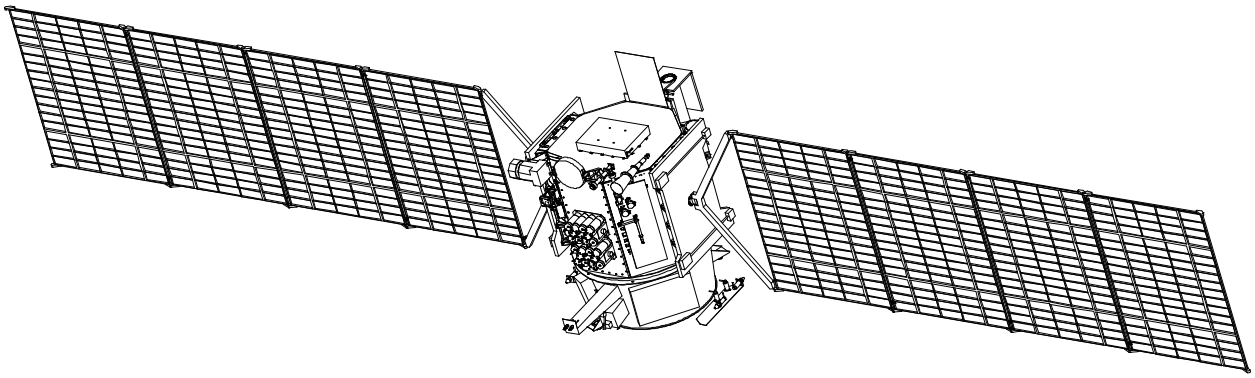
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Deep Space 1 Launch

Press Kit
October 1998



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RELEASE:

DEEP SPACE 1 SET TO TEST 12 NEW TECHNOLOGIES

An ion propulsion engine evocative of rocket systems described in science fiction is among 12 innovative technologies to be validated during NASA's Deep Space 1 mission. Also being tested are technologies designed to make spacecraft smaller, less expensive and capable of more independent decision-making so that they rely less on tracking and intervention by ground controllers.

The diminutive spacecraft, reaching just 8.2 feet (2.5 meters) in height, is being prepared to support possible launch October 15 through November 10, 1998, onboard a Delta II rocket from Cape Canaveral Air Force Station, FL. The launch window on October 15 opens at 8:04 a.m. EDT.

Deep Space 1 is the first launch of NASA's New Millennium Program, testing and validating new technologies in a series of deep space and Earth-orbiting missions. Although Deep Space 1 will test two science instruments, this mission is one of the first-ever deep space NASA launches to have technology, rather than science, as its key focus.

"Science mission project managers are reluctant to take the risk of using untested technologies," said Dr. Wesley Huntress, NASA's associate administrator for space science. "The New Millennium Program is devoted to testing out new technologies first so they can be used with greater confidence on upcoming faster, better, cheaper scientific missions of the early 21st century."

The technologies being tested on Deep Space 1 generally fall into two categories: those concerned with making future spacecraft smaller and less expensive, and those concerned with making spacecraft more autonomous.

The most important part of this high-risk, low-cost mission takes place during the six months immediately following launch, when Deep Space 1 will test most of its dozen new technologies. Much of the key testing will be completed within the first eight weeks after launch, and the technologies that the spacecraft depends on for its basic operation — such as new solar arrays and a radio or transponder — must be proven to work within the first hours after launch in order for the mission to proceed.

By the end of its prime mission, Deep Space 1 will have also demonstrated the feasibility of mission preparation periods to as short as 39 months from initial concept through launch, and of reducing mission budgets to nearly half that of other recent NASA missions. Deep Space 1 is budgeted at $152 million.

Xenon, the same gas that fills photo flash tubes and glows brightly in many lighthouse bulbs, will be the propellant for the ion propulsion system. Although this type of engine has

been tested in labs and on Earth-orbiting satellites, only now is it being flight-tested as the primary propulsion source on a deep space mission. If it proves successful in flight, ion drives are likely to be used on many future deep space and Earth-orbiting missions that would otherwise be impractical or unaffordable with conventional propulsion systems.

The small engine with the ghostly blue exhaust is deceptively powerful, more so than any engine ever before flown in space. Unlike the fireworks of most chemical rockets using liquid or solid fuels, the ion drive emits only an eerie blue glow as ionized atoms of xenon are pushed out of the engine. The almost imperceptible thrust from the system is equivalent to the pressure exerted by a sheet of paper held in the palm of a hand. Yet while the ion engine is very slow to pick up speed, over the long haul it can deliver 10 times as much thrust per pound of fuel as liquid or solid fuel rockets.

The mission also features three key experiments that give the spacecraft more autonomy in navigating and general decision-making. Autonomous navigation, when combined with the ion propulsion, "is like having one's car find its own way from Los Angeles to Washington, DC, and park itself within one foot of its destination, all the while getting 300 miles to the gallon," said Dr. Marc Rayman, Deep Space 1's chief mission engineer and deputy mission manager.

Two advanced, highly integrated science instruments are being tested in flight for the first time. Deep Space 1 will fly by asteroid 1992 KD in late July 1999, sending back images in infrared, ultraviolet and visible light. Also included are many investigations of charged particles in space called plasma — including the effects, if any, of the ion propulsion engine or its exhaust on the science instruments and the space environment.

Asteroid 1992 KD was chosen from more than 100 flyby possibilities. Its elliptical orbit curves within and outside Mars' orbit of the Sun, at its most distant extending more than three times farther from the Sun than Earth. Although scientists believe its diameter is approximately 2 to 3 miles (3 to 5 kilometers), they know little else about the object. With this flyby, they can learn more about its shape, size, surface composition, mineralogy, terrain and rotation speed.

During the encounter, new spacecraft autonomy software will attempt to guide Deep Space 1 to within 6 miles (10 kilometers) to the surface of the asteroid, and, if possible, even as close as 3 miles (5 kilometers). This will be the closest flyby of a solar system body ever attempted. 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.

A unique aspect of the New Millennium Program is its groundbreaking partnership with industry and academia. Six integrated product development teams comprised of more than 50 companies, research labs and universities are actively helping to identify and develop new technologies and instruments with the potential to revolutionize space exploration. Subject areas include autonomy, telecommunications, microelectronics, in-situ instruments, instrument technologies and modular systems.

In all, the technologies being tested include the ion propulsion system; the autonomous navigation system; an autonomous control system; a beacon system that sends simple tones to Earth to advise controllers of spacecraft health; a solar array with concentrator lenses; an integrated camera and imaging spectrometer; an integrated ion and electron spectrometer; a small deep-space transponder; a Ka-band solid-state power amplifier; low-power electronics; a multi-functional structure testing new packaging technology; and a power activation and switching module.

The Deep Space 1 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. Spectrum Astro Inc., Gilbert, AZ, was JPL's primary industrial partner in spacecraft development.

[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. The schedule for television transmissions for the Deep Space 1 launch will be available from the Jet Propulsion Laboratory, Pasadena, CA; Johnson Space Center, Houston, TX; Kennedy Space Center, FL, and NASA Headquarters, Washington, DC.

Status Reports

Status reports on mission activities for Deep Space 1 will be issued by the Jet Propulsion Laboratory's Media Relations Office. They may be accessed online as noted below. Audio status reports are available by calling (800) 391-6654 or (818) 354-4210.

Launch Media Credentialing

Requests to cover the Deep Space 1 launch must be faxed in advance to the NASA Kennedy Space Center newsroom at (407) 867-2692. Requests must be on the letterhead of the news organization and must specify the editor making the assignment to cover the launch.

Briefings

An overview of the mission will be presented in a news briefing broadcast on NASA Television originating from NASA Headquarters in Washington, DC, at 2 p.m. EDT September 22, 1998. A pre-launch briefing at Kennedy Space Center is scheduled at 11 a.m. EDT the day before launch.

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 from the Jet Propulsion Laboratory's World Wide Web home page at **http://www.jpl.nasa.gov/** . The Deep Space 1 mission also maintains a home page at **http://nmp.jpl.nasa.gov/ds1/** .

