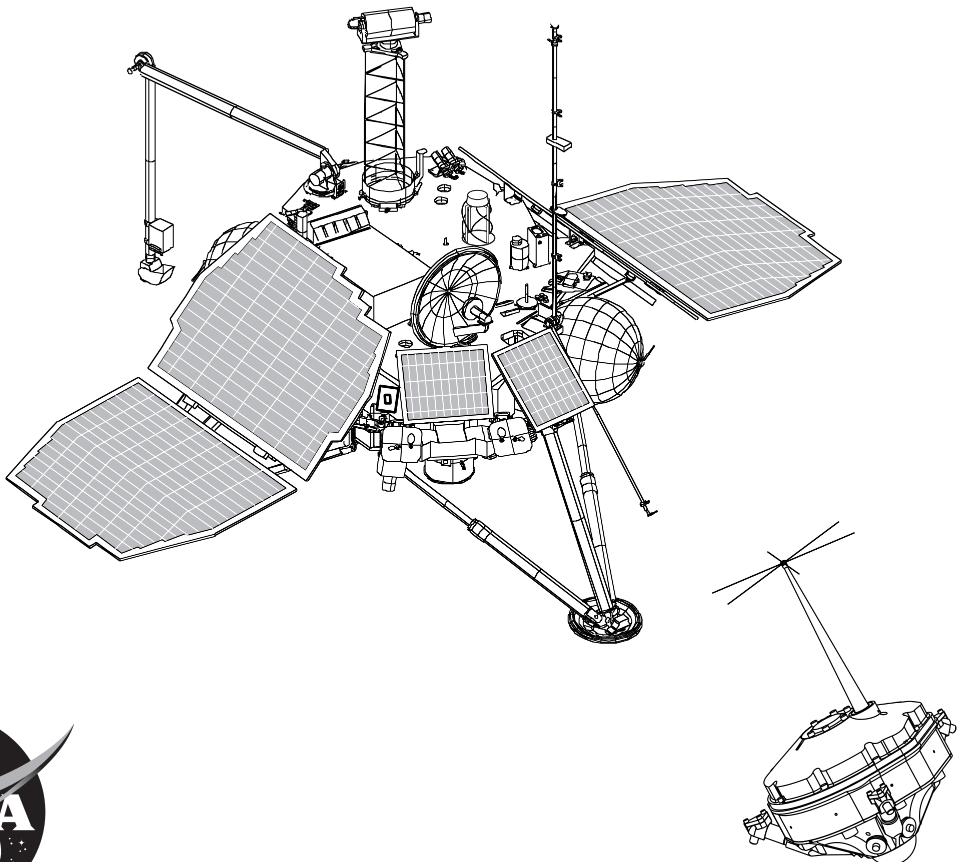
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mars Polar Lander/ Deep Space 2

Press Kit
December 1999



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RELEASE:

MARS POLAR LANDER, DEEP SPACE 2 SET FOR ARRIVAL

NASA returns to the surface of Mars on December 3 with a spacecraft that will land on the frigid, windswept steppe near the edge of Mars' south polar cap. Piggybacking on the lander are two small probes that will smash into the Martian surface to test new technologies.

The lander mission is the second installment in NASA's long-term program of robotic exploration of Mars, which was initiated with the 1996 launches of the currently orbiting Mars Global Surveyor and the Mars Pathfinder lander and rover, and included the recently lost Mars Climate Orbiter.

Mars Polar Lander will advance our understanding of Mars' current water resources by digging into the enigmatic layered terrain near one of its poles for the first time. Instruments on the lander will analyze surface materials, frost, weather patterns and interactions between the surface and atmosphere to better understand how the climate of Mars has changed over time.

Polar Lander carries a pair of basketball-sized microprobes that will be released as the lander approaches Mars and dive toward the planet's surface, penetrating up to about 3 feet (1 meter) underground to test 10 new technologies, including a science instrument to search for traces of water ice. The microprobe project, called Deep Space 2, is part of NASA's New Millennium Program.

A key scientific objective of the two missions is to determine how the climate of Mars has changed over time and where water, in particular, resides on Mars today. Water once flowed on Mars, but where did it go? Clues may be found in the geologic record provided by the polar layered terrain, whose alternating bands of color seem to contain different mixtures of dust and ice. Like growth rings of trees, these layered geological bands may help reveal the secret past of climate change on Mars and help determine whether it was driven by a catastrophic change, episodic variations or merely a gradual evolution in the planet's environment.

Today the Martian atmosphere is so thin and cold that it does not rain; liquid water does not last on the surface, but quickly freezes into ice or evaporates into the atmosphere. The temporary polar frosts which advance and retreat with the seasons are made mostly of condensed carbon dioxide, the major constituent of the Martian atmosphere. But the planet also hosts both water-ice clouds and dust storms, the latter ranging in scale from local to global. If typical amounts of atmospheric dust and water were concentrated today in the polar regions, they might deposit a fine layer every year, so that the top yard (or meter) of the polar layered terrains could be a well-preserved record showing 100,000 years of Martian geology and climatology.

The lander and microprobes will arrive December 3, 1999. They are aimed toward a target sector within the edge of the layered terrain near Mars' south pole. The exact landing site coordinates were selected in August 1999, based on images and altimeter data from the currently orbiting Mars Global Surveyor.

Like Mars Pathfinder, Polar Lander will dive directly into the Martian atmosphere, using an aeroshell and parachute scaled down from Pathfinder's design to slow its initial descent. The smaller Polar Lander will not use airbags, but instead will rely on onboard guidance and retro-rockets to land softly on the layered terrain near the south polar cap a few weeks after the seasonal carbon dioxide frosts have disappeared. After the heat shield is jettisoned, a camera will take a series of pictures of the landing site as the spacecraft descends. These are recorded onboard and transmitted to Earth after landing.

As the lander approaches Mars about 10 minutes before touchdown, the two Deep Space 2 microprobes are released. Once released, the projectiles will collect atmospheric data before they crash at about 400 miles per hour (200 meters per second) and bury themselves beneath the Martian surface. The microprobes will test the ability of very small spacecraft to deploy future instruments for soil sampling, meteorology and seismic monitoring. A key instrument will draw a tiny soil sample into a chamber, heat it and use a miniature laser to look for signs of vaporized water ice.

About 35 miles (60 kilometers) away from the microprobe impact sites, Mars Polar Lander will dig into the top of the terrain using a 6-1/2-foot-long (2-meter) robotic arm. A camera mounted on the robotic arm will image the walls of the trench, viewing the texture of the surface material and looking for fine-scale layering. The robotic arm will also deliver soil samples to a thermal and evolved gas analyzer, an instrument that will heat the samples to detect water and carbon dioxide. An onboard weather station will take daily readings of wind temperature and pressure, and seek traces of water vapor. A stereo imager perched atop a 5-foot (1.5-meter) mast will photograph the landscape surrounding the spacecraft. All of these instruments are part of an integrated science payload called the Mars Volatiles and Climate Surveyor.

Also onboard the lander is a light detection and ranging (lidar) experiment provided by Russia's Space Research Institute. The instrument will detect and determine the altitude of atmospheric dust hazes and ice clouds above the lander. Inside the instrument is a small microphone, furnished by the Planetary Society, Pasadena, CA, which will record the sounds of wind gusts, blowing dust and mechanical operations onboard the spacecraft itself.

The lander is expected to operate on the surface for 60 to 90 Martian days through the planet's southern summer (a Martian day is 24 hours, 37 minutes). The mission will continue until the spacecraft can no longer protect itself from the cold and dark of lengthening nights and the return of the Martian seasonal polar frosts.

Mars Polar Lander and Deep Space 2 are managed by the Jet Propulsion Laboratory for NASA's Office of Space Science, Washington, DC. Lockheed Martin Astronautics Inc., Denver, CO, is the agency's industrial partner for development and operation of the orbiter and lander spacecraft. JPL designed and built the Deep Space 2 microprobes. JPL is a division of the California Institute of Technology, Pasadena, CA.

[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 Mars arrival television transmissions 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 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.

Landing Media Credentialing

The Jet Propulsion Laboratory will operate a newsroom with facilities for journalists and broadcast crews from November 29 to December 10, 1999. Requests to cover the Mars Polar Lander and Deep Space 2 arrival must be faxed in advance to the JPL newsroom at (818 354-4537. Requests must be on the letterhead of the news organization and must specify the editor making the assignment to cover the launch. Reporters may also make arrangements to cover subsequent science operations at the University of California at Los Angeles.

Briefings

An extensive schedule of news and background briefings will be held at JPL during the landing period, with later briefings originating jointly from JPL and UCLA. A schedule of briefings is available on the Internet at JPL's Mars News site (below).

Internet Information

Extensive information on Mars Polar Lander and Deep Space 2, including an electronic copy of this press kit, press releases, fact sheets, status reports, briefing schedule and images, is available from the Jet Propulsion Laboratory's Mars News web site at **http://www.jpl.nasa.gov/marsnews** . The Mars program also maintains a home page at **http://marslander.jpl.nasa.gov/** .

Quick Facts

Mars Polar Lander

Dimensions: 3-1/2 feet (1.06 meters) tall by 12 feet (3.6 meters) wide
Weight: 1,270 lbs (576 kg) total, consisting of 639-lb (290-kg) lander plus 141 lbs (64 kg) propellant, 181-lb (82-kg) cruise stage, 309-lb (140-kg) aeroshell and heat shield
Science instruments: Mars Volatiles and Climate Surveyor (integrated package with surface imager, robotic arm with camera, meteorology package, and thermal and evolved gas analyzer); Mars Descent Imager; Lidar (including Mars microphone)
Power: Solar panels providing 200 watts on Mars' surface
Launch date: January 3, 1999
Earth-Mars distance at launch: 136.6 million miles (219.9 million km)
Earth-Mars distance at arrival: 157.2 million miles (253 million km)
One-way speed of light time Mars to Earth on landing day: 14 minutes, 4 seconds
Total distance traveled Earth to Mars: 470 million miles (757 million km)
Mars landing: December 3, 1999, at 12:01 p.m. Pacific Standard Time (actual event time in outer space; signals confirming flight events would be received on Earth about 14 minutes later)
Landing site: 76 degrees south latitude, 195 degrees west longitude, about 500 miles (800 km) from Mars' south pole
Estimated temperature at landing site: -73 F (-58 C)
Primary mission period: December 3, 1999 - March 1, 2000

Mars '98 Project

Mars Polar Lander cost: $110M spacecraft development, $10M mission operations; total $120 million (not including launch vehicle or Deep Space 2 microprobes)
Mars Climate Orbiter cost: $80M spacecraft development, $5M mission operations; total $85 million (not including launch vehicle)

Deep Space 2

Dimensions: aeroshell 11 inches (275 mm) high, 14 inches (350 mm) diameter; enclosing a forebody (penetrator) 4.2 inches (105.6 mm) long, 1.5 inches (39 mm) diameter; and an aftbody (ground station) 4.1 in (105.3 mm) high (plus 5-in (127-mm) antenna), 5.3 inches (136 mm) diameter
Weight: forebody 1.5 lbs (670 grams), aftbody 3.8 lbs (1,737 grams), aeroshell 2.6 lbs (1,165 grams); total 7.9 lbs (3,572 grams)
Power: Two lithium-thionyl chloride batteries providing 600 milliamp-hours each
Science instruments: sample collection/water detection experiment, soil thermal experiment, atmospheric descent accelerometer, impact accelerometer
Technologies: Total of 10 new technologies being flight-tested
Impact: December 3, 1999, at approximately 12:01 p.m. Pacific Standard Time (actual event time in outer space)
Estimated distance of probe impacts from Polar Lander: About 35 miles (60 km) northwest (1 degree north, 1 degree west of the lander)
Estimated distance of probe impacts from each other: Roughly 1 mile (2 km)
Duration of mission: 1 to 2 days
Cost: pre-launch development $28M, data analysis $1.6M; total $29.6 million

Mars at a Glance

General

❑ One of five planets known to ancients; Mars was Roman god of war, agriculture and the state
❑ Reddish color; occasionally the 3rd brightest object in night sky after the Moon and Venus

Physical Characteristics

❑ Average diameter 4,217 miles (6,780 kilometers); about half the size of Earth, but twice the size of Earth's Moon
❑ Same land area as Earth
❑ Mass 1/10th of Earth's; gravity only 38 percent as strong as Earth's
❑ Density 3.9 times greater than water (compared to Earth's 5.5 times greater than water)
❑ No planet-wide magnetic field detected; only localized ancient remnant fields in various regions

Orbit

❑ Fourth planet from the Sun, the next beyond Earth
❑ About 1.5 times farther from the Sun than Earth is
❑ Orbit elliptical; distance from Sun varies from a minimum of 128.4 million miles (206.7 million kilometers) to a maximum of 154.8 million miles (249.2 million kilometers); average distance from Sun, 141.5 million miles (227.7 million kilometers)
❑ Revolves around Sun once every 687 Earth days
❑ Rotation period (length of day) 24 hours, 37 min, 23 sec (1.026 Earth days)
❑ Poles tilted 25 degrees, creating seasons similar to Earth's

Environment

❑ Atmosphere composed chiefly of carbon dioxide (95.3%), nitrogen (2.7%) and argon (1.6%)
❑ Surface atmospheric pressure less than 1/100th that of Earth's average
❑ Surface winds up to 80 miles per hour (40 meters per second)
❑ Local, regional and global dust storms; also whirlwinds called dust devils
❑ Surface temperature averages -64 F (-53 C); varies from -199 F (-128 C) during polar night to 80 F (27 C) at equator during midday at closest point in orbit to Sun

Features

❑ Highest point is Olympus Mons, a huge shield volcano about 16 miles (26 kilometers) high and 370 miles (600 kilometers) across; has about the same area as Arizona
❑ Canyon system of Valles Marineris is largest and deepest known in solar system; extends more than 2,500 miles (4,000 kilometers) and has 3 to 6 miles (5 to 10 kilometers) relief from floors to tops of surrounding plateaus
❑ "Canals" observed by Giovanni Schiaparelli and Percival Lowell about 100 years ago were a visual illusion in which dark areas appeared connected by lines. The Mariner 9 and Viking missions of the 1970s, however, established that Mars has channels possibly cut by ancient rivers

Moons

❑ Two irregularly shaped moons, each only a few kilometers wide
❑ Larger moon named Phobos ("fear"); smaller is Deimos ("terror"), named for attributes personified in Greek mythology as sons of the god of war

