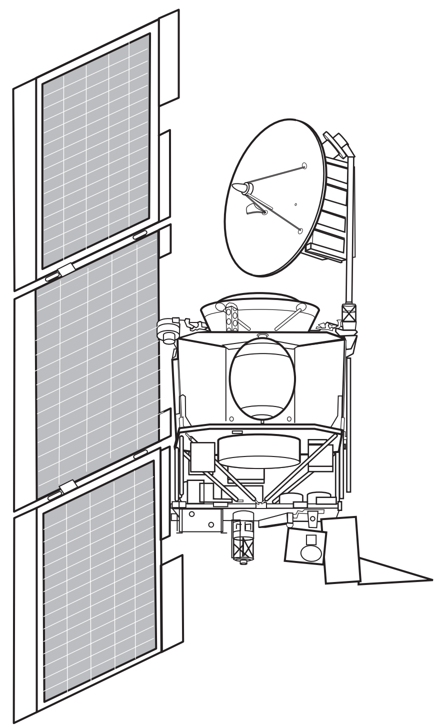
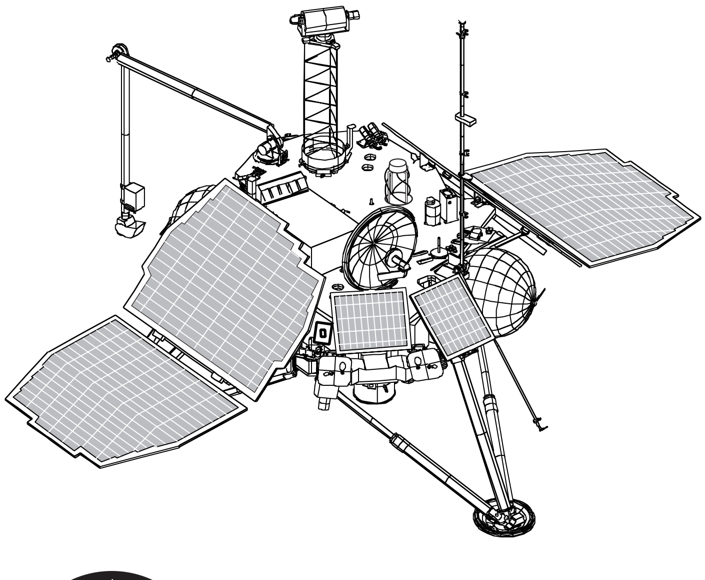
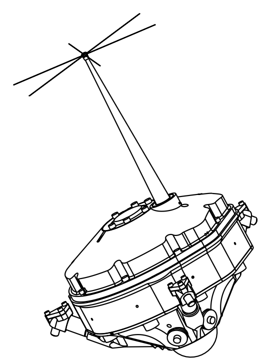
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

1998 Mars Missions

Press Kit
December 1998







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RELEASE:

1998 MARS ORBITER, LANDER, MICROPROBES SET FOR LAUNCH

NASA embarks on a return trip to Mars this winter with two spacecraft launches that will first send an orbiter to circle the red planet, then follow with another to land on the frigid, barren steppe near the edge of Mars' south polar cap. Piggybacking on the lander will be two small probes that will smash into the Martian surface to test new technologies.

Mars Climate Orbiter, scheduled for launch Dec. 10, and Mars Polar Lander, scheduled for launch Jan. 3, will seek clues to the history of climate change on Mars. Both will be launched atop identical Delta II launch vehicles from Launch Complex 17 A and B at Cape Canaveral Air Station, FL, carrying instruments to map the planet's surface, profile the structure of the atmosphere, detect surface ice reservoirs and dig for traces of water beneath Mars' rusty surface.

The lander also 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 1 meter (3 feet) 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.

The missions are 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.

The 1998 missions will advance our understanding of Mars' climate history and the planet's current water resources by digging into the enigmatic layered terrain near one of its poles for the first time. Instruments onboard the orbiter and 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.

Key scientific objectives are to determine how water and dust move about the planet 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 and resides in 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 meter (or yard) of the polar layered terrains could be a well-preserved record showing 100,000 years of Martian geology and climatology.

Nine and a half months after launch, in September 1999, Mars Climate Orbiter will fire its main engine to put itself into an elliptical orbit around Mars. The spacecraft will then skim through Mars' upper atmosphere for several weeks in a technique called aerobraking to reduce velocity and circularize its orbit. Friction against the spacecraft's single, 5.5-meter-long (18-foot) solar array will slow the spacecraft as it dips into the atmosphere each orbit, reducing its orbit period from more than 14 hours to 2 hours.