Quick Facts

Spacecraft

Dimensions: Core bus 3.6 feet deep by 3.6 feet wide by 4.9 feet high (1.1 by 1.1 by 1.5 meters); with all instruments and blankets attached, 6.9 by 5.6 by 8.2 feet (2.1 by 1.7 by 2.5 meters); with solar panels deployed, overall width 38.6 feet (11.8 meters)

Weight: 1,080 pounds (490 kilograms) total, composed of an 831-pound (377-kg) dry spacecraft plus 68 pounds (31 kg) hydrazine fuel and 181 pounds (82 kg) xenon

Power: 2,400 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 (MICAS)
7. Plasma Experiment for Planetary Exploration (PEPE)

Telecommunications:

8. Small Deep-Space Transponder
9. Ka-Band Solid-State Power Amplifier

Microelectronics:

10. Low-Power Electronics
11. Multifunctional Structure
12. Power Activation and Switching Module

Launch Vehicle

Type: Delta 7326 Med-Lite (first use of this model)

Weight: 331,380 pounds (150,311 kg)

Secondary payload: Second stage contains Students for the Exploration and Development of Space Satellite (SEDSat-1), amateur radio satellite that will also conduct remote sensing

Mission

Launch: Cape Canaveral Air Force Station, FL; date to be announced in late September. Spacecraft preparation will support a launch period October 15-November 10, 1998. On October 15, 71-minute window opens at 8:04 a.m. EDT

Primary technology validation: October-December 1998

Asteroid flyby: Asteroid 1992 KD on July 28 or 29, 1999

Program

Cost of mission: $94.8M pre-launch development; $43.5M launch service; $10.3M mission operations; $3.7M science; total $152.3 million

The New Millennium Program

NASA has an ambitious plan for space exploration in the next century. The agency envisions 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-orbiting 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 validation 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. It has 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 engineeers 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 are 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. Selected technologies that require validation in space are then flight-tested on New Millennium Program missions.

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 is most intense during the weeks immediately following launch, when most of the 12 technologies it carries will be actively tested. The primary mission will culminate in an asteroid flyby in late July 1999.

Launch Vehicle

Deep Space 1 will be launched on a variant of the Delta II launch vehicle known as a Delta 7326, the first use of this new model. The launch will take place from Space Launch Complex 17A at Cape Canaveral Air Station, FL.

The Delta 7326 is the first of the Med-Lite series of launch vehicles. Model 7925, a more powerful and expensive version of the Delta II, was used for NASA's Near Earth Asteroid Rendezvous (NEAR), Mars Pathfinder and Mars Global Surveyor missions.

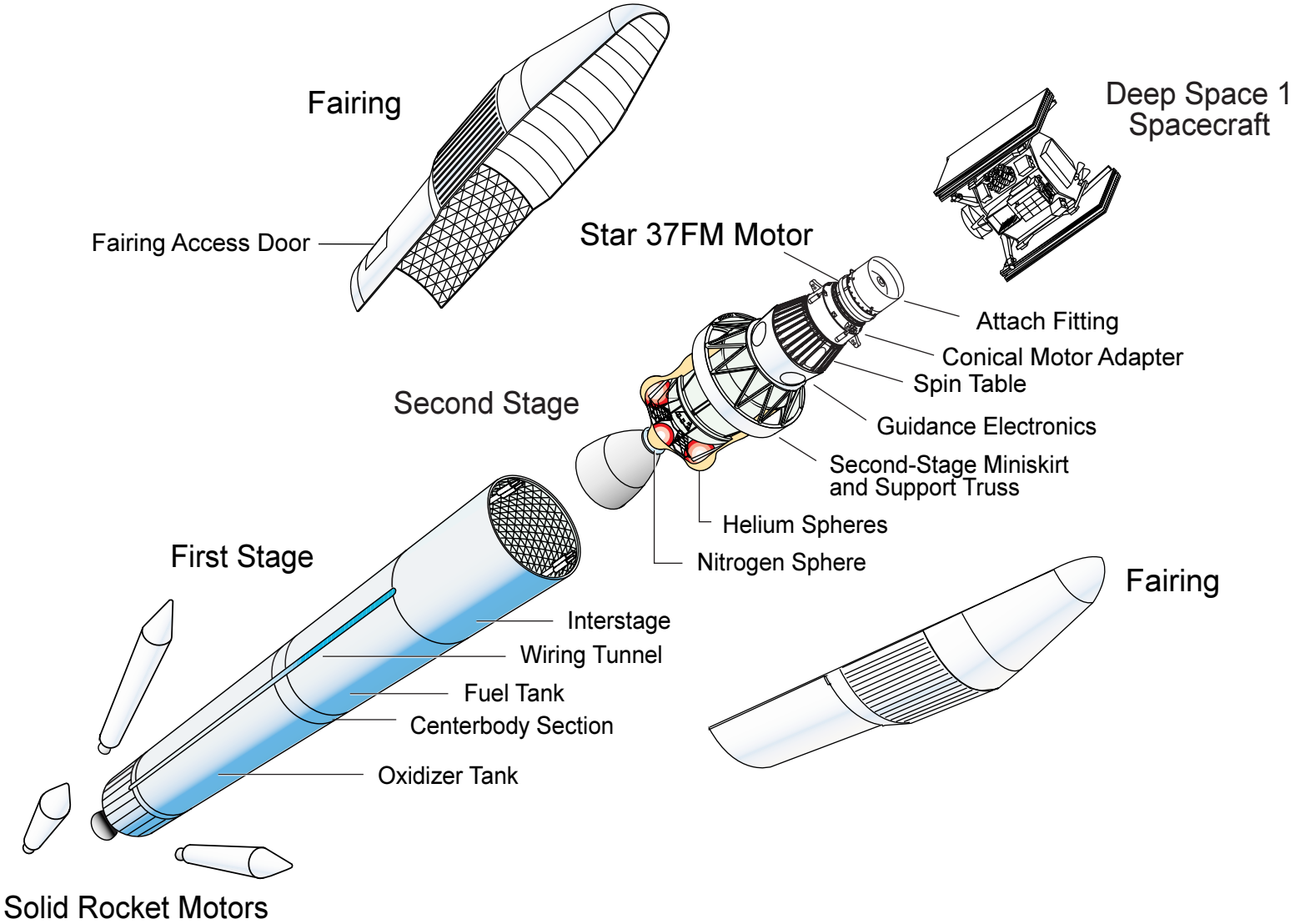
The numbering system used by the Boeing Co. (formerly McDonnell Douglas) to designate the various incarnations of the Delta II is used to denote the main components of the "stack" (first and second stage configurations, and upper stage, if any). The second digit refers to the number of solid rocket motors that augment the main liquid-propellant engine on the first stage. Thus, the Mars missions' 7925 vehicles had nine solid rocket motors (SRMs) ringing the periphery at their bases.

First stage. Deep Space 1 is less massive than either Mars spacecraft. Combined with the fact that it requires less energy leaving Earth in order to achieve its mission, Deep Space 1 needs just three solid rocket motors at liftoff.

As in previous Delta II models, the SRMs are designed to be jettisoned from the vehicle within 66 seconds after launch, after they have completed their task of augmenting the main engine's thrust and have exhausted all of their solid propellant. Each of the three solid rocket motors is 3.28 feet (1 meter) in diameter and 42.6 feet (13 meters) long; each contains 25,937 pounds (11,765 kilograms) of hydroxyl-terminated polybutadiene (HTPB) propellant and provides an average thrust of 100,270 pounds (446,023 newtons) at sea level. The casings on the solid rocket motors are made of lightweight graphite epoxy.

The main body of the first stage is 8 feet (2.4 meters) in diameter and 85.6 feet (26.1 meters) long. It is powered by an RS-27A engine, which uses 212,000 pounds (96,160 kilograms) of RP-1 (rocket propellant 1, a highly refined kerosene) and liquid oxygen as its fuel and oxidizer.

Second stage. The second stage is 8 feet (2.4 meters) in diameter and 19.7 feet (6 meters) long, and is powered by an AJ10-118K engine. The propellant is 13,000 pounds (5,900 kilograms) of Aerozine 50 (A-50), a mixture of hydrazine and unsymmetrical dimethyl hydrazine (UDMH), and nitrogen tetroxide as the oxidizer. This engine is restartable, and will



Delta launch vehicle

perform two separate burns during Deep Space 1's launch. A third burn will be executed to finalize the orbit for the Delta's secondary payload.