Historical Mars Missions

Mission, Country, Launch Date, Purpose, Results

[Unnamed], USSR, 10/10/60, Mars flyby, did not reach Earth orbit
[Unnamed], USSR, 10/14/60, Mars flyby, did not reach Earth orbit
[Unnamed], USSR, 10/24/62, Mars flyby, achieved Earth orbit only
Mars 1, USSR, 11/1/62, Mars flyby, radio failed at 65.9 million miles (106 million km)
[Unnamed], USSR, 11/4/62, Mars flyby, achieved Earth orbit only
Mariner 3, U.S., 11/5/64, Mars flyby, shroud failed to jettison
Mariner 4, U.S. 11/28/64, first successful Mars flyby 7/14/65, returned 21 photos
Zond 2, USSR, 11/30/64, Mars flyby, passed Mars but radio failed, returned no planetary data
Mariner 6, U.S., 2/24/69, Mars flyby 7/31/69, returned 75 photos
Mariner 7, U.S., 3/27/69, Mars flyby 8/5/69, returned 126 photos
Mariner 8, U.S., 5/8/71, Mars orbiter, failed during launch
Kosmos 419, USSR, 5/10/71, Mars lander, achieved Earth orbit only
Mars 2, USSR, 5/19/71, Mars orbiter/lander arrived 11/27/71, no useful data, lander destroyed
Mars 3, USSR, 5/28/71, Mars orbiter/lander, arrived 12/3/71, some data and few photos
Mariner 9, U.S., 5/30/71, Mars orbiter, in orbit 11/13/71 to 10/27/72, returned 7,329 photos
Mars 4, USSR, 7/21/73, failed Mars orbiter, flew past Mars 2/10/74
Mars 5, USSR, 7/25/73, Mars orbiter, arrived 2/12/74, lasted a few days
Mars 6, USSR, 8/5/73, Mars orbiter/lander, arrived 3/12/74, little data return
Mars 7, USSR, 8/9/73, Mars orbiter/lander, arrived 3/9/74, little data return
Viking 1, U.S., 8/20/75, Mars orbiter/lander, orbit 6/19/76-1980, lander 7/20/76-1982
Viking 2, U.S., 9/9/75, Mars orbiter/lander, orbit 8/7/76-1987, lander 9/3/76-1980; combined, the Viking orbiters and landers returned 50,000+ photos
Phobos 1, USSR, 7/7/88, Mars/Phobos orbiter/lander, lost 8/89 en route to Mars
Phobos 2, USSR, 7/12/88, Mars/Phobos orbiter/lander, lost 3/89 near Phobos
Mars Observer, U.S., 9/25/92, lost just before Mars arrival 8/21/93
Mars Global Surveyor, U.S., 11/7/96, Mars orbiter, arrived 9/12/97, currently conducting prime mission of science mapping
Mars 96, Russia, 11/16/96, orbiter and landers, launch vehicle failed
Mars Pathfinder, U.S., 12/4/96, Mars lander and rover, landed 7/4/97, last transmission 9/27/97
Nozomi (Planet-B), Japan, 7/4/98, Mars orbiter, currently in orbit around the Sun; Mars arrival delayed to 12/03 due to propulsion problem
Mars Climate Orbiter, U.S., 12/11/98; lost on arrival at Mars 9/23/99
Mars Polar Lander/Deep Space 2, U.S., 1/3/99, lander/descent probes; lander to set down near south pole 12/3/99; Deep Space 2 microprobes to smash into surface the same day

Mars, Water and Life

The planet Mars landed in the middle of immense public attention on July 4, 1997, when Mars Pathfinder touched down on a windswept, rock-laden ancient flood plain. Two months later, Mars Global Surveyor went into orbit, sending back pictures of towering volcanoes and gaping chasms at resolutions never before seen.

In December 1999, another lander will arrive at Mars. And every 26 months over the next decade, when the alignment of Earth and Mars are suitable for launches, still more robotic spacecraft will join them at the red planet.

These spacecraft carry varied payloads, ranging from cameras and other sensors to rovers and robotic arms. Some of them have their roots in different NASA programs of science or technology development. But they all have the goal of understanding Mars better, primarily by delving into its geology, climate and history.

With the announcement in 1996 by a team of scientists that a meteorite believed to have come from Mars contained what might be the residue of ancient microbes, public interest became regalvanized by the possibility of past or present life there. The key to understanding whether life could have evolved on Mars, many scientists believe, is understanding the history of water on the planet.

Mars and Life

Mars perhaps first caught public fancy in the late 1870s, when Italian astronomer Giovanni Schiaparelli reported using a telescope to observe "canali," or channels, on Mars. A possible mistranslation of this word as "canals" may have fired the imagination of Percival Lowell, an American businessman with an interest in astronomy. Lowell founded an observatory in Arizona, where his observations of the red planet convinced him that the canals were dug by intelligent beings – a view which he energetically promoted for many years.

By the turn of the century, popular songs told of sending messages between Earth and Mars by way of huge signal mirrors. On the dark side, H.G. Wells' 1898 novel "The War of the Worlds" portrayed an invasion of Earth by technologically superior Martians desperate for water. In the early 1900s novelist Edgar Rice Burroughs, known for the "Tarzan" series, also entertained young readers with tales of adventures among the exotic inhabitants of Mars, which he called Barsoom.

Fact began to turn against such imaginings when the first robotic spacecraft were sent to Mars in the 1960s. Pictures from the first flyby and orbiter missions showed a desolate world, pockmarked with craters like Earth's Moon. The first wave of Mars exploration culminated in the Viking mission, which sent two orbiters and two landers to the planet in 1975. The landers included experiments that conducted chemical tests in search of life. Most scientists interpreted the results of these tests as negative, deflating hopes of a world where life is widespread.

The science community had many other reasons for being interested in Mars apart from searching for life; the next mission on the drawing boards, Mars Observer, concentrated on a study of the planet's geology and climate. Over the next 20 years, however, new developments in studies on Earth came to change the way that scientists thought about life and Mars.

One was the 1996 announcement by a team from Stanford University, NASA's Johnson Space Center and Quebec's McGill University that a meteorite believed to have originated on Mars contained what might be the fossils of ancient microbes. This rock and other so-called Mars meteorites discovered on several continents on Earth are believed to have been blasted away from the red planet by asteroid or meteor impacts. They are thought to come from Mars because gases trapped in some of the rocks match the composition of Mars' atmosphere. Not all scientists agreed with the conclusions of the team announcing the discovery of fossils, but it reopened the issue of life on Mars.

Other developments that shaped scientists' thinking included new research on how and where life thrives on Earth. The fundamental requirements for life as we know it are liquid water, organic compounds and an energy source for synthesizing complex organic molecules. Beyond these basics, we do not yet understand the environmental and chemical evolution that leads to the origin of life. But in recent years it has become increasingly clear that life can thrive in settings much different from the longheld notion of a tropical soup rich in organic nutrients.

In the 1980s and 1990s, biologists found that microbial life has an amazing flexibility for surviving in extreme environments – niches that by turn are extraordinarily hot, or cold, or dry, or under immense pressures – that would be completely inhospitable to humans or complex animals. Some scientists even concluded that life may have begun on Earth in heat vents far under the ocean's surface.

This in turn had its effect on how scientists thought about Mars. Life might not be so widespread that it would be found at the foot of a lander spacecraft, but it may have thrived billions of years ago in an underground thermal spring. Or it might still exist in some form in niches below the frigid, dry, windswept surface wherever there might be liquid water.

NASA scientists also began to rethink how to look for signs of past or current life on Mars. In this new view, the markers of life may well be so subtle that the range of test equipment required to detect it would be far too complicated to package onto a spacecraft. It made more sense to collect samples of Martian rock, soil and air to bring back to Earth, where they could be subjected to much more extensive laboratory testing with state-of-the-art equipment.

Mars and Water

Mars today is too cold, with an atmosphere that is too thin, to support liquid water on its surface. Yet scientists who studied images from the Viking orbiters kept encountering features that appeared to be formed by flowing water – among them deep channels and canyons, and even features that appeared to be ancient lake shorelines. Added to this were more recent observations by Mars Pathfinder and Mars Global Surveyor which suggested widespread flowing water in the planet's past. Some scientists identified features which they believe appear to be carved by torrents of water with the force of 10,000 Mississippi Rivers.

There is no general agreement, however, on what form water took on the early Mars. Two competing views are currently popular in the science community. According to one theory, Mars was once much warmer and wetter, with a thicker atmosphere; it may well have boasted lakes or oceans, rivers and rain. According to the other theory, Mars was always cold, but water trapped as underground ice was periodically released when heating caused ice to melt and gush forth onto the surface.

In either case, the question of what happened to the water remains a mystery. Most scientists do not feel that Mars' climate change was necessarily caused by a cataclysmic event such as an asteroid impact that, perhaps, disturbed the planet's polar orientation or orbit. Many believe that the demise of flowing water on the surface could have resulted from gradual climate change over many millennia as the planet lost its atmosphere.

Under either the warmer-and-wetter or the always-cold scenario, Mars must have had a thicker atmosphere in order to support water that flowed on the surface even only occasionally. If the planet's atmosphere became thinner, liquid water would rapidly evaporate. Over time, carbon dioxide gas reacts with elements in rocks and becomes locked up as a kind of compound called a carbonate. What's left of Mars' atmosphere today is overwhelmingly carbon dioxide.

On Earth, shifting tectonic plates are continually plowing carbonates and other minerals under the surface; heated by magmas, carbon dioxide is released and spews forth in volcanic eruptions, replenishing the carbon dioxide in the atmosphere. Although Mars has no known active volcanoes and there are no signs of fresh lava flows, it had abundant volcanic activity in its past. However, Mars appears to have no tectonic plates, so a critical link in the process that leads to carbon dioxide replenishment in Earth's atmosphere is missing. In short, Mars' atmosphere could have been thinned out over many eons by entrapment of carbon dioxide in rocks across its surface.

That scenario, however, is just a theory. Regardless of the history and fate of the atmosphere, scientists also do not understand what happened to Mars' water. Some undoubtedly must have been lost to space. Water ice has been detected in the permanent cap at Mars' north pole, and may exist in the cap at the south pole. But much water is probably trapped under the surface – either as ice or, if near a heat source, possibly in liquid form well below the surface.

Polar Lander and Future Missions

Mars Polar Lander is designed to help scientists better understand the climate history of Mars, not to look for life. It does not, for example, contain any biology experiments similar to the chemistry lab on the Viking landers. However, its focus on Mars' climate and the role of water will have an impact on the life question. Water is also important as a resource for eventual human expeditions to the red planet.

In addition, the currently orbiting Mars Global Surveyor will aid the search for likely sites for future Mars robotic landers. Scientists are interested in three types of Martian environments which are potentially most favorable to the emergence and persistence of life. They are:

❑ **Ancient groundwater environments**. Early in the planet's history, liquid water appears to have been widespread beneath the surface. During the final stages of planetary formation, intense energy was dissipated by meteor impacts. This, along with active volcanoes, could have created warm groundwater circulation systems favorable for the origin of life.

❑ **Ancient surface water environments**. Also during early Martian history, water was apparently released from subsurface aquifers, flowed across the surface and pooled in low-lying

NASA Programs

Although they are targeted at the same planet, some Mars missions have their roots in different NASA programs. The following are the programs responsible for U.S. Mars missions in the present and recent past:

❑ **Mars Surveyor Program**. In 1994, NASA created a program to send spacecraft to the planet during each launch opportunity every 26 months over the next decade. The first spacecraft under the program, Mars Global Surveyor, was launched in 1996 and is currently in orbit at the planet. The Mars Surveyor Program missions in 1998 were Mars Polar Lander and the recently lost Mars Climate Orbiter, collectively known as the Mars Surveyor '98 project. All of NASA's Mars missions now planned for the first decade of the next century also fall under this programmatic umbrella. In order to save costs, a single industrial partner, Lockheed Martin Astronautics, was chosen to build and operate all of the Mars Surveyor spacecraft over several years. In addition, an ongoing project office called the Mars Surveyor Operations Project was created at JPL, consolidating management of mission operations across the multi-year program.

❑ **Discovery Program**. Created in 1992, NASA's Discovery Program competitively selects proposals for low-cost solar system exploration missions with highly focused science goals. Mars Pathfinder was the second mission approved and launched under the Discovery Program. Originally conceived as an engineering demonstration of a way to deliver a spacecraft to the surface of Mars with a novel approach using airbags to land, the mission evolved to include a science payload focused primarily on geology.

❑ **New Millennium Program**. Technology, rather than science, is at the center of NASA's New Millennium Program, created in 1994. The goal of the program is to identify and flight-test new technologies that will enable science missions of the early 21st century. Teams are formed with partners from government, private industry, academia and the nonprofit sector to develop promising technologies in spacecraft autonomy, telecommunications, microelectronics, science instruments and mechanical systems. Deep Space 2, the project that is sending two microprobes to piggyback on Mars Polar Lander, is the second mission under New Millennium. In addition to "Deep Space" missions to the solar system, a series of "Earth Orbiter" missions is also planned to test new technologies for Earth-observing spacecraft. These missions may also collect science data, but technology is always at the forefront.

regions. Evidence of the early climate of Mars and of ancient life, if any, may be preserved in sedimentary rocks in these environments.

❑ **Modern groundwater environments**. Life may have formed at any time, including recently, in habitats where subsurface water or ice is geothermally heated to create warm groundwater circulation systems. In addition, life may have survived from an early epoch in places beneath the surface where liquid water is present today.

These Martian environments can be investigated in several ways. We can get a glimpse of underground environments by using rovers to explore young craters and what appear to be the remains of water-eroded channels, and by drilling from lander spacecraft. Sensors on orbiters will search for the most likely reservoirs of water in these regions.

To investigate these scientific themes, NASA's Mars program will carry out the following implementation strategy for the initial phases of Mars exploration:

❑ The Mars orbiters in 1996 and 2001 will provide sufficient information to guide an early sample return from an ancient groundwater environment.

❑ Ancient surface-water environments will be explored in greater depth. When a sample-return mission is sent to Mars, it is extremely important to be able to identify minerals formed by water.

❑ Ancient and modern sites exhibiting evidence of hydrothermal activity will be studied, followed eventually by efforts to drill as deeply as possible below the surface.

Samples will be collected using rovers capable of extensive searches and of collecting and storing samples of rock and soil. Sophisticated sensors onboard rovers will help insure that diverse rock types are collected. Drills capable of reaching several yards (or meters) below the surface will also be used to analyze subsurface material. It is likely that it will be some time before space technologies will be able to drill to depths of a half-mile (kilometer) and more to access subsurface water.

Samples of the Martian atmosphere will also be brought back to Earth. The possible origin and evolution of life on Mars must be linked to the evolution of its atmosphere.