Finally, the spacecraft will use its thrusters to settle into a polar, nearly circular orbit averaging 421 kilometers (262 miles) above the surface. From there, the orbiter will await the arrival of Mars Polar Lander and serve as a radio relay satellite during the lander's surface mission. After the lander's mission is over, the orbiter will begin routine monitoring of the atmosphere, surface and polar caps for a complete Martian year (687 Earth days), the equivalent of almost two Earth years.

The orbiter carries two science instruments: the Pressure Modulator Infrared Radiometer, a copy of the atmospheric sounder on the Mars Observer spacecraft lost in 1993, and the Mars Color Imager, a new, light-weight imager combining wide- and medium-angle cameras. The radiometer will measure temperatures, dust, water vapor and clouds by using a mirror to scan the atmosphere from the Martian surface up to 80 kilometers (50 miles) above the planet's limb.

Meanwhile, the imager will gather horizon-to-horizon images at up to kilometer-scale (half-mile-scale) resolutions, which will then be combined to produce daily global weather images. The camera will also image surface features and produce a map with 40-meter (130-foot) resolution in several colors, to provide unprecedented views of Mars' surface.

Mars Polar Lander, launched a month after the orbiter is on its way, will arrive in December 1999, two to three weeks after the orbiter has finished aerobraking. The lander is aimed toward a target sector within the edge of the layered terrain near Mars' south pole. The exact landing site coordinates will be adjusted as late as August 1999, based on images and altimeter data from the currently orbiting Mars Global Surveyor.

Like Mars Pathfinder, Mars 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 Mars 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.

As it approaches Mars about 10 minutes before touchdown, the lander will release the two Deep Space 2 microprobes. Once released, the projectiles will collect atmospheric data before they crash at about 200 meters per second (400 miles per hour) 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 100 kilometers (60 miles) away from the microprobe impact sites, Mars Polar Lander will dig into the top of the terrain using a 2-meter-long (6-1/2-foot) 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 1.5-meter (5-foot) 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.

The Mars Climate Orbiter, Mars Polar Lander and Deep Space 2 missions 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 television transmissions for the Mars Climate Orbiter and Mars Polar Lander launches will be available from the Jet Propulsion Laboratory, Pasadena, CA; Johnson Space Center, Houston, TX; Kennedy Space Center, FL, and NASA Headquarters, Washington, DC.

Status Reports

Status reports on mission activities for the 1998 Mars missions will be issued by the Jet Propulsion Laboratory's Media Relations Office. They may be accessed online as noted below. Audio status reports are available by calling (800) 391-6654 or (818) 354-4210.

Launch Media Credentialing

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

Briefings

An overview of the missions will be presented in a news briefing broadcast on NASA Television originating from NASA Headquarters in Washington, DC, at 12 noon EST November 13, 1998. A pre-launch briefing at Kennedy Space Center is scheduled at 11 a.m. EST the day before each of the launches.

Internet Information

Extensive information on the 1998 Mars missions, including an electronic copy of this press kit, press releases, fact sheets, status reports and images, is available from the Jet Propulsion Laboratory's World Wide Web home page at **http://www.jpl.nasa.gov/** . The Mars Exploration Program maintains a home page at **http://mars.jpl.nasa.gov/** . The Deep Space 2 mission’s home page is at **http://nmp.jpl.nasa.gov/ds2/** .

Quick Facts

Mars Climate Orbiter

Dimensions: Main bus 2.1 meters (6.9 feet) tall, 1.6 meters (5.4 feet) wide and 2 meters (6.4 feet) deep; wingspan of solar array 5.5 meters (18 feet) tip to tip
Weight: 629 kg (1,387 lbs) total, consisting of 338-kg (745-lb) spacecraft plus 291 kg (642 lbs) fuel
Science instruments: Pressure Modulator Infrared Radiometer, Mars Color Imager
Power: Solar array providing up to 1,000 watts just after launch, 500 watts at Mars
Launch period: December 10-25, 1998
Earth-Mars distance at launch: 255.2 million km (158.6 million miles)
Earth-Mars distance at arrival: 196.2 million km (121.9 million miles)
Total distance traveled Earth to Mars: 669 million km (416 million miles)
Mars arrival date: September 23, 1999
Primary science mapping period: March 2000-January 2002

Mars Polar Lander

Dimensions: 1.06 meters (3-1/2 feet) tall by 3.6 meters (12 feet) wide
Weight: 576 kg (1,270 lbs) total, consisting of 290-kg (639-lb) lander plus 64 kg (141 lbs) propellant, 82-kg (181-lb) cruise stage, 140-kg (309-lb) aeroshell and heat shield
Science instruments: Mars Volatiles and Climate Surveyor (integrated package with surface imager, robotic arm, 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 period: January 3-27, 1999
Earth-Mars distance at launch: 219.9 million km (136.6 million miles)
Earth-Mars distance at arrival: 253 million km (157.2 million miles)
Total distance traveled Earth to Mars: 757 million km (470 million miles)
Mars arrival date: December 3, 1999
Primary mission period: December 3, 1999 - March 1, 2000