Third stage. The third and final stage of Deep Space 1's Delta 7326 is a Thiokol Star 37FM booster, measuring 5.5 feet (1.7 meter) long and 3 feet (0.9 meter) wide. Its motor carries 2,400 pounds (1,090 kilograms) of solid propellant, composed of a mixture of aluminum, ammonium perchlorate and hydroxyl-terminated polybutadiene (HTPB) solid propellant. By contrast, the Mars missions required a larger Star 48 motor to provide the last increment of energy needed to get to Mars. The Star 37 is being used for the first time on a Delta vehicle on Deep Space 1, although an identical version of this motor has been flown on other missions.

The third stage includes a spin table supporting small rockets which are used to spin up the third stage itself and the attached Deep Space 1 spacecraft. A yo-yo despin system consisting of two weights on cables that unwind is used to slow down the spinning after this stage has fired.

Secondary payload. The Delta II's second stage contains SEDSat-1, a satellite developed by Students for the Exploration and Development of Space and built by student engineers at the University of Alabama in Huntsville with the help of NASA engineers at the Marshall Space Flight Center and the Johnson Space Center. SEDSat-1 includes cameras capable of imaging Earth in a variety of narrow wave bands chosen to coordinate with ground-based observations across the country. Unlike data from other imaging satellites, SEDSat-1's data will be broadly accessible because they will be entirely in the public domain, distributed on the Internet via the World Wide Web.

SEDSat-1 also serves as an amateur radio communication satellite. It will store and forward digital packets transmitted to the satellite by ham radio users on the ground, and will also offer an analog repeater system.

Daily Launch Window

(Times EDT through 10/24/98, then EST)

Date	*Opening*	*Close*	*Duration*				
10/15/98	8:04:27	9:15:27	1:11:00	10/29/98	6:58:28	7:35:34	0:37:06
10/16/98	8:02:54	9:12:19	1:09:25	10/30/98	6:58:08	7:33:14	0:35:06
10/17/98	8:02:34	9:09:11	1:06:37	10/31/98	6:57:47	7:30:54	0:33:07
10/18/98	8:02:13	9:06:03	1:03:50	11/1/98	6:57:27	7:28:10	0:30:43
10/19/98	8:01:53	9:02:55	1:01:02	11/2/98	6:57:06	7:25:49	0:28:43
10/20/98	8:01:32	9:00:11	0:58:39	11/3/98	6:56:46	7:23:29	0:26:43
10/21/98	8:01:12	8:57:03	0:55:51	11/4/98	6:56:25	7:20:45	0:24:20
10/22/98	8:00:51	8:54:19	0:53:28	11/5/98	6:56:05	7:18:25	0:22:20
10/23/98	8:00:31	8:51:35	0:51:04	11/6/98	6:55:44	7:16:29	0:20:45
10/24/98	8:00:10	8:48:51	0:48:41	11/7/98	6:55:24	7:14:33	0:19:09
10/25/98	6:59:50	7:46:06	0:46:16	11/8/98	6:55:03	7:12:12	0:17:09
10/26/98	6:59:30	7:43:22	0:43:52	11/9/98	6:54:43	7:10:16	0:15:33
10/27/98	6:59:09	7:40:38	0:41:29	11/10/98	6:54:22	7:08:20	0:13:58
10/28/98	6:58:49	7:38:18	0:39:29				

Other innovative aspects of SEDSat-1 include a unique attitude determination system and new technology in active microsatellite control, as well as testing of nickel metal hydride batteries and advanced electronic components. Additional information on the satellite is available on the web at **http://www.seds.org/sedsat** .

Launch Timing

Launch period. The launch period opens on October 15, 1998, and continues through November 10. The launch date will be announced in late September.

The key motivation for launching during this time was to force the development of new techniques for building spacecraft and preparing for planetary missions in shorter time periods. From concept through launch, Deep Space 1 will have taken 39 months, considerably shorter than even other recent "faster, better, cheaper" NASA missions. After November 10, the launch pad must be cleared for the December launch of the Mars '98 Mars Climate Orbiter.

Daily window. The launch window on October 15 opens at 8:04:27 a.m. Eastern Daylight Time and extends for 71 minutes. After that date, the opening of the window moves progressively earlier each day. Note that clocks change from daylight savings to standard time on the morning of Sunday, October 25.

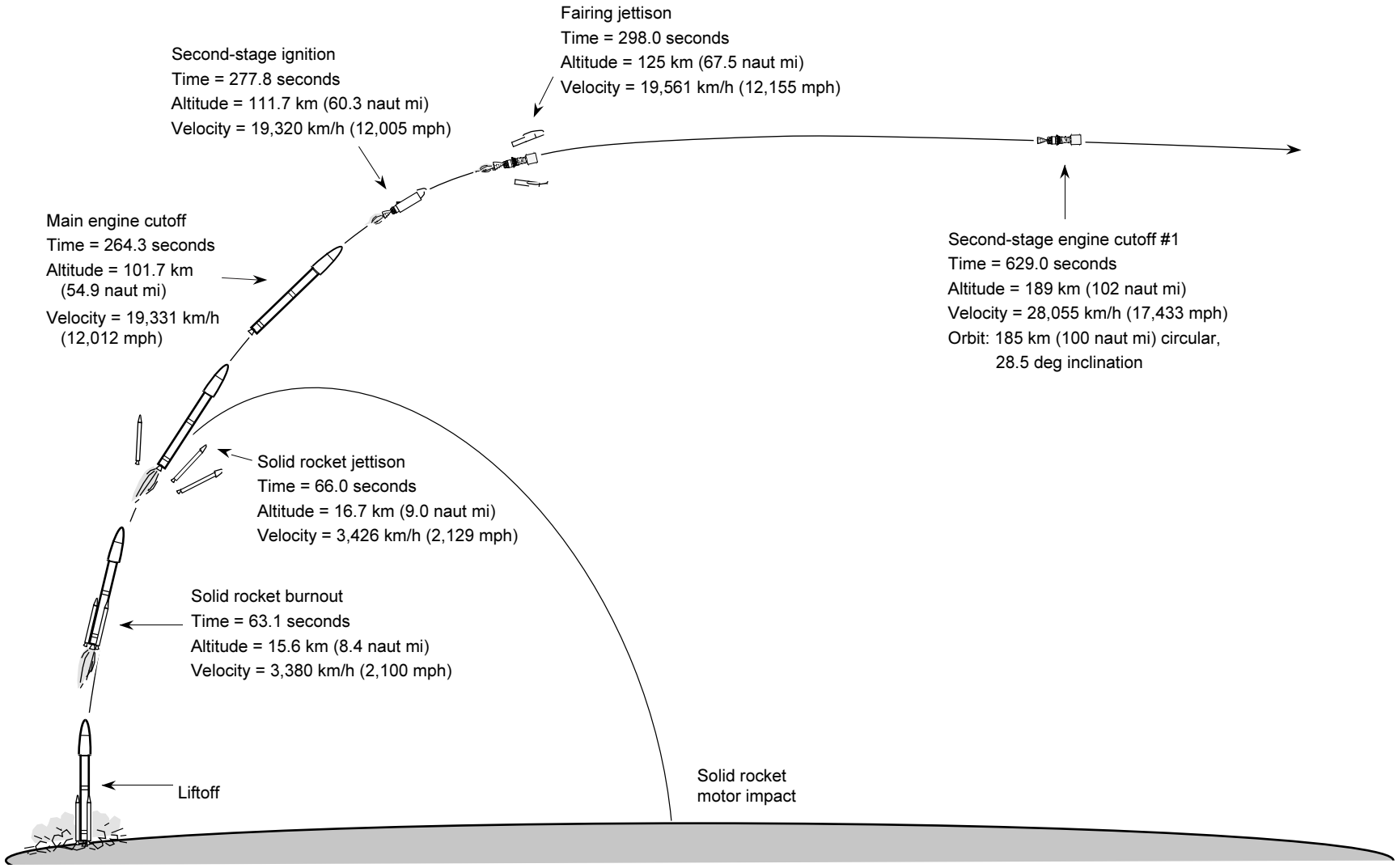
Launch Events

Launch occurs in three phases, consisting of liftoff and insertion into a 115-mile (185-kilometer) parking orbit; a coast of about a half hour, until the vehicle position is properly aligned relative to the direction it must leave Earth; and final injection to an escape trajectory. The total time needed to complete the process is a little under an hour.