In 2003 NASA and its international partners will see the first launch of a mission to collect samples and place them in Mars orbit to await their transport back to Earth. A mission in 2005 will include two spacecraft – a lander like the 2003 mission to collect surface samples, and a French-built orbiter to return both the 2003 and 2005 samples to Earth. A series of at least three sample return missions similar to this are expected to be carried out over the following decade.

Even if it turns out that Mars never harbored life, study of the planet can help in understanding life on our own. Much of the evidence for the origin of life on Earth has been erased

Mars Pathfinder Science Highlights

Launched December 4, 1996, Mars Pathfinder landed July 4, 1997, in Ares Vallis, an ancient flood plain in Mars' northern hemisphere. The spacecraft deployed a small robotic rover named Sojourner to study rocks at the landing site. Key science findings included:

❑ Chemical analyses returned by Mars Pathfinder indicate that some rocks at the landing site appear to be high in silica, suggesting differentiated parent materials. These rocks are distinct from the meteorites found on Earth that are thought to be of Martian origin.

❑ The identification of rounded pebbles and cobbles on the ground, and sockets and pebbles in some rocks, suggests conglomerates that formed in running water, during a warmer past in which liquid water was stable.

❑ Some rocks at the landing site appear grooved and fluted, suggesting abrasion by sand-sized particles. Dune-shaped deposits were also found in a trough behind the area of the landing site known as the Rock Garden, indicating the presence of sand.

❑ The soil chemistry of the landing site appears to be similar to that of the Viking 1 and 2 landing sites, suggesting that the soil may be a globally deposited unit.

❑ Radio tracking of Mars Pathfinder indicates that the radius of the planet's central metallic core is greater than 800 miles (1,300 kilometers) but less than roughly 1,250 miles (2,000 kilometers).

❑ Airborne dust is magnetic with each particle about 1 micron in size. Interpretations suggest the magnetic mineral is maghemite, a very magnetic form of iron oxide, which may have been freeze-dried on the particles as a stain or cement. The iron may have been leached out of materials in the planet's crust by an active water cycle.

❑ Whirlwinds called dust devils were frequently measured by temperature, wind and pressure sensors, suggesting that these gusts are a mechanism for mixing dust into the atmosphere.

❑ Imaging revealed early morning water ice clouds in the lower atmosphere, which evaporate as the atmosphere warms.

❑ Abrupt temperature fluctuations were recorded in the morning, suggesting that the atmosphere is warmed by the planet's surface, with heat convected upwards in small eddies.

❑ The weather was similar to weather encountered by Viking 1; there were rapid pressure and temperature variations, downslope winds at night and light winds in general. Temperatures at the surface were about 18 F (10 C) warmer than those measured by Viking 1.

❑ The atmosphere was a pale pink color due to fine dust mixed in the lower atmosphere, as was seen by Viking. Particle size and shape estimates and the amount of water vapor in the atmosphere are also similar to Viking observations.

Mars Global Surveyor Science Highlights

Launched November 7, 1996, Mars Global Surveyor entered orbit around Mars on September 12, 1997, and achieved its final orbit by skimming through the planet’s upper atmosphere in a technique called aerobraking. The prime science mapping mission began in spring 1999, although the spacecraft had collected much science data during the aerokbraking period. Key findings include:

- The planet's magnetic field is not globally generated in the planet's core, but is localized in particular areas of the crust. Multiple magnetic anomalies were detected at various points on the planet's surface, indicating that magma solidified in an ancient magnetic field as it came up through the crust and cooled very early in Mars' evolution.

- Mars' very localized magnetic field also creates a new paradigm for the way in which it interacts with the solar wind, one that is not found with other planets. While Earth, Jupiter and other planets have large magnetospheres, and planets like Venus have strong ionospheres, Mars' small, localized magnetic fields are likely to produce a much more complicated interaction process as these fields move with the planet's rotation.

- New temperature data and closeup images of the Martian moon Phobos show its surface is composed of powdery material at least 3 feet (1 meter) thick, caused by millions of years of meteoroid impacts. Measurements of the day and night sides of Phobos show extreme temperature variations on the sunlit and dark sides of the moon. Highs were measured at 25 F (-4 C) and lows registered at -170 F (-112 C).

- New images suggest that some areas previously thought to be shorelines of ancient lakes or oceans do not show landforms expected at shorelines. Some areas of the northern hemisphere are the flattest terrain yet observed in the solar system, with elevations that vary only a few feet over many miles, suggesting formation by a sedimentary process.

- An area near the Martian equator was found to have an accumulation of the mineral hematite, consisting of tiny crystallized grains of iron oxide that on Earth typically originate in standing bodies of water. The material has been previously detected on Mars in more dispersed concentrations, and is widely thought to be an important component of the materials that give Mars its red color.

- The spacecraft’s altimeter has given scientists their first global three-dimensional map of the Martian surface. The instrument’s profiles of the northern ice cap show an often striking surface topology of canyons and spiral troughs in the polar cap, made of water ice and carbon dioxide ice, that can reach depths as great as 3,600 feet (1 kilometer) below the surface. Many of the larger and deeper troughs display a staircase structure, which may ultimately be correlated with seasonal layering of ice and dust that was observed by NASA's Viking mission orbiters in the late 1970s. At 86.3 degrees north, the highest latitude yet sampled, the cap achieves an elevation of 6,600 to 7,900 feet (1.25 to 1.5 miles, or 2 to 2.5 kilometers) over the surrounding terrain.

- Images reveal much more layering than previously known in the terrain of the south polar region, where Mars Polar Lander will land on December 3, 1999. Pictures show swirling bands of eroded, layered rock, reminiscent of the edges of Alaskan ice sheets, and an array of light and dark mottled patterns blanketing the frigid floor of the south pole. They reveal that Mars Polar Lander’s target landing zone at about 76 degrees south latitude is more rugged and geologically diverse than scientists had previously thought.

by movement of the planet's crust and by weathering. Fortunately, large areas of Mars' surface date back to the very earliest period of planetary evolution – about 4 billion years ago, overlapping the period on Earth when pre-biotic chemical evolution first gave rise to life. Thus, even if life never developed on Mars, studies of the planet may yield crucial information about the pre-biotic chemistry that led to life on Earth.

Where to Next?

In 1998, NASA conducted a review of its multi-year Mars program, calling in outside experts to help evaluate and refine the architecture for the direction of the effort. The review resulted in a new approach to achieve a series of sample-return missions beginning early in the next decade. Details are subject to change as plans evolve, but the following are the basic missions foreseen:

- ❑ **2001:** NASA will launch a lander and orbiter broadly similar to Mars Polar Lander and Mars Climate Orbiter. The orbiter, equipped with three science instruments, will be the first planetary spacecraft to be launched from the west coast of the United States. The lander will touch down near Mars' equator, carrying a spare Mars Pathfinder rover, a robotic arm and several other science instruments, including three that will return data in support of eventual human exploration.

- ❑ **2003:** NASA will begin the series of sample-return missions with launch of a lander and rover that will search for soil and rock samples and return them to a mini-ascent vehicle that will loft the samples to Mars orbit. The European Space Agency (ESA), in collaboration with the Italian space agency (ASI), will provide an orbiter. ASI may also provide a drill and other robotic elements for landers beginning in this year. NASA's Human Exploration and Development of Space (HEDS) enterprise may also begin providing science and technology experiments for the large lander. As early as this year, NASA and the French space agency, CNES, may also launch a "micromission" spacecraft designed to deliver payloads such as communications/navigation relays, penetrators, small landers or exploration balloons.

- ❑ **2005:** NASA and CNES will launch an orbiter, lander and rover on a French-provided Ariane 5 rocket. The lander and rover will search for soil and rock samples, and return them to a mini-ascent vehicle that will loft the samples to Mars orbit. CNES will provide the orbiter spacecraft that will retrieve the 2003 and 2005 samples from Mars orbit and return them to Earth in a vehicle provided by NASA. The samples will reach Earth in 2008. The lander may also carry an ASI-provided drill and additional payloads, perhaps contributed by ASI, CNES, HEDS or other partners. The CNES spacecraft will also carry four miniature landers called "netlanders." In addition, NASA and CNES may collaborate on two "micromissions."

- ❑ **2007-2009:** As currently envisioned, NASA's strategy will be to continue to collect samples from different types of Martian terrain and place them in Mars orbit for later retrieval. In 2007, NASA would launch another lander, rover and ascent vehicle. NASA and CNES may collaborate on two more "micromissions," and HEDS may provide more experiments. In 2009, NASA would again launch a lander, rover and ascent vehicle. Current plans call for another orbiter provided by CNES that will retrieve the 2007 and 2009 samples from Mars orbit and return them to Earth in a vehicle provided by NASA.

- ❑ **2011-2013:** The plans for these years are being formulated. They may include "robotic outposts" -- interacting robotic units undertaking complex science investigations.

Mars Polar Lander

Mars Polar Lander will settle onto the surface of the red planet, much as Mars Pathfinder did in 1997. But instead of inflating airbags to bounce on the surface as it lands, Mars Polar Lander will use retro-rockets to slow its descent, like the Viking landers of the 1970s. Instead of a rover, Mars Polar Lander is equipped with a robotic arm that will dig into the soil near the planet's south pole in search of subsurface water and fine-scale layering that may physically record past changes in climate.

The lander will also conduct experiments on soil samples acquired by the robotic arm and dumped into small ovens, where the samples will be heated to drive off water and carbon dioxide. Surface temperatures, winds, pressure and the amount of dust in the atmosphere will be measured on a daily basis, while a small microphone records the sounds of wind gusts or mechanical operations onboard the spacecraft.

Mission Overview

Launch. Mars Polar Lander was launched January 3, 1999, at 3:21 p.m. Eastern Standard Time on a Delta II rocket from Space Launch Complex 17B at Cape Canaveral Air Station, FL. The Delta II was a model 7425 with two liquid-fuel stages augmented by four strap-on solid-fuel boosters, and a third-stage Thiokol Star 48B solid-fuel booster.

At the time of launch, the lander was encased within an aeroshell attached to a round platform called the cruise stage. Because the lander's solar panels are folded up within the aeroshell, a second set of solar panels is located on the cruise stage to power the spacecraft during its interplanetary cruise. Shortly after launch, these hinged solar panels unfolded and the spacecraft fired its thrusters to orient the solar panels toward the Sun. Fifty-eight minutes after launch, the 112-foot-diameter (34-meter) antenna at the Deep Space Network complex in Canberra, Australia, acquired Polar Lander's signal.

Interplanetary cruise. By the time it reaches Mars on December 3, 1999, Polar Lander will have spent 11 months in cruise. The spacecraft's flight path is called a Type 2 trajectory because it has taken the lander more than 180 degrees around the Sun, enabling it to target a landing zone near Mars' south pole. By comparison, Mars Pathfinder followed a Type 1 trajectory which took it less than 180 degrees around the Sun, reaching Mars in only seven months. During the first leg of its trip, Mars Polar Lander flew slightly inward toward the Sun before spiraling out beyond Earth's orbit to Mars. Toward the end of cruise, it has been flying slightly out past the orbit of Mars before returning inward to intersect the planet's orbit.

Throughout cruise, the spacecraft has been communicating with Earth using its X-band transmitter and the medium-gain horn antenna on the cruise stage. During the first 30 days after launch, the spacecraft was tracked from 10 to 12 hours per day. During quiet phases of the flight, when spacecraft operations are at a minimum, one four-hour tracking session per day has been conducted.

Forty-five days before Mars arrival, tracking will be increased. At least three four-hour sessions per day are required for high-precision navigation, with continuous tracking when possible. Starting 30 days before arrival, nearly continuous tracking sessions have switched between Mars Polar Lander and the currently orbiting Mars Global Surveyor in order to fine-tune the lander's final approach to Mars.

During interplanetary cruise, Polar Lander was scheduled to fire its thrusters in up to six maneuvers to adjust its flight path. The first of these trajectory correction maneuvers was carried out January 21, 1999. This maneuver, which lasted 3 minutes, removed a small bias in the lander's trajectory that was introduced at launch to send the third stage of the Delta II rocket, which was trailing behind the spacecraft, past Mars rather than directly toward the planet. The maneuver also corrected minor injection errors caused by the spacecraft's liftoff. In the second trajectory maneuver, carried out March 15, 1999, the spacecraft's thrusters fired for about 10 seconds.

The next maneuver, which took place September 1, 1999, was called a site adjustment maneuver. Designed to fine-tune the spacecraft's landing site based on recent images of the Mars south pole area from the currently orbiting Mars Global Surveyor, this required the thrusters to fire for 30 seconds.

The next maneuver was carried out October 30, 1999, when the thrusters fired for 12 seconds. Another trajectory maneuver is scheduled at about 10 a.m. Pacific Standard Time on Tuesday, November 30, 1999. An optional sixth maneuver is tentatively scheduled to take place if required at about 5:30 a.m. landing day -- Friday, December 3, 1999.

(For bookkeeping purposes, the Polar Lander project refers to these thruster firings as follows: January 21, trajectory correction maneuver #1; March 15, trajectory correction maneuver #2; September 1, site adjustment maneuver; October 30, trajectory correction maneuver #3; November 30, trajectory correction maneuver #4; and December 3, (optional) trajectory correction maneuver #5.)

Science instruments were tested and calibrated during two week-long periods during cruise. Five of the instruments were checked out the week of April 5-9, 1999. The second period of tests took place September 8-9, 1999.

Science instrument checkout data and spacecraft engineering data gathered during the cruise was transmitted to Earth via the Deep Space Network's 230-foot-diameter (70-meter) antennas. Use of these large dish antennas allowed ground controllers to receive data at higher data rates than possible with the smaller 112-foot (34-meter) antennas.

The meteorological package's pressure transducer was powered on for a few minutes each month during cruise for calibration. The surface stereo imager twice took images of dark space inside the lander's aeroshell during cruise to calibrate its charge-coupled device (CCD) detectors.

Pre-entry events. Preparations for the lander's entry into the Martian atmosphere will begin 14 hours in advance, when the final tracking coverage of the cruise period begins. This will be the final opportunity for ground controllers to gather navigation data before entry. About 18 hours before entry, software which normally puts the spacecraft in safe mode in reaction to unexpected events will be disabled for the remainder of the spacecraft's flight and descent to the surface.

An opportunity to transmit commands for thruster firings to fine-tune the flight path occurs between nine and seven hours before entry. If a final trajectory correction maneuver is required, computer commands for that thruster firing could be sent to the spacecraft during this window. The maneuver would be executed at 6-1/2 hours before entry.

