasted off the comet, as well as the pristine interior material exposed by the impact. Deep Impact is led by Dr. Michael A'Hearn of the University of Maryland, College Park; managed by JPL; and built by Ball Aerospace, Boulder, CO.

Program/Project Management

The Deep Space 1 mission is managed by the Jet Propulsion Laboratory for NASA's Office of Space Science, Washington, DC. At NASA Headquarters, Dr. Edward Weiler is associate administrator for space science. Ken Ledbetter is director of the Mission and Payload Development Division. Lia LaPiana is program executive for Deep Space 1. Dr. Tom Morgan is program scientist.

At the Jet Propulsion Laboratory, Dr. Fuk Li is program manager for the New Millennium Program. For Deep Space 1, David Lehman is project manager, Dr. Marc Rayman is chief mission engineer and deputy mission manager and Dr. Philip Varghese is mission manager; Dr. Robert Nelson is project scientist.

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