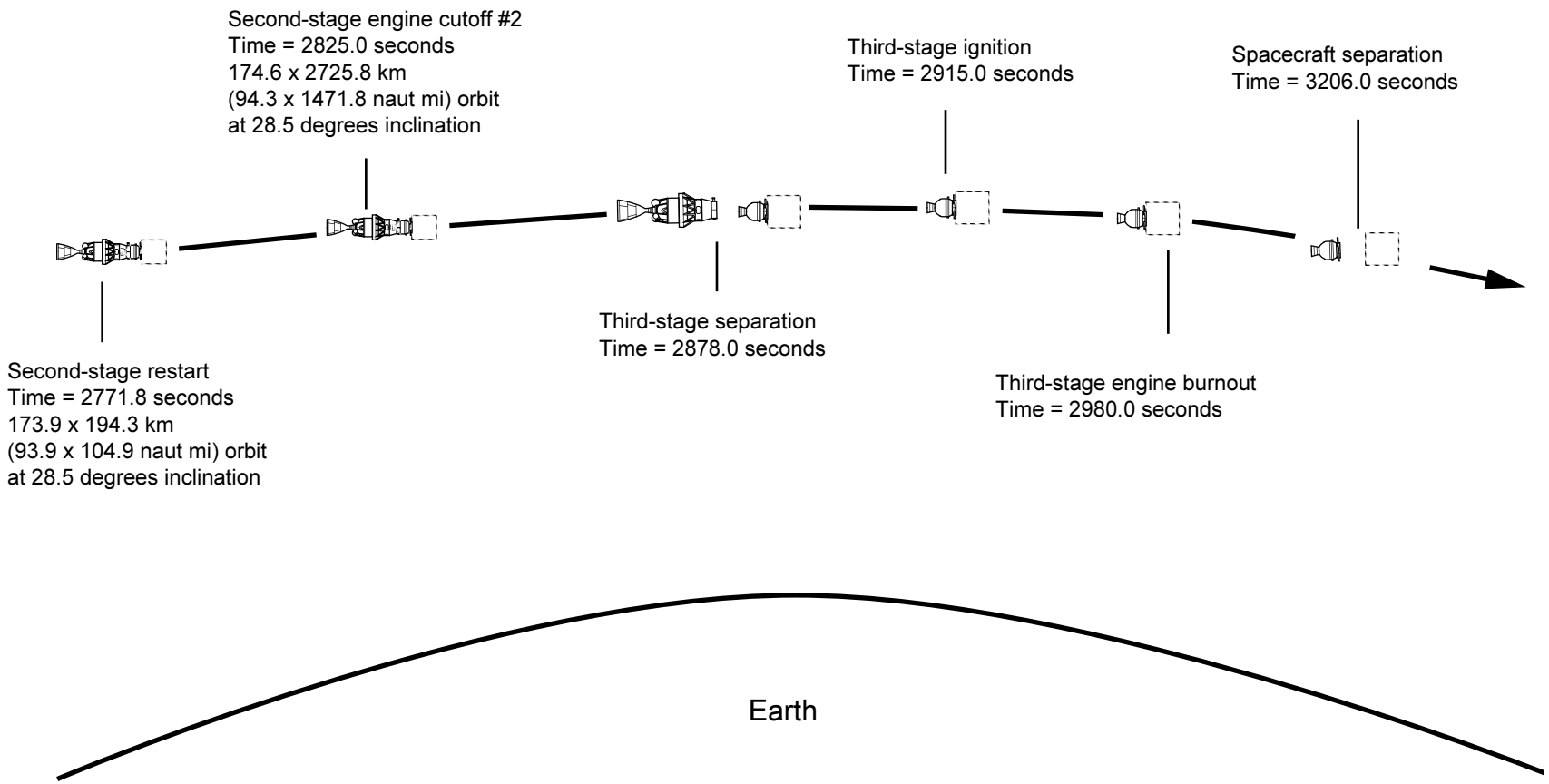
Liftoff. Liftoff will take place from Launch Complex 17A at Cape Canaveral Air Force Station, FL. Shortly after clearing the gantry tower, with all three solid rocket motors operating in concert with the main engine, the vehicle will begin a slow pitch, arching as it flies southeast over the Atlantic Ocean. At 35 seconds, the vehicle will have attained the speed of sound, mach 1. The trio of solid motors will exhaust their 39 tons of propellant after 63 seconds, and will be catapulted free of the central stack by separation charges at an altitude of about 10 miles (16 kilometers).

Slightly more than three minutes later, at an altitude of 63 miles (101 kilometers), the first-stage engine will have consumed the contents of its propellant tanks. The empty stage separates, almost immediately followed by ignition of the second-stage engine.

Twenty seconds after the second stage is fired, with most of Earth's atmosphere below it, the protective aerodynamic covering surrounding the spacecraft — the payload shroud, or fairing — cleaves open like a clam shell, peels off and drops away, exposing the spacecraft to the near vacuum of space. At this point the second stage pitches the vehicle over, flattening its



Launch boost phase



Launch injection phase

angle of flight relative to the ground until it becomes nearly parallel to Earth's surface.

Finally, 10-1/2 minutes after leaving Cape Canaveral, and nearly 1,550 miles (2,500 kilometers) downrange, the vehicle's guidance system senses that the velocity to attain orbit has been reached, and the second-stage engine is commanded to shut down. Unlike the first stage, which burned itself to depletion, there is still propellant left in the second stage. Most of this propellant will be used to begin the final burst of energy needed to propel the spacecraft away from Earth 36 minutes later.

Coast and final injection. The vehicle now coasts in a circular orbit inclined 28.5 degrees to the equator, down and across the Atlantic Ocean, over the southern part of Africa and the southern tip of Madagascar, continuing over the Indian Ocean.

As the vehicle reaches near its orbit's most southerly extreme — 47 minutes after launch and about 3,000 miles (4,800 kilometers) west of Australia — the second stage is commanded to life for a second time. This burn lasts nearly a minute, raising the velocity by a few hundredths of a mile (kilometer) a second. But this is enough that the third stage can take over and fling itself and the Deep Space 1 spacecraft away from Earth with enough energy to allow them to just escape our planet's gravity field.

The third stage is spin-stabilized, so it must be set rotating before being released from the spent second stage in order for it to remain in the proper orientation for its burn. Fifty seconds after second-stage shutdown, while the third stage remains attached to the second stage, a pair of small rocket motors fire to spin up the third stage. These spin-up rockets are mounted on a turntable platform supporting the third stage, which is free to rotate; it is spun up to 63 rpm before being released from the second stage. Forty seconds later the Star 37 fires for 65 seconds, rapidly accelerating the vehicle to its final escape velocity. The spacecraft and third stage are now irrevocably on course for interplanetary space.

At this point, the spinning upper stage and its passenger, the Deep Space 1 spacecraft, must be despun so that the spacecraft can be separated and acquire its proper cruise orientation. This is accomplished by a set of weights that are reeled out from the side of the spinning vehicle on flexible lines, much as a spinning ice skater slows by extending her arms.

The spacecraft is launched with its radio transmitter, its flight computer and most of its electronics turned off. Thermal control heaters and the radio receiver are on, as is the circuitry needed to detect separation from the launch vehicle.

Finally, 54 minutes after liftoff and 345 miles (550 kilometers) above northwestern Australia, a set of springs gently pushes the spacecraft and inert Star 37 upper stage apart, and Deep Space 1 begins its technology validation mission into deep space.

Post-Separation Events

Separation from the launch vehicle triggers turn-on of power to Deep Space 1's flight

computer. The computer initializes itself, or "boots up," in about 30 seconds. Once booted, the computer begins to put the spacecraft into flight mode.