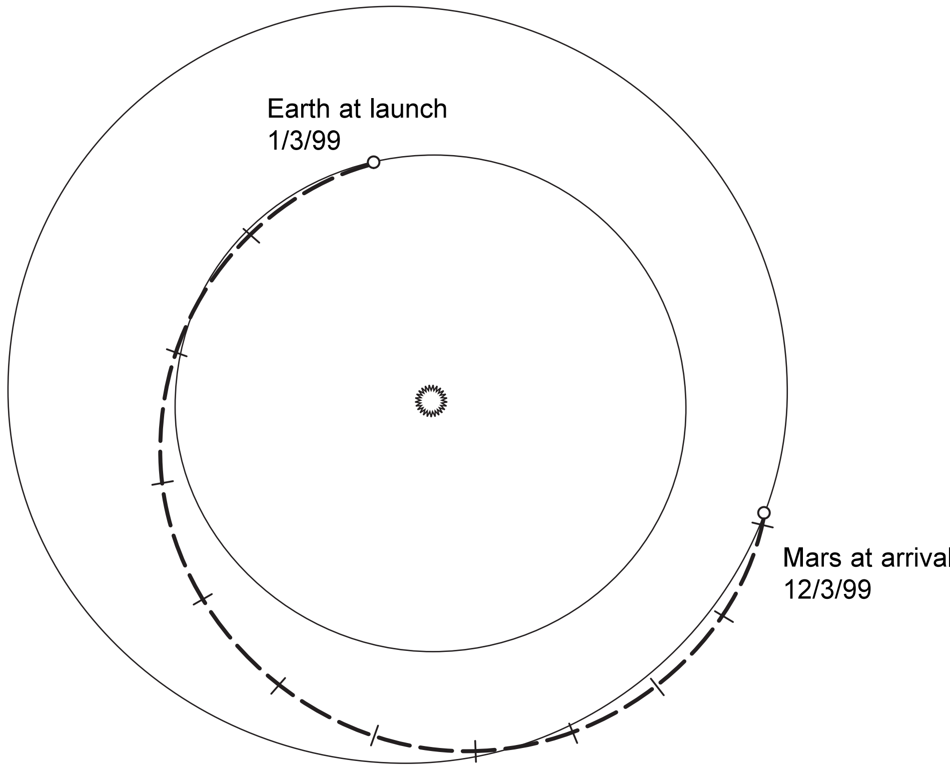
Starting about five hours before entry, heaters on the lander's thrusters will be turned on. A one-hour tracking session will begin 75 minutes before entry. This session will be used to monitor spacecraft health and status and perform tracking after the final thruster firing. A pyro valve will fire at 40 minutes before entry to pressurize the descent engines. Fifteen minutes before entry, software controlling the Mars Descent Imager will be initialized.

About 10 minutes before entry, the spacecraft will be commanded to switch to inertial navigation – computing its position, course and speed from gyroscopes and accelerometers. Six minutes before entry, the spacecraft will begin pulsing its thrusters for 80 seconds to turn it to its entry orientation. Five minutes before entry and 10-1/2 minutes before landing, the cruise stage will separate from the aeroshell-encased lander. Cut off from the cruise stage's solar panels, the lander will rely on its internal battery until it can unfold its own solar panels on the planet's surface. The Deep Space 2 microprobes, piggybacking on the lander's cruise stage, will be jettisoned about 18 seconds later. The lander will then be commanded to assume the correct orientation for atmospheric entry.

Entry, descent and landing. Traveling at about 15,400 miles per hour (6.9 kilometers per second), the spacecraft will enter the upper fringe of Mars' atmosphere some 33 to 37 seconds later. Onboard accelerometers, sensitive enough to detect "G" forces as little as 3/100ths of Earth's gravity, will sense when friction from the atmosphere causes the lander to slow slightly. At this point, the lander will begin using its thrusters to keep the entry capsule aligned with its direction of travel.

The spacecraft's descent from the time it hits the upper atmosphere until it lands takes about five minutes and 30 seconds to accomplish. As it descends, the spacecraft will experience G forces up to 12 times Earth's gravity, while the temperature of its heat shield rises to 3000 F (1650 C).

About two minutes before landing, the lander's parachute will be fired from a mortar (or small cannon) when the spacecraft is moving at about 960 miles per hour (430 meters per second) some 4.5 miles (7.3 kilometers) above the Martian surface. Ten seconds after the parachute opens, the Mars Descent Imager will be powered on and the spacecraft's heat shield will be jet-



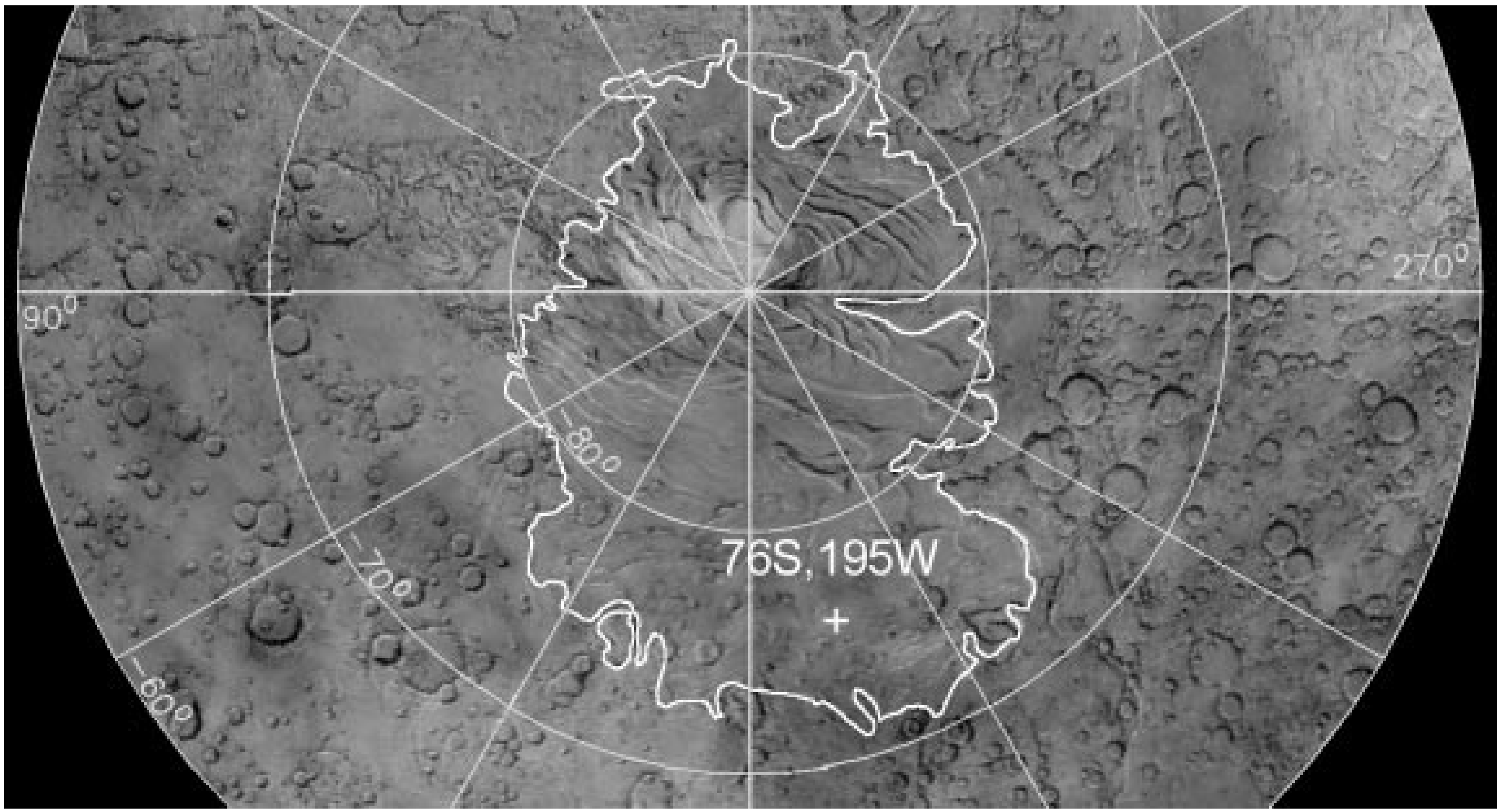
Lander's interplanetary trajectory

tisoned. The first descent image will be taken 0.3 seconds before heat-shield separation. The imager will take a total of about 30 pictures during the spacecraft's descent to the surface.

About 70 to 100 seconds before landing, the lander legs will be deployed; 1.5 seconds after that, the landing radar will be activated. The radar will be able to gauge the spacecraft's altitude about 44 seconds after it is turned on, at an altitude of about 1.5 miles (2.5 kilometers) above the surface.

Shortly after radar ground acquisition, when the spacecraft is traveling at about 170 miles per hour (75 meters per second) some 4,600 feet (1.4 kilometers) above the surface, the thrusters that the spacecraft has used for maneuvers throughout its cruise will be turned off, and the backshell will separate from the lander. The descent engines will be turned on one-half second later, turning the lander so its flight path gradually becomes vertical.

The pulse-modulated descent engines will maintain the spacecraft's orientation as it descends. The engines will fire to roll the lander to its proper orientation so that it lands with the solar panels in the best orientation to generate power as the Sun moves across the sky. The radar will be turned off at an altitude of about 130 feet (40 meters) above the surface, and the spacecraft continues using its gyros and accelerometers for inertial guidance as it lands.



Lander's target landing site

Once the spacecraft reaches either an altitude of 40 feet (12 meters) or a velocity of 5.4 miles per hour (2.4 meters per second), the lander will drop straight down at a constant speed. The descent engines will be turned off when touchdown is detected by sensors in the footpads. The engines will have been on for a total of about 40 seconds during final descent to the surface.

Post-landing. The lander is expected to touch down at 4:20 a.m. local time at the Mars landing site (12:01 p.m. Pacific Standard Time). (Because radio signals take 14 minutes to travel from Mars to Earth, during the landing the mission team will be watching events in "Earth-received time," with landing noted at 12:15 p.m. To avoid confusion, all subsequent times of mission events discussed below are stated in "Earth-received time," when a signal would be received on Earth. Actual events will have taken place on the spacecraft about 14 minutes earlier in each case.)

Shortly after landing, software which puts the spacecraft in safe mode in reaction to unexpected events will be reenabled. The descent imager will be turned off 60 seconds after landing.

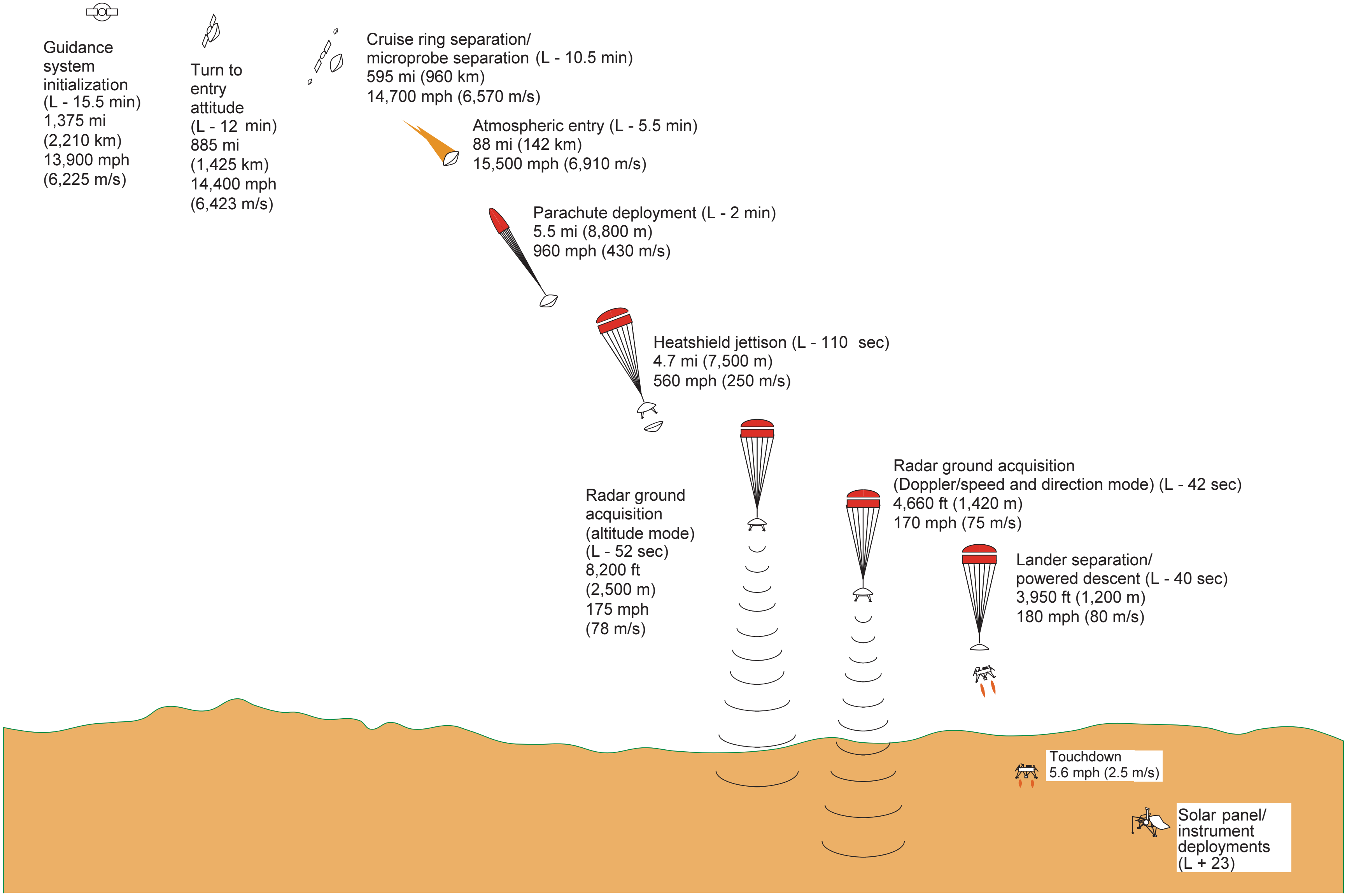
After waiting five minutes to allow for dust kicked up by the landing to settle, the lander's solar arrays will be unfolded. Eight minutes after landing, while the medium-gain antenna is being turned to point at Earth, the spacecraft's gyros will be used like compasses to determine which way is north. The spacecraft's inertial measurement units will then be powered off.

After gyrocompassing is completed, the medium-gain antenna will turn to point to Earth. This antenna slew may take up to 16 minutes to complete. A vertical scan will then be taken by the surface stereo imager before its boom is deployed. Both the meteorological and imager masts will then be raised.

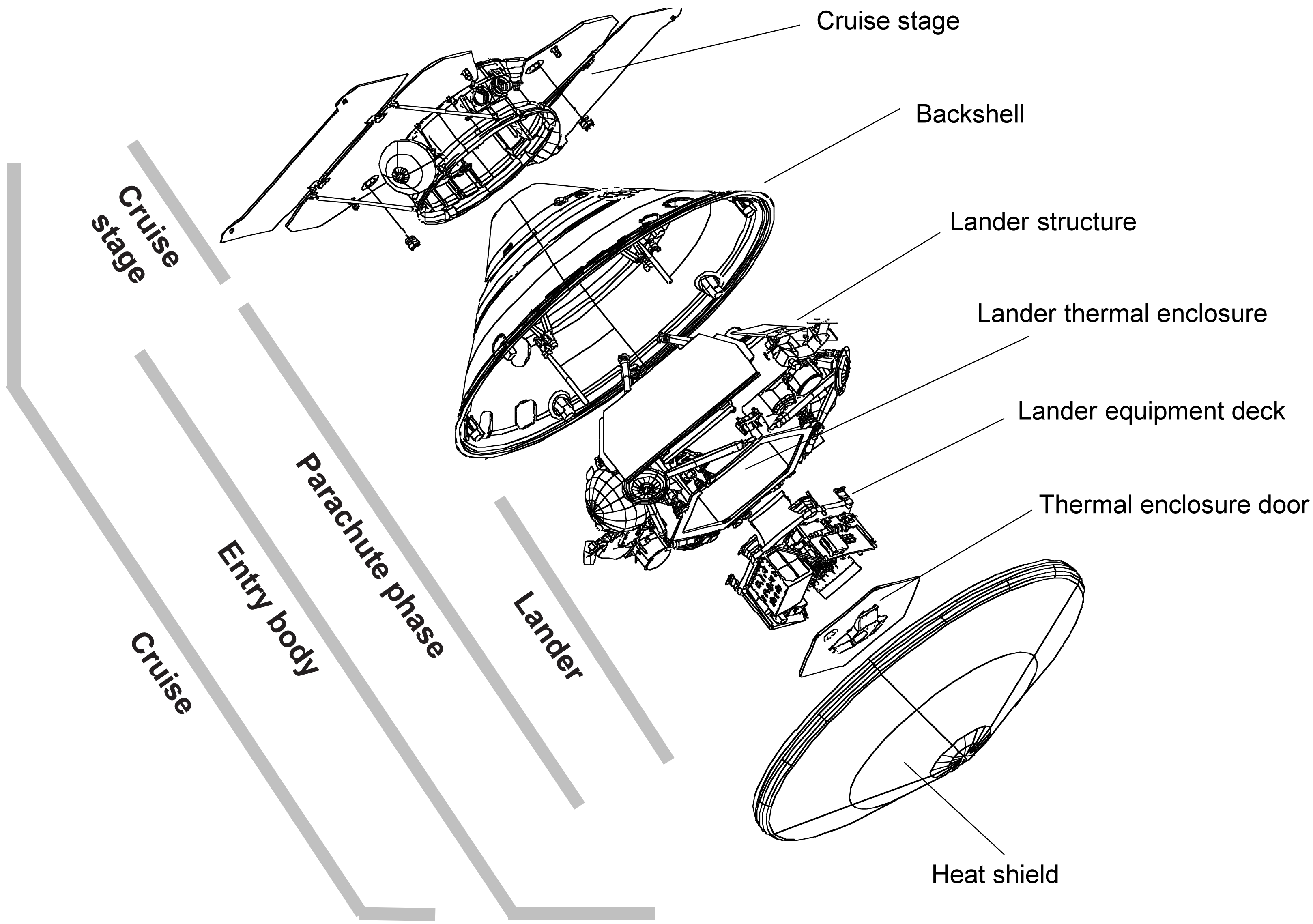
First signal. The first opportunity to hear from the lander will take place when it begins transmitting directly to Earth using its dish-shaped medium-gain antenna about 23 minutes after landing; this signal is expected to be received at 12:39 p.m. PST. This transmission session will end 45 minutes later, or 1:24 p.m. PST, and would include engineering data on the lander's entry, descent and landing, as well as a possible low-resolution black-and-white picture from the undeployed camera on the lander's deck. At 1:46 p.m. PST, the lander shuts down and "sleeps" for four hours and 40 minutes while its solar panels recharge its onboard battery. No wakeups occur during this time.

Assuming that all is normal with the spacecraft, it will power up again at 6:26 p.m. PST and turn on its receiver. At this time, mission controllers expect that they would send the lander commands such as what data rate to use for later radio transmissions. The receiver will continue listening for commands from Earth until 7:41 p.m. PST.

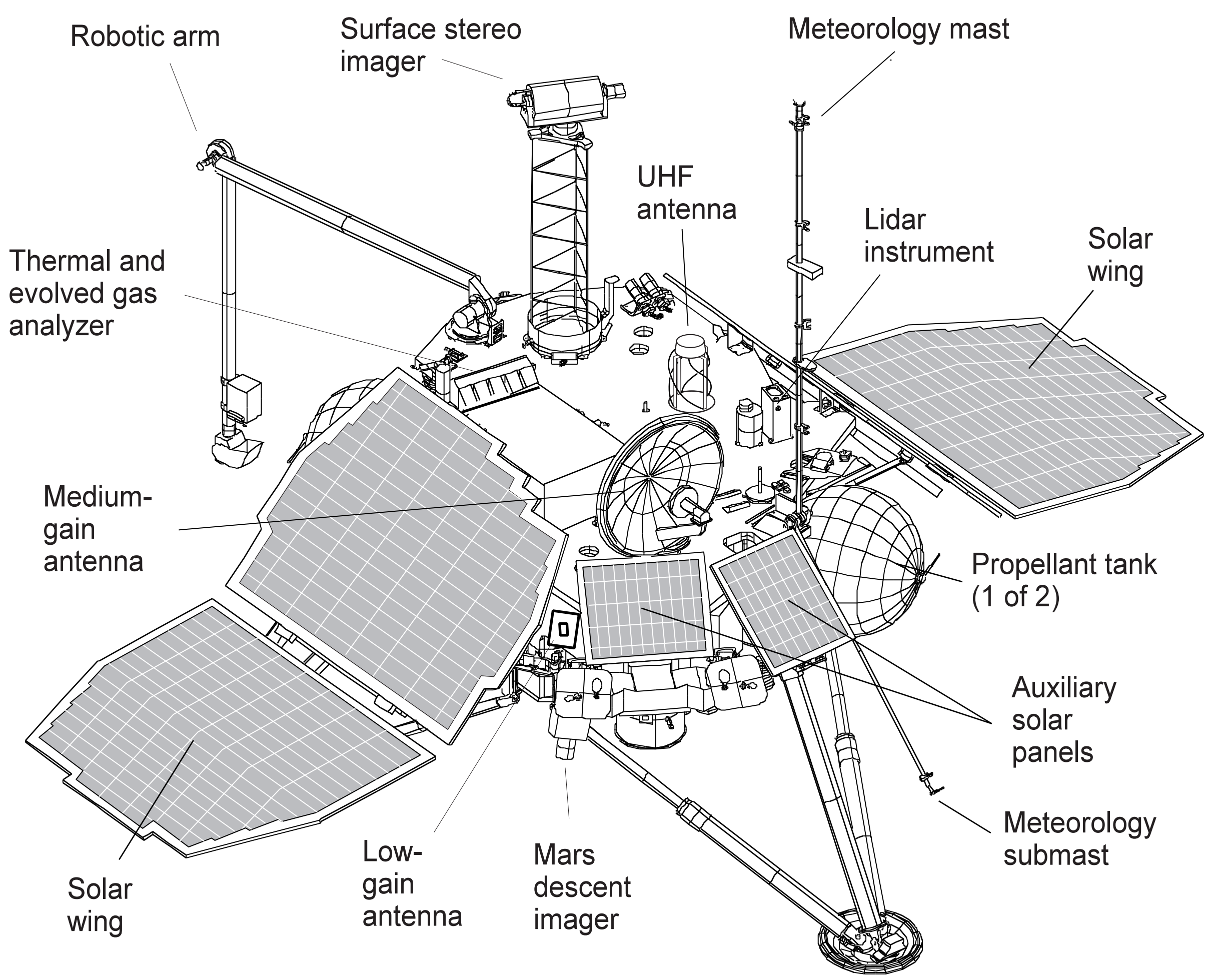
At 8:09 p.m., the lander will begin transmitting to Earth until 10:45 p.m. After that session concludes, the lander will run through a sequence that takes about half an hour as it prepares to shut down for the night. At 11:24 p.m. PST the lander will power down.



Entry, descent and landing



Lander flight system



Mars Polar Lander spacecraft

Nighttime activities. The lander's onboard computer and meteorological package will be activated several times during the Martian night. Because of the extreme latitude during the Martian southern summer, the Sun actually will not set at any time during the lander's prime mission. The normal schedule calls for the meteorological package to be powered on for a few minutes for temperature and pressure observations, at about 9 p.m., 1 a.m. and 5 a.m. local Mars time. Each time the experiment is turned on, data will be sent via the UHF antenna to the orbiter for relay to Earth. The lidar instrument may also be activated during the night.

During the first Martian night following landing, these wakeups will take place Saturday, December 4, at 12:16-12:41 a.m., 4:22-4:48 a.m., 8:29-8:55 a.m. and 12:36-1:01 p.m.

Sol 1. For mission planning purposes, engineers refer to Martian days, or "sols," each of which is 24 hours, 37 minutes in length. Landing day is referred to as "sol 0," while the next Martian day, which corresponds to evening California time on Saturday, December 4, is called "sol 1."

The schedule of activities from this point forward depends greatly on the condition of the spacecraft. If everything is operating very well, mission controllers will carry out a nominal mission calling for lander wakup at 7:06 p.m. PST Saturday, December 4. The lander would transmit to Earth for nearly five hours from 7:32 p.m. to 12:19 a.m. PST. If all is going well, the lander could send any remaining data on entry, descent and landing from the descent imager and other science instruments. If the mission team has to deal with any spacecraft anomalies, however, some of these activities may be delayed.

Initial science operations that would be conducted during the first day or two of the landed mission would normally include the first motion test of the robotic arm, a health check of the thermal and evolved gases analyzer, observations by the lidar instrument, and additional pictures by the surface stereo imager and the camera on the robotic arm. Periodic meteorological temperature and pressure observations will continue to be taken, and an additional set of water vapor and carbon dioxide readings will be gathered from laser sensors on the meteorological mast.

Within the first few days of the mission, the team hopes to assemble an initial 360-degree color panorama of the landing site from the camera on the lander's deck. In addition, picture frames from the descent imager would be released and later assembled into a "movie."

Payload activities. When the flight team concludes that the lander is ready to begin science operations, the spacecraft's robotic arm will be turned on and instructed to acquire a sample of soil on the surface. If the mission is going extremely well, this sample would be delivered the the lander's small test ovens no earlier than sol 4 and 5 (late evening on Tuesday and Wednesday, December 7-8); this could be scheduled later for a variety of reasons based on the spacecraft's state. While the arm is working, the thermal and evolved gas analyzer will be powered on for warm-up and calibration. The soil sample will be imaged by the camera mounted on the robotic arm and delivered to one of the analyzer's "ovens." This experiment will use an LED indicator to confirm automatically that a soil sample has been delivered.

After the science team receives verification that the sample has been delivered, a low-temperature cook sequence which heats the sample to 80 F (27 C) will begin on the next Martian day after the sample is delivered. If the sample has not been successfully delivered, another attempt will be made. The robotic arm will return to the trench to measure soil temperature by inserting a probe into the ground. At the conclusion of the soil cook sequence, the thermal and evolved gas analyzer will be powered off for the night and the soil sample will remain in the oven to cool overnight. On the next day the experiment will run a high-temperature cook sequence, heating the soil sample to 1,880 F (1,027 C).

The meteorological package will take weather measurements throughout each day. Lidar observations are also planned. Throughout the 90-day primary mission, science experiments will collect data on atmospheric conditions and weather patterns, observe changes in the landscape and search for evidence of subsurface or surface water.

Telecommunications modes. Originally most data from Polar Lander was to be sent first to Mars Climate Orbiter for relay to Earth, but that spacecraft was lost upon arrival at Mars on September 23, 1999. Fortunately, the lander has two other modes for communication with Earth. The lander is able to communicate directly with Earth – either sending data or receiving commands – using its X-band radio and medium-gain antenna. The lander can also send data (but not receive commands) via the currently orbiting Mars Global Surveyor. The lander can communicate directly with Earth via X-band at up to 12,600 bits per second over the Deep Space Network's 230-foot (70-meter) antennas, or at 2,100 bits per second over 112-foot (34-meter) antennas. Using Mars Global Surveyor as a relay, the lander can send data at 128,000 bits per second.

For the first few days of the mission, the lander will exclusively use its X-band radio to transmit directly to Earth. If the mission is proceeding normally, the relay through Global Suveyor would first be tested on about sol 4 (the evening of Tuesday, December 7). If both the direct-to-Earth and Global Surveyor relay paths are working well, the mission team expects to use both of them for different types of data. Information that the mission team wants to receive quickly on critical operations such as robot arm digs would be sent directly to Earth, whereas data that is gathered over a longer period of time for products such as photo panoramas might be sent via Global Surveyor.

Spacecraft engineering data will be delivered to the spacecraft team at Lockheed Martin Astronautics in Denver, CO, and at JPL in Pasadena, CA. Science data will be delivered to the experiment principal investigators at their home institutions. Experimenters will be able to obtain data on a daily basis and send commands for the next day's activities.

Extended mission. If the lander science payload continues to operate well, the primary mission of three months may be extended. Lander activities in an extended mission would include continued use of the robotic arm's camera and surface stereo imager; ongoing temperature, pressure, dust and atmospheric opacity measurements; and continued monitoring of spacecraft performance in the harsh environment of Mars' southern polar region, as summer wanes and seasonal frosts begin to return.

Contingencies. If the spacecraft is not behaving normally immediately upon landing, there are several contingency scenarios from which the mission team could recover and still carry out a full mission.

If no signal is received within the first few minutes when Polar Lander is scheduled to transmit after touchdown at 12:39 p.m. PST Friday, December 3, the team will first check the ground system to make sure that the problem is not on Earth. They would then listen again during a one-hour period beginning at approximately 2:20 p.m. the same day. Polar Lander would transmit at this time if it entered a "safe mode" immediately upon touchdown. Like all other planetary spacecraft, the lander has onboard fault-protection software that puts it into a standby state, or "safe mode," in response to certain types of abnormal events. In safe mode, the lander is placed into a protective state and awaits commands from Earth.