After powering on various engineering subsystems, the spacecraft enters "detumble mode," designed to steady the spacecraft and remove any residual spin or wobble after being released from the launch vehicle. A star sensor determines the spacecraft's orientation based on the stars it detects in its field of view. The spacecraft then points its "sun side" to where the sun will be after it leaves Earth's shadow; the two wing-like solar panels are unfolded and latched, also pointing to where the sun will be.

After the spacecraft exits Earth's shadow, it turns on its radio transmitter and transmits telemetry about its health to Earth. The first transmission will be received about 75 to 90 minutes after launch by NASA's Deep Space Network station at Canberra, Australia, and relayed to the mission control center at JPL in California. In the process, two of the mission's technologies -- the solar arrays and the deep-space transponder -- will undergo their first test. Operations personnel at JPL will evaluate spacecraft health and make any corrections to protect its safety as needed and command it into its flight operations modes. The spacecraft battery, which provides the only source of energy until the spacecraft exits Earth's shadow, begins to be recharged by the solar array.

Once all is well, ground controllers will send a command to activate a sequence of computer commands stored in onboard memory before launch. This sequence will control the spacecraft perhaps over the next few days.

Prime Mission

After the operations team is satisfied that the spacecraft is safe and healthy, and resolves any of the problems that can crop up in the early days of the flight of a new spacecraft, the primary mission of validating technologies begins. The initial focus will be on testing the technologies supporting the ion propulsion system.

Because the ion drive uses power from advanced-technology solar arrays, the first job is to determine how much power the arrays actually generate and to understand how the arrays' concentrating lenses need to be pointed relative to the Sun to get the most power.

Once the solar arrays are understood, the mission operations team's attention will turn to the ion propulsion system. A variety of checks are needed to characterize the system that controls the xenon and to prepare the complex thruster for operation. Several days will be devoted to this activity, which will culminate in thrusting at six different throttle levels.

During the engine thrusting, NASA's Deep Space Network will measure the Doppler shift of the spacecraft's radio signal. This can be used to reveal the speed of the spacecraft, in the same way that the pitch of a siren changes as it approaches and then recedes from a listener. Although the ion drive's thrust is small, the sensitive receivers of the Deep Space Network will be able to measure the change in the spacecraft speed by as little as 1/5,000th of a mile per hour

(0.1 millimeter per second). This will provide engineers with reference values to use in measuring the degradation of the ion propulsion system over the thousands of hours that it may be used during the mission. In addition, it will yield specific thrust values that will be compared with laboratory predictions, thus providing an important validation. Until this point, all mission planning work is conducted on the basis of predicted thrust; after this point, it can rely on actual measured thrust.

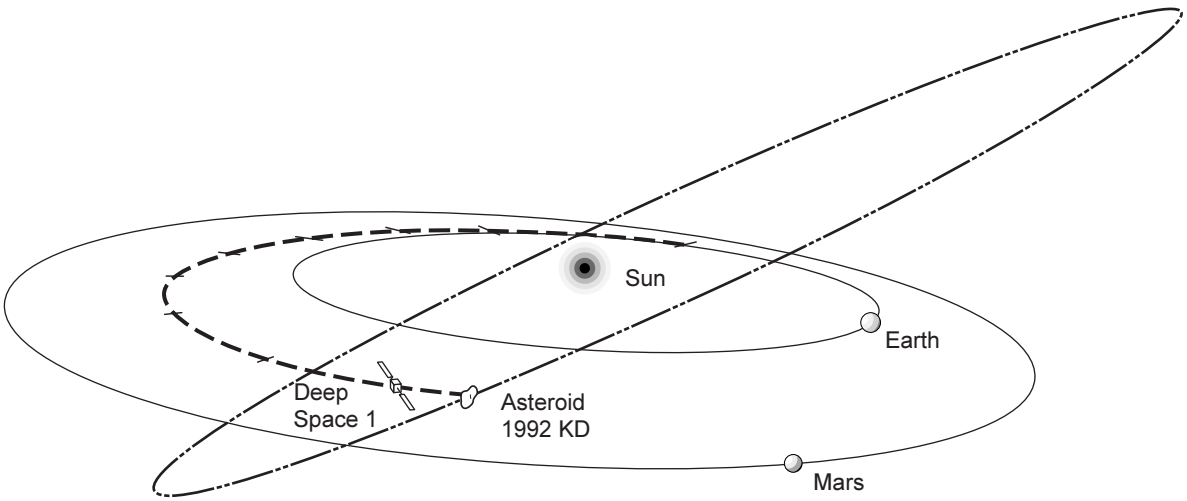
The schedule for these initial tests is somewhat uncertain; given that ground controllers will be dealing with new technologies, it is not known how long it will take to get the spacecraft ready for the tests. Still, it is expected they will be complete within two weeks of launch. If there is time, the Miniature Integrated Camera Spectrometer (MICAS) will be turned on and initial images will be collected to determine how well the new instrument performs. MICAS has a cover that is transparent in the visible and infrared but not the ultraviolet. This cover will not be opened for another month to allow plenty of time for residual gases emanating from the spacecraft to dissipate); therefore the first pictures will be visible and infrared, but not ultraviolet. Images of reference star fields will be taken to characterize the sophisticated optical design. Views of Earth and the Moon may also be taken, although such images will require a complex turn that will be attempted so early in the mission only if the attitude control system has been fully certified.

The final early validation that may be conducted focuses on Deep Space 1's autonomous onboard navigation system, AutoNav. This system will be allowed to formulate and issue commands to the attitude control system and to MICAS to collect images of distant asteroids to determine the spacecraft's position in the solar system. Later in the mission AutoNav will use the results of its analyses to change the firing of the ion propulsion system.

All of these initial validations are expected to reveal unexpected behaviors of the technologies: if their performance could have been predicted with certainty, they would not need to be validated. Thus, tests of the solar arrays, the ion drive, MICAS and AutoNav may have to be repeated or modified based on early test results; new software may have to be developed for the spacecraft's onboard computer or for the ground control system.

Between two and four weeks after launch, a rehearsal of long-term ion drive thrusting will be attempted. This will involve up to 10 days of thrusting, interrupted every other day for AutoNav to execute its commands for imaging of reference asteroids. This cycle will offer the operations team experience with the kind of events that will be typical later in the mission and for future missions that use ion propulsion.

After the rehearsal period, ion drive thrusting will be suspended for about two weeks so that the spacecraft and ground operations performance can be evaluated. During this break, if time permits, the cover on MICAS will be opened and the high voltage for its ultraviolet detector will be turned up gradually. At each step, engineers will evaluate the instrument to determine whether it is safe to proceed to the next level. A similar procedure will be used for turning on the Plasma Experiment for Planetary Exploration (PEPE), which requires high voltage for its electron and ion analyzers. Other activities occurring during this hiatus in thrusting may



Primary mission trajectory

include further tests of the basic spacecraft subsystems and possibly the first use of the Ka-band telecommunications system.

Before thrusting resumes, a final set of tests on the ion drive is planned. These tests will include operating PEPE with the thruster on and off to establish the effects of the emitted xenon ions and electrons on the local space environment and on the spacecraft. MICAS images taken with and without the thruster operating may be used to determine if an ultraviolet glow from the xenon surrounds the spacecraft.

By approximately six weeks after launch, the ion drive will be commanded to resume long-term thrusting. The thrusting may continue for several months, with planned interruptions decreasing to once per week to allow for reference asteroid photography. When AutoNav is certified ready, it will be allowed to use its own calculations to change the direction of the thrusting. The overall duration of the thrusting will depend upon many factors, including the date of launch, the accuracy of the launch vehicle's flight, the performance of the solar arrays and the ion drive, and the number of times onboard software has been forced to stop thrusting to accommodate other spacecraft needs.

Asteroid Flyby

The mission will attempt an encounter with asteroid 1992 KD in July 1999 to give the spacecraft's technologies an opportunity to be tested on a scientifically interesting body. This encounter is not required for the validation of the 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 flyby date is tentatively July 28 or 29, depending on launch events and details of the performance of the ion engine, the advanced solar arrays and AutoNav.