If no signal is received during this time period, the next time that mission controllers will attempt to listen for a signal is a 2-1/2-hour period beginning at approximately 8:09 p.m. Friday, December 3. Mission controllers will have sent commands to the lander instructing it to transmit at this time while it moves its dish antenna sequentially in order to find Earth.

If the lander is still silent, mission controllers will attempt to listen for a signal is a one-hour period beginning at approximately 9 p.m. Saturday, December 4. Polar Lander would transmit at this time if it entered a safe mode after touchdown but before its first scheduled transmission session.

The next time that mission controllers will attempt to listen for a signal is at approximately 10 p.m. Sunday, December 5. At this time, Polar Lander would automatically switch to its UHF transmitter and attempt to send data via Mars Global Surveyor if it has not been instructed otherwise in commands from Earth.

If the lander receives no commands from Earth for six days, its "command loss timer" would time out and it would automatically begin switching out hardware subsystems and attempting to radio Earth. Mission managers believe it is more likely, however, that they would be actively sending commands to the spacecraft to execute such hardware swaps if contact is not established within the first day or two after landing.

Spacecraft

The lander stands 3-1/2 feet (1.06 meters) tall from the ground to the top of the science deck and measures 12 feet (3.6 meters) wide. The dry spacecraft weighs 1,129 pounds (512 kilograms); loaded with propellant, the weight is 1,270 pounds (576 kilograms). The spacecraft is constructed of a composite material with a honeycomb aluminum core and graphite-epoxy facesheets bonded to each side of the bus.

The landing legs are made of aluminum and are equipped with compression springs to deploy the legs from the stowed position. Tapered, crushable aluminum honeycomb inserts in each leg provide the shock absorption necessary for landing. The lander's central enclosure houses the onboard computer, power distribution, the 12-cell nickel-hydrogen battery, a unit that controls battery charging, and radio equipment.

A separate component deck outside of the central electronics enclosure contains gyroscopes, electronics to fire pyrotechnic devices used to deploy instruments, and radar equipment that will be used only during entry, descent and landing at Mars arrival.

The lander's solar arrays are inverted and shaped like gull wings, extending about 12 feet (3.6 meters) when fully deployed. They are expected to provide up to 200 watts of electrical power on the Martian surface.

Most systems on the lander are redundant; it contains two computers, two radios, and so on, so that if one fails the other can take over. The main equipment that is not redundant are the landing radar, battery and science instruments.

Cruise stage. During the flight from Earth to Mars, the lander has been attached to a circular cruise stage and propulsive lander/entry assembly. After the 11-month flight to Mars, the cruise stage will be jettisoned just before atmospheric entry, providing a clean aerodynamic shape for the spacecraft's plunge toward the surface.

Onboard the cruise stage are two solar arrays used to generate power during cruise. Telecommunications during cruise will be routed through an X-band medium-gain horn antenna and a low-gain antenna. The cruise stage also contains a radio frequency power amplifier.

Entry, descent and landing system. When it dives into the atmosphere, the lander is encased in an aeroshell featuring a 7.9-foot-diameter (2.4-meter) heat shield. The heat shield shares the same nose radius and cone angle of the shield on Mars Pathfinder, but the Mars Polar Lander heat shield is smaller in diameter.

The 27-foot-diameter (8.4-meter) parachute made of polyester fabric will be deployed by a mortar, or small cannon, to ensure that it separates properly and inflates instantaneously.

Propulsion. The lander is equipped with four clusters of thrusters, each of which contains one large thruster producing 5 pounds (22 newtons) of force and one small thruster providing 1 pound (4.4 newtons) of force. The lander's final descent will be controlled by 12 descent engines, or retro-rockets, each delivering 60 pounds (266 newtons) of force, arranged in three groups on the underside of the lander; they will be pulsed on and off as the lander descends. Two spherical propellant tanks underneath the lander's solar arrays carry 141 pounds (64 kilograms) of hydrazine for all of the spacecraft's engines and thrusters.

Power. The lander obtains its power from a total of six solar panels. The four larger panels are arranged as a pair of wings on either side of the lander, and are deployed after landing. Two smaller panels fixed to the side of the lander were added to increase the total power output after the main solar panels were made as large as possible while still fitting in the launch vehicle's fairing or nose cone. During the southern Martian summer at the time of arrival, the sun never sets below the horizon at the landing site. A rechargeable 16-amp-hour nickel-hydrogen battery will keep the central electronics enclosure relatively warm (above -22 F (-30 C)) during -110 F (-80 C) night-time temperatures near the Martian pole. The lifetime of the battery will probably be the main factor determining how long the lander operates. As nights grow colder in late Martian summer, the battery will eventually be unable to provide enough power to keep the spacecraft enclosure warm at night. The lander would then freeze, ending the mission.

Telecommunications. The lander contains two radio systems, one in the UHF (ultra-high-frequency) band close to the upper channels on a conventional television set, and the other in the microwave X-band. Each system includes both a transmitter and receiver as a combined unit called a transponder. The UHF system, which is used only to communicate with Mars Global Surveyor when that orbiter is acting as a relay between the lander and Earth, has a single dedicated antenna.

The X-band system communicates directly with Earth through one of two antennas mounted on the lander deck – a dish-shaped medium-gain antenna that must be pointed at Earth, or a non-directional low-gain antenna. During interplanetary cruise, the X-band system communicates with Earth using a horn-shaped medium-gain antenna and radio frequency power amplifier mounted on the cruise stage.

Science Objectives

Mars Polar Lander will touch down in a unique region of Mars near the border of the southern polar cap at a latitude of about 76 degrees south. The lander is the only spacecraft planned by any space agency to study an area of Mars this far south or north.

Polar Lander is designed to study the volatiles (materials that change form readily, such as water) and climate history of Mars. To that end, its scientific goals are to:

- ❑ Land on the layered terrain in Mars' south polar region.

- ❑ Search for evidence related to ancient climates and more recent periodic climate change.

- ❑ Give a picture of the current climate and seasonal change at high latitudes and, in particular, the exchange of water vapor between the atmosphere and ground.

- ❑ Search for near-surface ground ice in the polar regions, and analyze the soil for physically and chemically bound carbon dioxide and water.

- ❑ Study surface morphology (forms and structures), geology, topography and weather of the landing site.

Mars has polar caps at both its north and south poles. Both caps include a permanent or residual cap visible year-round, and a temporary or seasonal cap that appears in winter and disappears in summer. In the north, the permanent cap is water ice, while in the south the permanent cap is mostly carbon dioxide ice with perhaps some water. The north's permanent cap is 10 times larger than the south's; it remains a mystery as yet why the caps differ so. The south's seasonal cap is larger than the north's, which is caused by the fact that the southern winter takes place when Mars is farthest in its orbit from the Sun.

Both poles show signs of an unusual layered terrain, whose alternating bands of color may contain different mixtures of dust and ice. Like growth rings of trees, these layered geological bands may help unravel the mystery of past climate change on Mars. They may also help determine whether geologically recent climate change may be driven by changes in the tilt of the planet's rotation axis, or by changes in the shape of Mars' orbit around the Sun. This may lend insight on how the planet evolved from a wetter ancient climate -- whether this was driven by a catastrophic change, or merely a gradual evolution in the planet's environment. One of the lander's primary science objectives is to conduct a visual survey of this largely unknown dome of ice and dust, and provide a technical protrait of the mineralogical makeup of the layered terrain.

Landing site. In planning the lander mission, scientists desired to place the spacecraft onto the layered terrain near the south pole but land on bare soil, not the seasonal carbon dioxide frost. The longitude chosen is the area where the south pole's layered terrain extends the farthest north. At this longitude, seasonal frost also dissipates earliest in the southern spring.

Polar Lander was launched toward the center of a swath of terrain measuring about 4,000 square kilometers (1,500 square miles) centered at 75 degrees south latitude, 210 degrees west longitude. Scientists expected to make the final landing site selection once Mars Global Surveyor could return important data on the appearance and the altitude of the south polar layered terrain. Because of its prolonged aerobraking phase, Global Surveyor was unable to start its systematic mapping of Mars until March 1999, some two months after the launch of Polar Lander. Except for a handful of images taken in January 1998, the next opportunity for Global Surveyor to observe the landing target sector in sunlight was in June 1999, when the south polar region again emerged into sunlight.

Based on data from Global Surveyor's altimeter and camera, scientists selected a primary and secondary landing site for Polar Lander. A thruster firing in September 1999 targeted the lander to 76 degrees south latitude, 195 degrees west longitude. Imaging has continued as the seasonal frosts have retreated across the landing site, revealing a strangely textured terrain with relatively low relief, but with complicated patterns of bright and dark ground. With a thruster firing carried out on October 30, 1999, Polar Lander remains targeted to the primary site.

Science payload. Mars Polar Lander carries three science investigations: the Mars Volatiles and Climate Surveyor (MVACS); the Mars Descent Imager; and a Light Detection and Ranging (Lidar) instrument.

MVACS. The Mars Volatiles and Climate Surveyor is an integrated instrument package designed to carry out a variety of studies of the surface environment, weather and geology of the south pole region. Dr. David Paige of UCLA is the principal investigator. MVACS includes the following four component systems:

❑ **Surface stereo imager**. The imager, mounted on top of a 5-foot (1.5-meter) mast that will pop up from the lander's deck, is identical to the imager on the Mars Pathfinder lander. It will capture panoramas of the landing site, and provide imaging support for other payload elements such as the robotic arm and the thermal and evolved gas analyzer. The imager will also take pictures of magnets attached to the lander's deck to identify any magnetic material that collects there. It can perform imaging of the Sun to study aerosols or water vapor in the atmosphere. The imager has a spectral range from violet to near-infrared (400- to 1,100-nanometer wavelength). Two sets of lenses are mounted slightly more widely apart than a normal pair of human eyes in order to capture stereo images; the two sets of optics share a single charge-coupled device (CCD) detector. Two filter wheels allow the imager to take pictures in various spectral ranges. Drs. Peter Smith of the University of Arizona, Tucson, and H. Uwe Keller of the Max Planck Institut fuer Aeronomie, Germany, are co-investigators for the imager. The magnetic properties experiments are supplied by the University of Copenhagen, Denmark.

❑ **Robotic arm**. This jointed 6-1/2-foot (2-meter) arm attached to the lander's deck has an articulated member on its end with a digging scoop, camera and temperature probe. The scoop will dig trenches and deliver soil samples to the thermal and evolved gas analyzer on the lander's deck. Pictures taken by the camera will show fine-scale layering of surface and subsurface materials, if any, as well as fine-scale texture of soil samples and sides of the trenches dug by the scoop. The temperature probe will measure the ambient temperature and thermal conductivity of the soil.

❑ **Meteorology package**. The lander's weather station includes a 4-foot (1.2-meter) mast with a wind speed and direction sensor, temperature sensors and tunable diode lasers that detect water vapor and isotopes of water and carbon dioxide. A 3-foot (0.9-meter) submast with a wind speed sensor and two temperature sensors points downward from the lander's deck. The submast is designed to study atmospheric effects in the zone just 4 to 6 inches (10 to 15 centimeters) above the surface to determine the threshold wind speed required for dust storms to start. Drs. David Crisp and Randy May of JPL and Ari-Matti Harri of the Finnish Meteorological Institute are co-investigators for the weather package.

❑ **Thermal and evolved gas analyzer**. This instrument heats soil samples and analyzes them to determine concentrations of volatiles such as water or carbon dioxide, whether present as ice or in volatile-bearing minerals. The robotic arm deposits soil samples in a receptacle, which is then mated with a cover to form a small oven; heater wires like the coils in a toaster heat the sample gradually across a range of temperatures up to 1,880 F (1,027 C). The heater is able to achieve this heat with the limited power of the solar-powered spacecraft because the sample chamber holds only 1/300th of an ounce (0.1 gram) of material. As it is heated, gases are released (or "evolved") from the sample. A tunable diode laser, meanwhile, emits beams of light which passes through the gases to a detector. Any carbon dioxide or water vapor in the gas absorbs some of the laser light, which is measured by the detector. Once used, the ovens cannot be used again; the instrument can perform a total of eight soil analyses during the lander mission. Dr. William Boynton of the University of Arizona, Tucson, is co-investigator for the instrument.

Mars Descent Imager. This imager will take approximately 30 pictures as the lander descends toward Mars' surface, beginning just before heat-shield ejection at an altitude of about 5 miles (8 kilometers) and continuing until landing. The first pictures will show areas of Mars 5.6 miles (9 kilometers) square with a resolution of 25 feet (7.5 meters) per pixel, while the final pictures will show an area 30 feet (9 meters) square with a resolution of 1/3 inch (9 mm) per pixel. The imager has a single camera head with an electronically shuttered charge-coupled device (CCD) which will capture black-and-white images 1,000 by 1,000 pixels. Dr. Michael Malin of Malin Space Science Systems Inc., San Diego, CA, is principal investigator.

Lidar. This instrument is a distant cousin to radar, emitting pulses of energy and then detecting their echo as they bounce off material in the atmosphere. But instead of the radio pulses used in radar, the lidar instrument sends out pulses of light from a laser. The transmitter uses a gallium aluminum arsenide laser diode to emit 2,500 pulses of near-infrared light each second upward from the lander's deck. A detector then times how long it takes the pulses to return, allowing scientists to locate and characterize ice and dust hazes in the lower part of Mars' atmosphere (below about 1 to 2 miles (2 to 3 kilometers)). The instrument is fixed, pointing straight up from the lander. The lidar instrument is provided by the Russian Academy of Science's Space Research Institute (IKI) under the sponsorship of the Russian Space Agency. The principal investigator is Dr. V. S. Linkin of IKI. The lidar investigation is the first Russian experiment to be flown on a U.S. planetary spacecraft.

A unique feature of Mars Polar Lander is that it will be the first planetary spacecraft to carry a microphone to capture the sounds of another world. Despite Mars' extremely thin atmosphere, the microphone may pick up sounds of winds and mechanical events on the lander.

Contained within the electronics box for the lidar experiment, the microphone is enclosed in a package 2 by 2 by 1/2 inches (5 by 5 by 1 centimeters), weighs less than 1.8 ounces (50 grams) and uses less than 100 milliwatts of power. Designed to accommodate the limited rate at which lander data are returned to Earth, the microphone records and returns the loudest 10-second signal heard during a listening period. Later in the mission, longer sound records may be returned. The package takes advantage of many off-the-shelf technologies, such as a sound processor chip used in talking toys and educational computers that listen and respond to spoken words. The microphone itself is a type used in hearing aids.

A project of the Planetary Society, Pasadena, CA, the microphone was approved by NASA to be flown as part of the Russian lidar experiment payload. Planetary Society Executive Director Dr. Louis Friedman is responsible for the microphone, which was designed, constructed and tested at UC Berkeley's Space Sciences Laboratory under the direction of Dr. Janet Luhmann.

Planetary Protection

The U.S. is a signatory to the United Nations' 1966 Treaty of Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies. Known as the "Outer Space Treaty," this document states in part that exploration of the Moon and other celestial bodies shall be conducted "so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter."

NASA policy establishes basic procedures to prevent contamination of planetary bodies. Different requirements apply to different missions, depending on which solar system object is targeted and the spacecraft or mission type (flyby, orbiter, lander, sample-return and so on). For some bodies such as the Sun, Moon and Mercury, there are no outbound contamination requirements. Current requirements for the outbound phase of missions to Mars, however, are particularly rigorous. Planning for planetary protection begins during pre-mission feasibility planning.

Planetary protection requirements called for the surfaces of the Mars Polar Lander spacecraft to contain a maximum of about 250 spores per square yard (300 spores per square meter) and 300,000 spores total. To meet this goal, the spacecraft was cleaned to the same level as the Viking landers before they were sterilized.

Technicians at Lockheed Martin Astronautics in Denver continually cleaned the spacecraft throughout development by rubbing down surfaces with ethyl alcohol. Large surface areas, such as the thermal blankets and parachute, had to be baked for about 50 hours at 230 F (110 C). The number of spores is determined by sampling the surfaces and conducting a special microbiological assay. In general, the procedure was the same as the sterilization methods used on the Mars Pathfinder lander. The spacecraft was checked constantly during processing at Lockheed Martin Astronautics and was given a final inspection just before it was encapsulated in its aeroshell. Results of that effort produced a spacecraft with an average spore burden density of no more than 250 spores per square yard (300 spores per square meter).

A final inspection and spore count was performed at NASA's Kennedy Space Center, FL, before the spacecraft is integrated with the Delta II launch vehicle. That test assured that the lander contained fewer than 300,000 spores total.

Deep Space 2

The Deep Space 2 project is sending two identical microprobes along on the Mars Polar Lander spacecraft. Released shortly before the lander enters the planet's atmosphere, the probes will dive toward the surface and bury themselves up to about three feet (1 meter) underground.

As a project under NASA's New Millennium Program, the main purpose of Deep Space 2 is to flight-test new technologies to enable future science missions – demonstrating innovative approaches to entering a planet's atmosphere, surviving a crash-impact and penetrating below a planet's surface. As a secondary goal, the probes will search for water ice under Mars' surface.

Mission Overview

At the time of launch, the two Deep Space 2 probes were attached to the cruise stage on the Mars Polar Lander spacecraft. To simplify hardware and operations, there are no electrical interfaces between the probes and the lander's cruise stage. The probes are powered off during cruise, so there is no communication with them from installation on the launch pad until after impact on the Martian surface.

Five minutes before the lander enters Mars' upper atmosphere on December 3, 1999, the lander will jettison the cruise stage. The force of separation will initiate mechanical pyro devices, which in turn will separate the microprobes from the cruise stage about 18 seconds later. Each Deep Space 2 entry system consists of a basketball-size aeroshell containing a probe somewhat larger than a softball.

Upon release from the lander's cruise stage, the probes switch on power from their lithium batteries, and an onboard computer microcontroller powers up. The microcontroller performs a series of measurements of onboard subsystems to verify their health after the 11-month cruise to Mars.

About four minutes after power-up, the probes will enter Mars' atmosphere. A descent accelerometer is turned on and samples "G" forces 20 times a second until impact. Four minutes after entering the atmosphere, an impact accelerometer begins sampling "G" forces 25,000 times a second. When impact is detected, data from the event is stored in computer memory, and the impact accelerometer is turned off.

The two probe systems will hit the Martian surface about the same time as Mars Polar Lander's landing some 35 miles (60 kilometers) away. Upon impact, the acorn-shaped aeroshell will shatter, and the probe inside will separate into two parts. The bullet-shaped forebody will penetrate as far as 3 feet (1 meter) below the surface, depending on the hardness of the soil. The aftbody will remain on the surface to relay data back to Earth via the Mars Global Surveyor spacecraft, which has been orbiting Mars since September 1997. The forebody and aftbody communicate with each other via a flexible cable.

Unlike any spacecraft before, the Deep Space 2 probes smash into the planet at speeds of up to 400 miles per hour (200 meters per second). The probe's electrical and mechanical systems must withstand this crushing impact. This is achieved with a combination of advanced materials, mechanical designs and microelectronic packaging techniques developed based on extensive testing. After impact, the systems must withstand extreme temperatures. The fore-body buried in the Martian soil must withstand temperatures as low as -184 F (-120 C), while the aftbody that remains on the surface is exposed to an environment as low as -112 F (-80 C).

Landed mission. Following impact, the probes collect data to flight-validate their microelectronic and micromechanical technologies. Minimum data to validate most of these technologies will be collected within the first 30 minutes after impact, while minimum data from the sample/water experiment will be collected within about 10 hours after impact. Data collection will continue until the probe batteries are depleted in about one to three days.

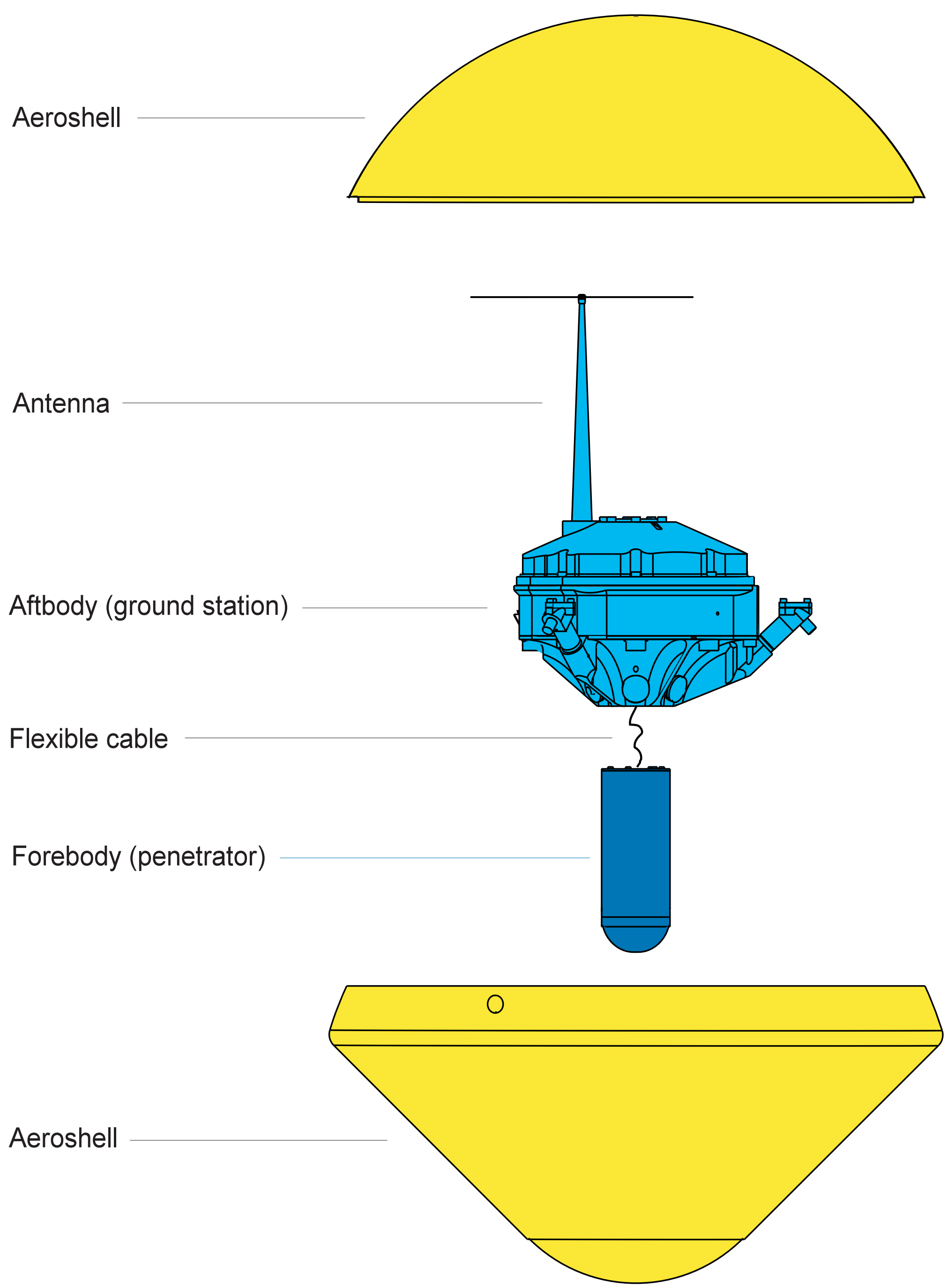
Each probe will transmit data to the orbiting Mars Global Surveyor using a radio in the UHF band (at frequencies near the upper channels of a conventional TV set) at a rate of 7,000 bits per second. The first such communications session is expected within eight hours after impact. Normally each probe will be in a low-power listening mode until it receives a signal from Mars Global Surveyor telling it to transmit data. The orbiter may either transmit the data to Earth immediately, or store the data temporarily and transmit them as soon as possible.

The first opportunity for a communication pass between Global Surveyor and the micro-probes will take place at about 7:27 p.m. PST Friday, December 3. During a pass about 15 minutes, 16 seconds long, Global Surveyor will switch back and forth between communicating with each of the microprobes for about two minutes apiece, relaying the data to Earth immediately. It is possible that contact may not be made on the first pass due to the orientation of the microprobes in the Martian soil. If this is the case, contact may be established during any of a series of communications passes carried out every two hours for the first day or two after arrival.

The microprobe data are buffered onboard Global Surveyor using the memory of its camera. The data therefore are first sent to Malin Space Science Systems in San Diego, CA, which is responsible for the Global Surveyor camera. The Malin team may be able to determine about an hour after the communication pass if any data from the microprobes are present. The data will then be forwarded to JPL, where scientists may get their first look at the contents perhaps another hour later.

Science mission. Deep Space 2 has a secondary goal of collecting science data. Accelerometer data from the descent and impact will provide an estimate of the density of the atmosphere and hardness of the soil. After impact, the probes will measure the thermal conductivity and potential water content of the subsurface soil adjacent to the bullet-like probe fore-body.

Following the first successful transmission to Global Surveyor, a micromotor will drive



Deep Space 2 flight system

a small drill bit out the side of the probe's forebody. Bits of soil engaged by the drill bit will fall into a small heater cup, which is sealed by firing a pyro which closes a door. The soil is then heated, driving any water vapor into the analysis chamber. If water is present, it will be detected by measuring the difference in light intensity of a laser shining through the vapor. The tunable diode laser is set so that its light is at the point in the spectrum where water absorbs light.

Soil conductivity is determined by measuring the rate at which the forebody cools after plunging into the ground. Temperature readings are taken throughout the landed mission by two sensors mounted at opposite ends of the probe's forebody.

End of prime mission. The prime mission ends when the probes transmit to Mars Global Surveyor one set of data evaluating the project's engineering technologies. This transmission is expected within 10 hours after impact, but may take place up to 36 hours after impact. At the end of the prime mission, the probes will continue to collect and transmit data on soil thermal conductivity as the probes gradually cool, as well as soil temperature variations, until their batteries are depleted.

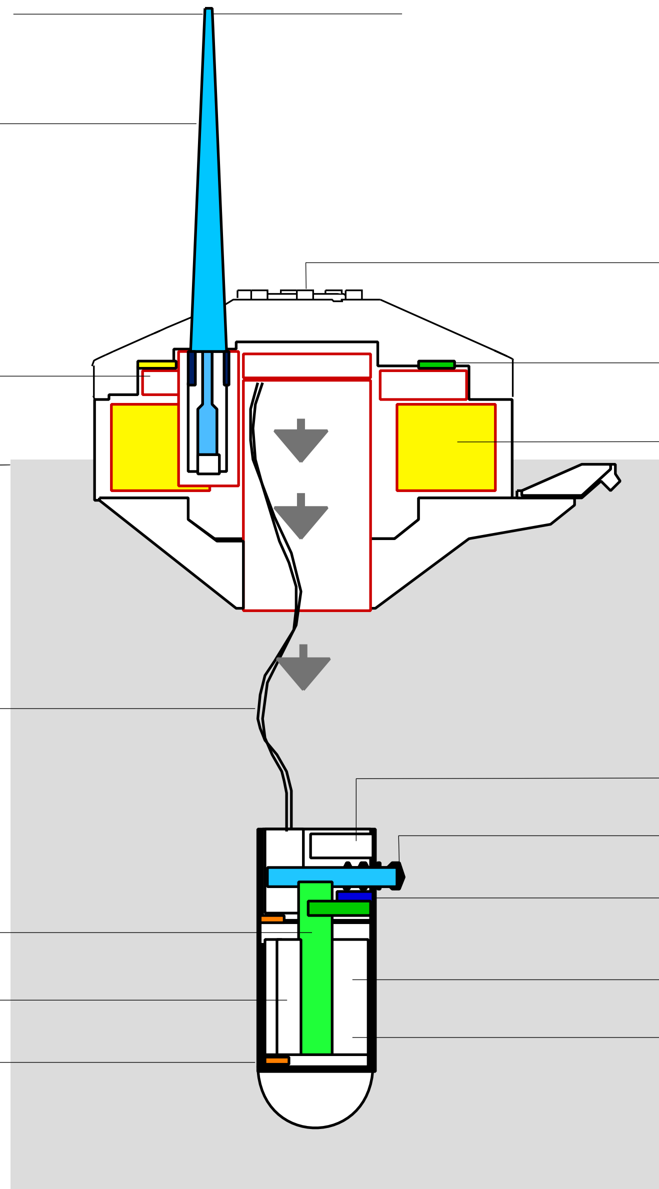
Technologies

Deep Space 2 is the second mission of NASA's New Millennium Program, whose goal is to greatly increase the efficiency and lower costs of space science missions through new technologies. Each New Millennium mission is designed to test specific technologies never before used in space missions.

Deep Space 2 will test technologies that could pave the way for future missions featuring multiple landers released from a single spacecraft, possibly distributed around an entire planet or other body. Such networks of probes offer a unique window on global processes such as weather or seismic activity of a planet.