Asteroid 1992 KD, which was discovered in May 1992 by astronomer Eleanor Helin of

JPL, was chosen from more than 100 flyby possibilities. 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 orbit is also highly elliptical; the closest it gets to the Sun is a point midway between Earth and Mars, whereas at its most distant it is more than three times father from the Sun than Earth, or more than halfway out to the giant planet Jupiter. Although scientists believe the asteroid's diameter is about 2 to 3 miles (3 to 5 kilometers), they know little else about it. With this flyby, they will be able to learn more about its shape, size, surface composition, mineralogy, terrain, rotation speed and, perhaps, its interaction with the solar wind. MICAS and PEPE will be will be used to gather images and other data on the asteroid and its environment.

In the final 30 days of the spacecraft's approach to the asteroid, AutoNav will collect optical navigation images and conduct trajectory correction maneuvers at increasing frequencies to control the targeting of the final encounter. During the encounter, AutoNav will attempt to guide the spacecraft to within 6 miles (10 kilometers) of the asteroid's surface, making it the closest flyby of a solar system body ever attempted. During the encounter, the spacecraft will fly past the asteroid at a relative velocity of about 33,500 miles per hour (54,000 kilometers per hour).

The last opportunity for a trajectory correction maneuver will be three hours before the closest approach. If previously enabled by ground command, AutoNav will analyze approach images to determine if a closer encounter is safe. If so, the onboard system will execute a "bold maneuver" autonomously with no ground intervention to reduce the closest approach altitude to 3 miles (5 kilometers).

During the final approach, MICAS will switch between taking navigation pictures for AutoNav, and collecting images and spectra for MICAS technology validation and 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 100 to 150 feet (30 to 50 meters) per pixel.

The spacecraft is expected to take 10 days to transmit to Earth all of its technology validation and science data from the asteroid flyby. At that point it will resume thrusting with the ion propulsion system.

End of Prime Mission

The Deep Space 1 primary mission will conclude September 18, 1999, near the end of the federal government's fiscal year. By this time, all of the technology validation will have been accomplished.

If the spacecraft is healthy and NASA chooses to continue the mission, an extended mission may be possible. 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 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. During an extended mission, tests may be conducted that subject the advanced technologies to extreme stress in a way that is not reasonable during the primary mission.

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 guides and controls the spacecraft and receives telemetry. The DSN 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. DSN stations feature precision-pointed, high-gain, parabolic reflector antennas; some of these giant dishes are 112 feet (34 meters) in diameter, while the most sensitive are 230 feet (70 meters) in diameter. They work together with high-power transmitters and ultra-low-noise amplifiers to optimize the communication link with spacecraft millions of miles (kilometers) away. All data gathered by antennas at the three complexes are communicated directly to the control center at JPL, 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 (AMMOS) 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. AMMOS 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 entirely on the operations system's multimission capability for mission operations.

Compared to some other solar system spacecraft, Deep Space 1 will make many decisions on its own and will require 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 pass-

es as available will help reduce competition between spacecraft projects for antenna time on the DSN system.

DSN engineers are also very interested in Deep Space 1's 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 will fly 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 new web site titled "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** .

Both the Boys and Girls Clubs of America and ITEA are participating in a Deep Space 1 "National Countdown" activity, through which thousands of school children are taking 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.

The 12 Technologies

The technologies being tested on Deep Space 1 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.

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 carries a total of 181 pounds (82 kilograms) 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 which are charged positive and negative, respectively, 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 62,000 miles per hour (100,000 kilometers 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 puts out 1/50th of a pound (90 millinewtons) 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 1/200th of a pound (20 milli-newtons) of thrust. Since Deep Space 1's solar arrays are never expected to supply 2,500 watts of power, the ion engine will not be run at full thrust during the mission.

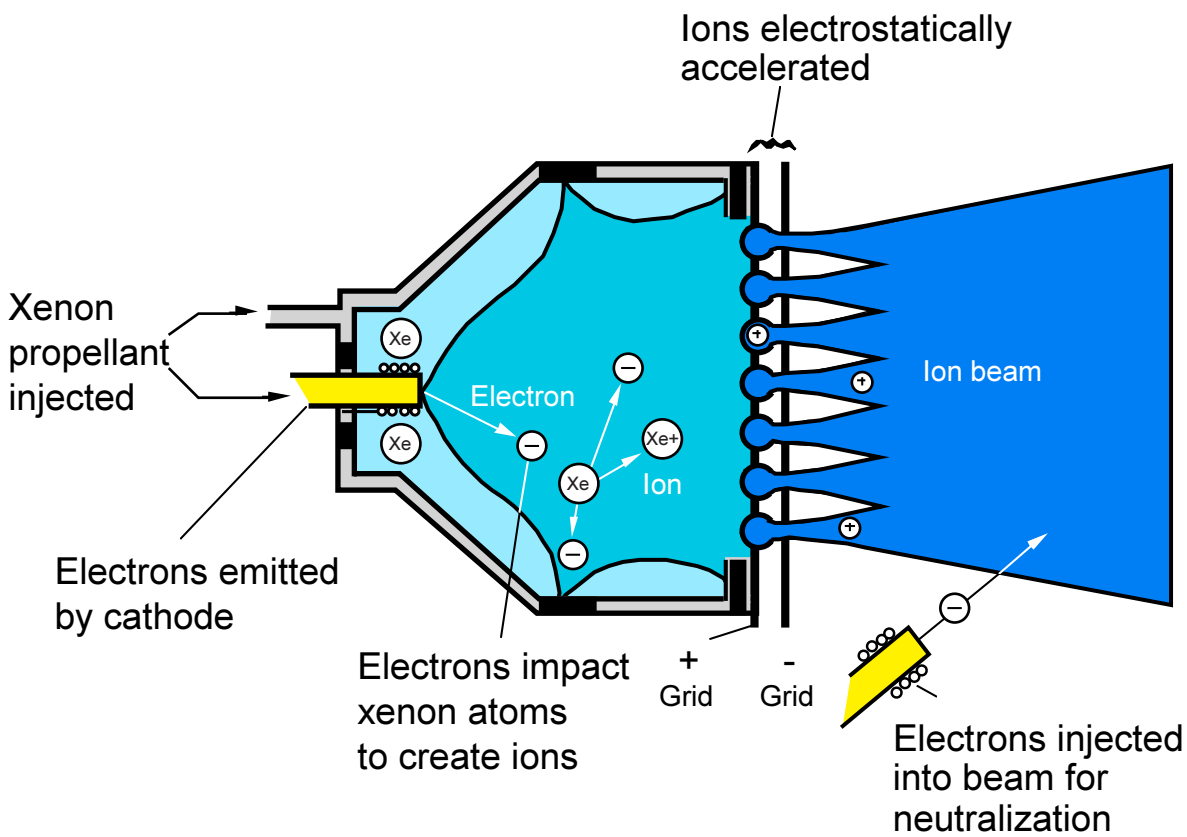
The engine's magic, however, lies in its staying power. Such a minute force could never be used to launch a spacecraft from Earth's surface, but it is ideal for the cruise segment of interplanetary journeys lasting months or years. With constant operation over time, an ion engine can provide substantial 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 more than 8,000 miles per hour (nearly 13,000 kilometers 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 12 inches (30 centimeters) 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 Lewis Research Center, Cleveland, OH, built the first ion engine in 1959.

In 1964, a pair of NASA Lewis 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.

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



Ion propulsion system

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 Power 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 that 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 Deep Space 1 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.

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 44 by 63 inches (113 by 160 centimeters). At launch, the wings fold up so that the spacecraft fits into the launch vehicle's fairing; when fully extended, the wings measure 38.6 feet (11.8 meters) 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 2,400 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 concentrator 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.

The solar concentrator array was developed by AEC-Able Engineering Inc., Goleta, CA; Tecstar, City of Industry, CA; Entech, Keller, TX; NASA's Lewis 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 technologies being tested 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 will dramatically improve this process by allowing the spacecraft to take over the parts of the navigation job formerly carried out by ground controllers.