To meet this goal, the mission was challenged to develop an entry and landing system that is very small, lightweight and capable of conducting experiments on both the surface and subsurface of a planet or similar body while surviving environmental extremes. Deep Space 2 will validate the following new technologies:

Entry system. Unlike other probes, the Deep Space 2 aeroshell is not required to be pointed or spin-stabilized when it enters Mars' atmosphere. Its design uses the same principle as a shuttlecock, or birdie, in badminton; most of the weight is placed well ahead of the aeroshell's center of pressure to insure that the heat shield passively aligns itself even if it is tumbling when it enters Mars' atmosphere. In addition, the entry system is "single-stage" from atmospheric entry until impact – there are no parachutes, retro rockets or airbags to slow the probes down. In fact, the aeroshell is not even jettisoned by the probe, but accompanies it to the surface of the planet where it shatters on impact. This very simple system greatly reduces the number of tests required to demonstrate that the design works, and thus greatly reduces the costs to the mission. The entry system was designed at JPL. Aerodynamic analysis was per-



Deep Space 2 probe

formed at NASA's Langley Research Center, Hampton, VA.

The aeroshell's heat shield is made of an advanced thermal protection system known as SIRCA-SPLIT (silicon-impregnated, reusable ceramic ablator - secondary polymer layer-impregnated technique). This material is capable of maintaining the probe's internal temperature to within a few degrees of -40 F (-40 C) while the heat shield surface experiences temperatures of up to 3,500 F (2,000 C). This material was developed and tested by NASA's Ames Research Center, Moffet Field, CA. The silicon carbide aeroshell structure was developed by Poco Specialty Materials, Decatur, TX.

Testing of the entry system design went through many phases. Early tests included dropping test articles made of clay pots, Styrofoam or Pyrex from airplanes two miles (3 kilometers) high. Silicon carbide, the same material used in sandpaper, was selected as the material for the aeroshells, each of which weighs less than 2.6 pounds (1.2 kilogram). Final tests of a prototype aeroshell with a probe model were conducted using an airgun at Eglin Air Force Base, Fort Walton Beach, FL, where the probe system was shot into the ground at speeds up to 400 miles per hour (200 meters per second).

Penetrator system. Deep Space 2 is the first penetrator sent by NASA to another planet. Development of the penetrator system required an aggressive test program with a continuous design/develop/test/fix approach. The probe's bullet-like forebody is designed with a half-circle nose to ensure penetration over a wide range of entry conditions. The aftbody features a wide frontal area to limit penetration and a "lawn dart" face which helps the aftbody anchor to Mars' surface. Tests were performed using an airgun in Socorro, New Mexico, in partnership with Sandia National Laboratories and the New Mexico Institute of Mining and Technology's Energetic Materials Research and Test Center.

High-G packaging techniques. Crashing into a planet at 400 miles per hour (200 meters per second) presents a unique challenge in the design of electrical and mechanical systems. Decelerations could reach levels up to 30,000 G's in the forebody and 60,000 G's in the aftbody (one "G" is equivalent to the force of gravity on Earth's surface). This is the same as requiring a desktop computer to operate after being hit by a truck at 400 miles per hour. In comparison, Mars Pathfinder experienced forces of about 17 G's during its landing.

There are two standard approaches for insuring high-G survival. One is to cushion the object, and the other is to provide a very rigid structure that allows the shock wave to pass through the object without deflecting it enough to break any of its components. For Deep Space 2, cushioning is impractical because of the extreme decelerations and the small size of the probes; engineers thus chose a rigid structure approach.

The mechanical design features a "prism" electronics assembly, a science "block" and selective use of materials to maximize structural rigidity. The electrical design features chip-on-board and three-dimensional high-density-interconnect packaging, encapsulated wire bonds and extensive use of flexible interconnects instead of wires. Assemblies are also typically bonded together to minimize potential loose parts and to distribute loads evenly.

Micro-telecommunications system. Each probe features a miniaturized radio transmitter and receiver system weighing less than 1-3/4 ounces (50 grams), 9.9 square inches (64 square centimeters) in size, and consuming less than 500 milliwatts in receive mode and 2 watts in transmit mode. The system was developed at JPL.

Ultra-low-temperature lithium battery. The probe's batteries must be able to provide 600 milliamp-hours of power at temperatures as low as -112 F (-80 C). To meet those extreme needs, the Deep Space 2 project developed a new non-rechargeable lithium-thionyl chloride battery. The cells use a lithium tetrachlorogallate salt instead of the more conventional lithium aluminum chloride salt to improve low-temperature performance and reduce voltage delays.

Each probe uses two batteries composed of four “D-sized” cells weighing less than 1.4 ounce (40 grams) each. The batteries operate within a range of 6 to 14 volts and have a shelf life of three years. The batteries were developed by Yardney Technical Products, Pawcatuck, CT.

Power microelectronics. Power conditioning, regulation and switching for electronics in the bullet-shaped forebody are controlled by a power microelectronics unit making use of application-specific integrated circuits (ASICs) in which both digital and analog components are incorporated onto a single chip. The unit weighs less than 1/5th of an ounce (5 grams), has a volume of one-third cubic inch (5.6 cubic centimeters) and requires 5/100ths of 1 milliwatt to operate. The unit was developed by Boeing Missiles & Space, Kent, WA.

Advanced microcontroller. The spartan computer system on the probes centers around an 80C51 microprocessor, a low-power chip used in products ranging from microwave ovens and videocassette recorders to cars and computer peripherals. The 8-bit system includes 128K of random access memory (RAM), 128K of permanent memory, and 32 digital-to-analog and analog-to-digital converters. The system is designed to use very low power (less than 6 milliwatts running at 10 megahertz, one-half milliwatt in sleep mode) with small volume (0.13 cubic inch (2.2 cubic centimeters)) and mass (1/10th of an ounce (3.2 grams)). Electronic circuits are embedded in plastic to ensure survival during the 30,000-G impact event. The microcontroller was developed by a consortium led by the U.S. Air Force’s Phillips Laboratory and including Mission Research Corp., the Boeing Co., NASA’s Langley Research Center, Technology Associates, General Electric and the University of Tennessee.

Flexible interconnects. Normal wire cabling could easily break under the extreme “G” forces that the probes will endure, so a different approach was required. The flexible interconnect are strips made of alternating layers of copper traces and polyimide. The latter, a type of thin polymer or plastic film, is also used in thermal blankets on spacecraft, while the copper traces are similar to the thin copper paths on a computer or radio circuit board. Flexible interconnects are much lighter, more compact and more flexible than standard wire cables. On the Deep Space 2 probes, they are used between all electronic subsystems, and for the umbilical which connects the forebody (penetrator) to the aftbody (ground station). During flight, the umbilical is folded in a canister like a fire hose; at impact, the umbilical unfolds as the penetrator pulls away. The flexible interconnect system was developed by JPL in partnership with Lockheed Martin Astronautics, Denver, CO. The units were fabricated at Electrofilm Manufacturing Co., Valencia, CA, and Pioneer Circuits Inc., Santa Ana, CA.

Sample collection/water detection experiment. Each probe will obtain a sample of subsurface soil using a small, ruggedized drill run by an electric motor. When the motor is powered on, a latch is released and the drill shaft extends sideways from the forebody (penetrator), pulling less than 1/250th of an ounce (100 milligrams) of soil into a small cup which is then sealed. The sample is then heated, turning any water ice in the soil into water vapor. A small tunable diode laser emits a beam of light through the vapor to a detector; if water vapor is present, it will absorb some of the light. The laser assembly is similar to tunable diode lasers flown on meteorology experiments on Mars Polar Lander, but is much smaller (about the size of a thumbnail) and thus has lower sensitivity. During operation, the water detection experiment requires a peak power of 1.5 watts. The sampling collection system is about 1 cubic inch (11 cubic centimeters) in size and weighs less than 1.6 ounce (50 grams). The instrument electronics is about one-third cubic inch (4.8 cubic centimeters) in size and weighs less than one-third ounce (10 grams). The tunable diode laser is about 1/50th of a cubic inch (0.3 cubic centimeter) in size and weighs less than 1/30th of an ounce (1 gram). The sample collection/water detection experiment was developed by JPL.

Soil thermal conductivity experiment. The probes will use temperature sensors to measure how fast the forebody or penetrator cools down after impact, revealing how quickly heat dissipates in the soil. This approach requires far less energy than similar previous experiments on planetary missions, which have used onboard heaters to test the soil. On the Deep Space 2 probes, two platinum-resistor temperature sensors are mounted in the forebody.

Design, development and testing. Because of the many challenges associated with developing NASA's first planetary penetrator system, Deep Space 2 embarked on a rigorous design and test program. This started in spring 1995 to evaluate early design concepts before the project was formally approved in the fall of that year. Early tests included releasing prototype probes from airplanes and helicopters.

As test articles became more sophisticated and expensive, the need for a more controlled test environment became necessary. To accomplish this, the project teamed with Sandia National Laboratories and the New Mexico Institute of Mining and Technology's Energetic Materials Research and Test Center in Socorro, New Mexico, to use a Sandia airgun. This massive airgun has a 18-foot-long (5.5-meter), 6-inch-diameter (15-centimeter) barrel and rests on an 18-wheeler truck. After mounting the test article in the barrel, pressurized air is used to hurl the probe into the desert floor at speeds of up to 400 miles per hour (200 meters per second). More than 70 airgun tests over a period of two years were performed to validate the probe design under worst-case entry conditions. The last test of impact survivability was performed in September 1998.

A variety of tests were performed to validate the aeroshell design. Tests were performed at Eglin Air Force Base in Fort Walton Beach, FL, to verify that the aeroshell shatters on impact, leaving the probe to penetrate the surface. Eglin provided a large airgun 20 feet (6 meters) long and 15 inches (38 centimeters) in diameter and led the test operations. Tests of the aeroshell's aerodynamic properties were performed initially at Eglin's Wright Laboratory Ballistic Range and later at a transonic wind tunnel in Kalingrad, Russia, capable of simulating Martian atmospheric pressures. The aeroshell's heat shield material was tested at an arcjet facility at NASA's Ames Research Center, Moffet Field, CA.

Science Objectives

As a mission under NASA's New Millennium Program, the main focus of Deep Space 2 is testing new technologies on behalf of future science missions. In the process, however, the probes collect data of interest not only to engineers developing technologies but also to scientists studying the environment of Mars. NASA thus organized a team of scientists to work with the data that the probe's instruments will deliver.

The objectives for Deep Space 2's science measurements dovetail with those of Mars Polar Lander, which is focused on understanding the climate of Mars. Deep Space 2 will attempt to:

- Determine if ice is present in the subsurface soil;
- Estimate the thermal conductivity of the soil at depth;
- Determine the atmospheric density throughout the probes' entire descent;
- Characterize the hardness of the soil and possibly the presence of any layering on a scale of many inches to a few feet (tens of centimeters).

The layered terrain around Mars' south pole is believed to consist of alternating layers of wind-deposited dust and water and/or carbon dioxide ice condensed out of the atmosphere. These deposits are thought to record the evidence of climate variations on Mars, much like the growth rings of a tree. Deep Space 2 will help give clues about where water ice is located today on Mars and how materials are deposited in the polar layered terrains. Since the two Deep Space 2 probes and Mars Polar Lander will touch down at different locations up to about 35 miles (60 kilometers) apart, data from each of them will tell scientists how much the polar terrain varies from one site to another.

Science activities on Deep Space 2 are organized as four investigations:

- **Sample collection/water detection experiment**. This experiment will obtain a tiny soil sample and heat it to detect any water that may be present. The presence or absence of water ice at a given depth will be compared to analysis of soils excavated by the robotic arm on Mars Polar Lander. One hypothesis is that much of the water that once flowed on Mars' surface is now frozen underground; this experiment will help to refine theories of the fate of Martian water. Science team members selected for this experiment are Dr. Bruce Murray, California Institute of Technology, and Dr. Aaron Zent, NASA Ames Research Center.

- **Soil thermal conductivity experiment**. Temperature sensors in the forebody or penetrator will show how quickly the probe's heat dissipates into the surrounding soil. This will provide information about Mars' polar layered deposits. A very low conductivity would indicate very fine-grain material, likely to have been wind-deposited. On the other hand, a very high conductivity would indicate large amounts of ice in the soil. Soil conductivity has a strong influence on the subsurface temperature, and thus the depth at which ice is predicted to be stable over many annual cycles. Dr. Paul Morgan, Northern Arizona University, and Dr. Marsha Presley, Arizona State University, were selected to analyze data from this experiment.

- **Atmospheric descent accelerometer**. The aftbody houses a descent accelerometer that will measure the drag on the probes as they descend through the Martian atmosphere. This single piece of information can allow scientists to develop profiles of many meteorological factors in Mars' atmosphere, including density, temperature and pressure at various altitudes. Science team members for atmospheric science are Dr. David C. Catling and Dr. Julio A. Magalhaes of NASA Ames Research Center.

❑ **Impact accelerometer**. The impact accelerometer will provide an estimate of the hardness of the soil, and possibly the presence of small-scale layers that can be compared with the materials encountered by the robotic arm on Mars Polar Lander. Scientists can interpret these terrain layers in terms of the geologic materials they are probably made of, such as ice layers, wind-blown dust and sediments. Data on the small-scale strata of Mars' polar layered terrains could yield important information on climate evolution. Dr. Ralph D. Lorenz, University of Arizona, and Dr. Jeffrey E. Moersch, NASA Ames Research Center were selected for this experiment.

Program/Project Management

Mars Polar Lander and Deep Space 2 are managed by the Jet Propulsion Laboratory, Pasadena, CA, for NASA's Office of Space Science, Washington, DC. At NASA Headquarters, Dr. Edward Weiler is associate administrator for space science. Dr. Carl Pilcher is science director for solar system exploration. Ken Ledbetter is director of the Mission and Payload Development Division, and Dr. William Piotrowski is acting director of the Mars Exploration Program. Steven Brody is Mars Polar Lander program executive, and Joseph Boyce is Mars Polar Lander program scientist. Lia LaPiana is Deep Space 2 program executive, and Dr. Michael Meyer is Deep Space 2 program scientist.

At the Jet Propulsion Laboratory, Dr. Charles Elachi is director of the Space and Earth Science Programs Directorate. For Mars Polar Lander, Dr. John McNamee was project manager for spacecraft development, Richard Cook is project manager for operations, Dr. Sam Thurman is flight operations manager and Dr. Richard Zurek is project scientist. At Lockheed Martin Astronautics, Denver, CO, Dr. Edward A. Euler is the company's program director for Mars Polar Lander.

At JPL, Dr. Fuk Li is manager of the New Millennium Program, and Dr. David Crisp is New Millennium program scientist. For Deep Space 2, Sarah Gavit is project manager, Kari Lewis is chief mission engineer and Dr. Suzanne Smrekar is project scientist.

11-30-99 HQ