Every other solar system spacecraft ever flown has cruised for long periods in a ballis-

tic, or bullet-like, trajectory — unpowered except for occasional gravity assists from planetary flybys or brief firings of hydrazine thrusters. Because it is the first deep space mission that will feature long-term thrusting by an onboard engine, Deep Space 1 calls for a different approach to navigation.

Deep Space 1 will find its location in the solar system by taking images of known asteroids and comparing their positions to background stars. The orbits of 250 asteroids and the positions of 250,000 stars are stored in computer memory at launch. Using the positions of the asteroid and stars, the actual spacecraft location can be determined. During the initial checkout phase of the mission, images of four to five asteroids will be taken about three times per week. During most of the remainder of the mission, about seven asteroids will be imaged once per week, except during the asteroid flyby.

In most cases, the trajectory changes that AutoNav calls for will be implemented through changes in the ion engine's thrust profile. In some cases, small maneuvers will be 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 the new AutoNav technology is 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 is designed to be able to cope with a wide range of propulsion performance.

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. Compared by some to the HAL 9000 system that ran the spacecraft in the science-fiction novel and movie "2001: A Space Odyssey," Deep Space 1's Remote Agent 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 of time; 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 will not control Deep Space 1 throughout the mission; software will be transmitted to the spacecraft after launch to control the ion engine and selected other systems during specific test periods.

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 230-foot (70-meter) antennas of the Deep Space Network to track a spacecraft, a mission might get by with an antenna only 10 to 30 feet (3 to 10 meters) 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 which conveys the same information. 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 will not rely on the beacon monitor continuously, instead using it during selected test periods. 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 a camera, an ultraviolet imaging spectrometer and an infrared imaging spectrometer, all within one 26-

pound (12-kilogram) package.

MICAS serves three functions on Deep Space 1. First, tests of the instrument's performance establish its usefulness for future space science missions. Second MICAS is used to gather images for the spacecraft's autonomous navigation subsystem. Finally, the instrument collects valuable science data during the mission, particularly during the asteroid flyby.

The instrument's two black-and-white visible imaging channels, ultraviolet imaging spectrometer and infrared imaging spectrometer all share a single 4-inch-diameter (10-centimeter) telescope. One of the visible-range detectors is a charge-coupled device, while the other is an active pixel sensor. The two imaging spectrometers operate in "push-broom" mode, meaning that the instrument must sweep across the target body to collect data.

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, 13-pound (6-kilogram) package.

PEPE serves three functions. First, it validates the design for a suite of space physics instruments in one package. Second, it assists in determining the effects of the ion engine on spacecraft surfaces and instruments and on the space environment, including interactions with the solar wind. And finally, it conducts scientifically interesting measurements during cruise and the asteroid flyby.

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, 6.6-pound (3-kilogram) 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.

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 as-yet-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 will not only test transponder performance but conduct experiments more generally in Ka-band communications.

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 will be conducted through Goldstone.

The Ka-Band Solid State Power Amplifier was developed by Lockheed Martin, Valley Forge, PA.

Microelectronics Technologies

❑ **Low-Power Electronics**. This is one of three experiments concerned with microelectronics. The experiment involves low-voltage technologies, low-activity logic, low-energy architectures and micro-power management. Devices being tested include a ring oscillator, transistors and a multiplier, 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 Activation 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 grouped in redundant pairs, 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.

Mars Pathfinder Technologies

An increasing trend in NASA's current era of "faster, better, cheaper" missions is for spacecraft missions to benefit and borrow from technologies flown on recent predecessors. Deep Space 1 has taken full advantage of this opportunity, making use particularly of many technologies derived from Mars Pathfinder.

From antennas and computers to cables and headsets, there are many technology links between these missions. Although these are not advanced technologies in the way that Deep Space 1's showcase 12 technologies are, this synergy between missions has helped boost reliability and save costs. Some of the many connections between the two missions:

❑ Deep Space 1's high-gain antenna is a flight spare from Mars Pathfinder (i.e. the antenna was obtained as a backup for Mars Pathfinder, but wasn't needed).

❑ Deep Space 1's propulsion drive electronics, which control the spacecraft's hydrazine thrusters, were inspired by and modeled after Mars Pathfinder's system.

❑ The processor for Deep Space 1's computer is identical to its Mars Pathfinder counterpart (the chip is a RAD 6000 radiation-hardened reduced instruction set computer (RISC) of IBM heritage).

❑ Such Deep Space 1 flight software as the sequencing mechanism and the command and telemetry infrastructure was inspired by and modeled after Mars Pathfinder's flight software.

❑ The Deep Space 1 software mode controller infrastructure is the same as its Mars Pathfinder counterpart. The controller allows the spacecraft to be configured easily for various phases of the mission. Instead of the flight team sending commands to power on or off individual components, the controller allows engineers merely to call for a given configuration (for example, early cruise configuration, asteroid flyby configuration, etc.).

❑ Deep Space 1 took advantage of a variety of Mars Pathfinder test equipment, including cables, headsets and work stands, all of which helped Deep Space 1's bottom line.

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.

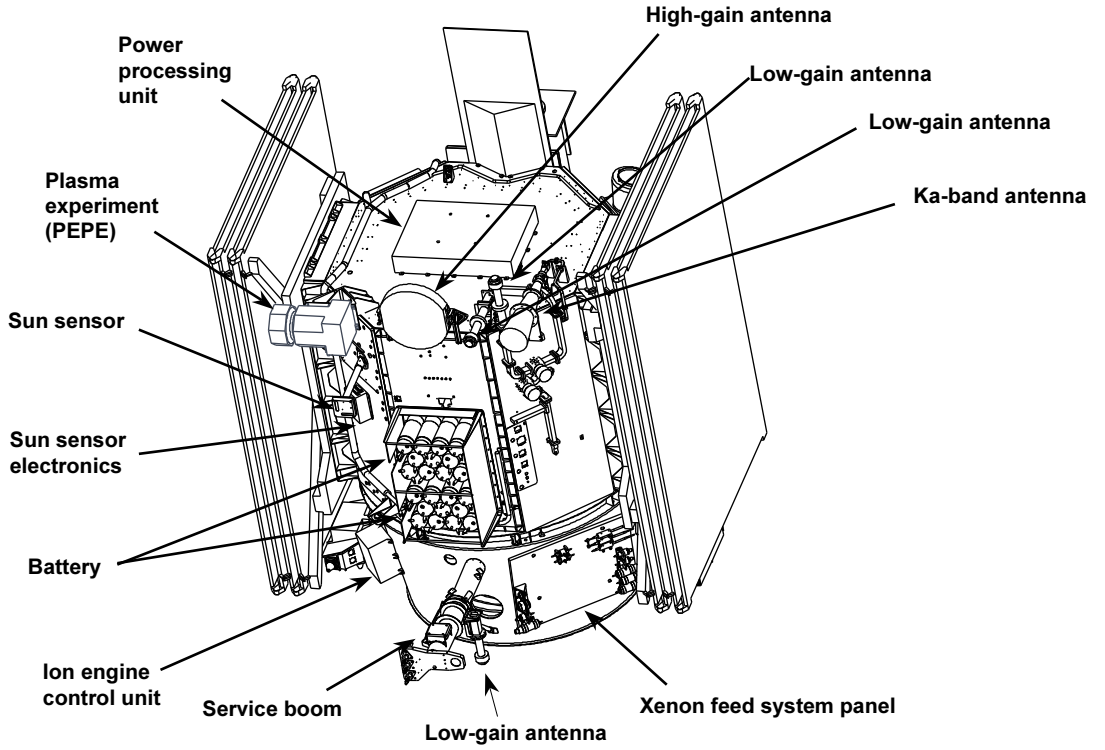
Traditional spacecraft have used redundant systems to lower risk; if an onboard computer or star sensor gives out, the spacecraft can switch to a backup. NASA's philosophy in launching Deep Space 1, however, is to mount a technologically challenging, low-cost mission. Most of the spacecraft therefore 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.

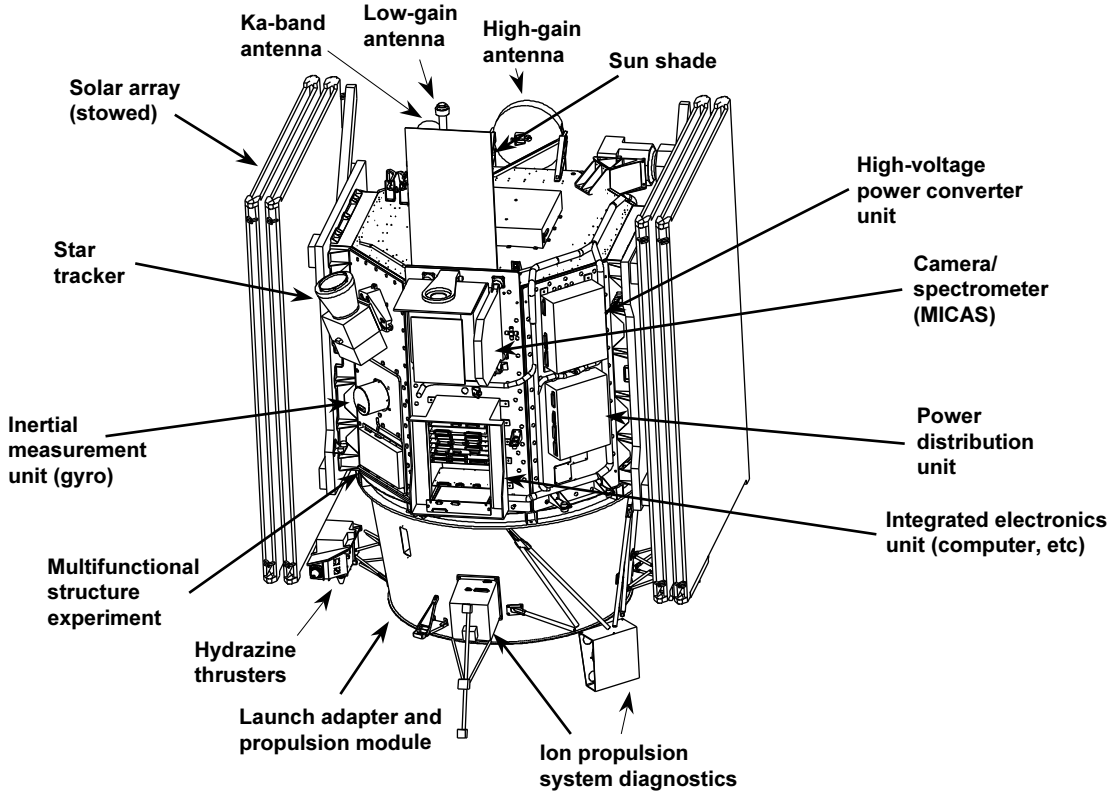
The central spacecraft structure, or "bus," is aluminum. Most components are mounted on the exterior of the bus, making them easy to access and replace during pre-launch integration and testing. A boom is attached to help technicians reach the battery plug and hydrazine, helium and xenon lines when the 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.

The spacecraft was built by Spectrum Astro Inc., Gilbert, AZ.





Deep Space 1 spacecraft

Science Objectives

Unlike most solar system missions, Deep Space 1 is driven by technology validation rather than science objectives. Even so, the spacecraft's two science instruments will collect valuable data, particularly during the asteroid flyby. NASA thus organized a team of scientists to work with the data those instruments deliver.

Some science data will be collected during the interplanetary cruise, including measurements of the solar wind and distant imaging and spectroscopy of other bodies. The gathering of science data will be a key focus of the asteroid flyby in July 1999.

Among preliminary science goals for the Miniature Integrated Camera Spectrometer (MICAS) are the investigation of the structure, composition, brightness variations and texture of asteroid 1992 KD.

The Plasma Experiment for Planetary Exploration (PEPE) will investigate the composition of the solar wind and the interaction between the solar wind the the asteroid's surface. In addition, it will measure any isotopes that may be a part of the asteroid. Engineers will use data from PEPE to assess the effect of ion propulsion on the instrument itself.

At asteroid 1992 KD, experiments are designed to generate 3-D terrain models and to investigate outgassing and rotational parameters, along with crater size, frequency and distribution. These data will be compared to information about such asteroids as Gaspra, Ida, Dactyl and Mathilde, all of which have previously been visited by various spacecraft.

Members of the science team are:

Dr. Robert Nelson, JPL, Project Scientist
Dr. Laurence Soderblom, U.S. Geological Survey, Flagstaff, AZ, MICAS Group Leader
Dr. David T. Young, Southwest Research Institute, San Antonio, TX, PEPE Group Leader
Dr. Frances Bagenal, University of Colorado
Dr. Daniel Boice, Southwest Research Institute
Dr. Daniel Britt, University of Arizona
Dr. Robert H. Brown, Lunar and Planetary Laboratory, University of Arizona
Dr. Bonnie Buratti, JPL
Dr. Wing Ip, Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, Germany
Dr. Jurgen Oberst, DLR Institute of Planetary Exploration, Berlin
Dr. Tobias Owen, University of Hawaii
Dr. Bill Sandel, Lunar and Planetary Laboratory, University of Arizona
Dr. Alan Stern, Southwest Research Institute, Boulder, Colorado
Dr. Nicholas Thomas, Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, Germany
Dr. Joseph J. Wang, JPL
Dr. Roger Yelle, Boston University

What's Next

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

❑ **Deep Space 2**. Only two and a half months after Deep Space 1's launch, Deep Space 2 will depart on a mission to Mars in January 1999. Deep Space 2 will send two small probes weighing 4.5 pounds (2 kilograms) each aboard the Mars '98 project's Mars Polar Lander. The microprobes will be released shortly before the spacecraft reachs Mars; each is designed to impact and penetrate the Martian surface up to a depth of about 3 feet (1 meter). The microprobes' technologies include temperature sensors for measuring the thermal properties of the Martian soil, and a subsurface soil collection and analysis instrument. The microprobes will join instruments on the Mars Polar Lander in searching for subsurface water on Mars. Deep Space 2 is managed by JPL.

❑ **Earth Orbiter 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 Orbiter" series that will evaluate technologies in local orbit. An advanced, lightweight scientific instrument designed to produce visible and short-wave infrared images of Earth's land surfaces was selected as Earth Orbiter 1. The mission is scheduled for launch in May 1999.

Earth Orbiter 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 Orbiter 1 is managed by NASA's Goddard Space Flight Center, Greenbelt, MD.

❑ **Earth Orbiter 2**. This mission will encompass the Space-Readiness Coherent Lidar Experiment (Sparcle), flying in the cargo bay of the Space Shuttle. Scheduled for launch in 2001, the mission is designed to determine whether a space-based sensor can accurately measure global winds within Earth's atmosphere from just above the surface to a height of about 10 miles (16 kilometers). Earth Orbiter 2 is managed by NASA's Goddard Space Flight Center.

❑ **Other New Millennium missions.** Among many candidate New Millennium Program mission proposals under study are Deep Space 3, a mission that would fly three spacecraft in precise formation in orbit around the Sun to implement an optical interferometer sensitive enough to detect planets around other stars.

Deep Space 4/Champollion, also under study, would test 20 new technologies while landing a spacecraft for the first time on the nucleus of an active comet. The spacecraft would send back both standard and stereo pictures, and possibly attempt to return a sample of the comet nucleus.

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 six miles (10 kilometers) 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 on January 10, 1999, and become the first spacecraft ever to orbit an asteroid. It will study Eros from as close as nine miles (15 kilometers) for at least a year, until early 2000. NEAR was built and is managed by Johns Hopkins University's Applied Physics Laboratory, Laurel, MD.

❑ **Stardust**: This technically daring Discovery program mission will fly a spacecraft to within 100 miles (160 kilometers) of the nucleus of comet Wild-2 to capture actual 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 is scheduled for launch in February 1999, with the sample due back on 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 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.

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. Wesley Huntress is associate administrator for space science. Ken Ledbetter is director of the Mission and Payload Development Division.

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, Dr. Philip Varghese is mission manager and Leslie Livesay is spacecraft manager; Dr. Robert Nelson is project scientist. At Spectrum Astro, Peter Klupar is the company's Deep Space 1 project manager.

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