Mars '98 Project

Cost: $193.1M spacecraft development, $42.8M mission operations; total $235.9 million for both orbiter and lander (not including launch vehicles or Deep Space 2)

Deep Space 2

Dimensions: aeroshell 275 mm (11 inches) high, 350 mm (14 inches) diameter; enclosing a forebody (penetrator) 105.6 mm (4.2 inches) long, 39 mm (1.5 inches) diameter; and an aftbody (ground station) 105.3 mm (4.1 in) high (plus 127-mm (5-in) antenna), 136 mm (5.3 inches) diameter
Weight: forebody 670 grams (1.5 lbs), aftbody 1,737 grams (3.8 lbs), aeroshell 1,165 grams (2.6 lbs; total 3,572 grams (7.9 lbs)
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
Cost: pre-launch development $28M, data analysis $1.2M; total $29.2 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; at times the third brightest object in night sky after the Moon and Venus

Physical Characteristics

❑ Average diameter 6,780 kilometers (4,217 miles); 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 206.7 million kilometers (128.4 million miles) to a maximum of 249.2 million kilometers (154.8 million miles); average distance from Sun, 227.7 million kilometers (141.5 million miles)
❑ Revolves around Sun once every 687 Earth days
❑ Rotation period (length of day in Earth days) 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 40 meters per second (80 miles per hour)
❑ Local, regional and global dust storms; also whirlwinds called dust devils
❑ Surface temperature averages -53 C (-64 F); varies from -128 C (-199 F) during polar night to 27 C (80 F) at equator during midday at closest point in orbit to Sun

Features

❑ Highest point is Olympus Mons, a huge shield volcano about 26 kilometers (16 miles) high and 600 kilometers (370 miles) across; has about the same area as Arizona
❑ Canyon system of Valles Marineris is largest and deepest known in solar system; extends more than 4,000 kilometers (2,500 miles) and has 5 to 10 kilometers (3 to 6 miles) 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 106 million km (65.9 million miles)
[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, science mapping starts 3/99
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 Earth orbit; swingbys of Earth's Moon 9/24/98 and 12/18/98; leaves Earth's orbit 12/20/98; Mars arrival 10/99

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 1998 and January 1999, another orbiter and lander will be sent to 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 sci-

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 are Mars Climate Orbiter and Mars Polar Lander, 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.

entists 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.

The 1998 and Future Missions

Mars Climate Orbiter and Mars Polar Lander are designed to help scientists better understand the climate history of Mars, not to look for life. They do not, for example, contain any biology experiments similar to the chemistry lab on the Viking landers. However, their 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, Mars Climate Orbiter and 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

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 has since been adjusting its orbit by skimming through the planet’s upper atmosphere in a technique called aerobraking. Although the prime science mapping mission begins in spring 1999, the spacecraft has collected much science data so far. 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 data on the planet's mineralogy and topography suggest that Mars had abundant water and was warmer in its early history. 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 three-dimensional views of Mars' north polar ice cap. Initial profiles 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 in December 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 75 degrees south latitude is more rugged and geologically diverse than scientists had previously thought.

apparently released from subsurface aquifers, flowed across the surface and pooled in low-lying 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

Where to Next?

In the summer of 1998, NASA conducted a review of its multi-year Mars program, calling in outside experts to help evaluate and refine the architecture for the future 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. Some of the details are subject to change as plans evolve, but the following are the basic missions recommended by the review:

❑ **2001:** NASA will launch an orbiter and lander broadly similar to the 1998 Mars spacecraft. 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, as well as international partners, 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 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 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 and place them in Mars orbit for later retrieval. In 2007, NASA will 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 will launch a lander and rover that will search for soil and rock samples and return them to an 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:** Although plans for these years are uncertain, a repeat of the 2007-2009 strategy is currently envisioned.

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, 1998 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 meters (or yards) 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 kilometer (half-mile) 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 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 prebiotic chemistry that led to life on Earth.

Mars Climate Orbiter

Mars Climate Orbiter will carry two science instruments, one of which is a copy of an instrument carried by the Mars Observer spacecraft, which was lost in 1993. Between them, Mars Climate Orbiter and the currently orbiting Mars Global Surveyor carry all but one of the entire suite of science instruments from Mars Observer. In addition, both orbiters will provide radio relay support for Mars Polar Lander.

Mission Overview

Launch vehicle. Mars Climate Orbiter will be launched on a variant of Boeing's Delta II launch vehicle known as a Delta 7425. The vehicle is similar to the 7925, a more powerful version of the Delta II used for NASA's Near Earth Asteroid Rendezvous (NEAR), Mars Pathfinder and Mars Global Surveyor missions, except that it uses four strap-on solid rocket boosters instead of nine.

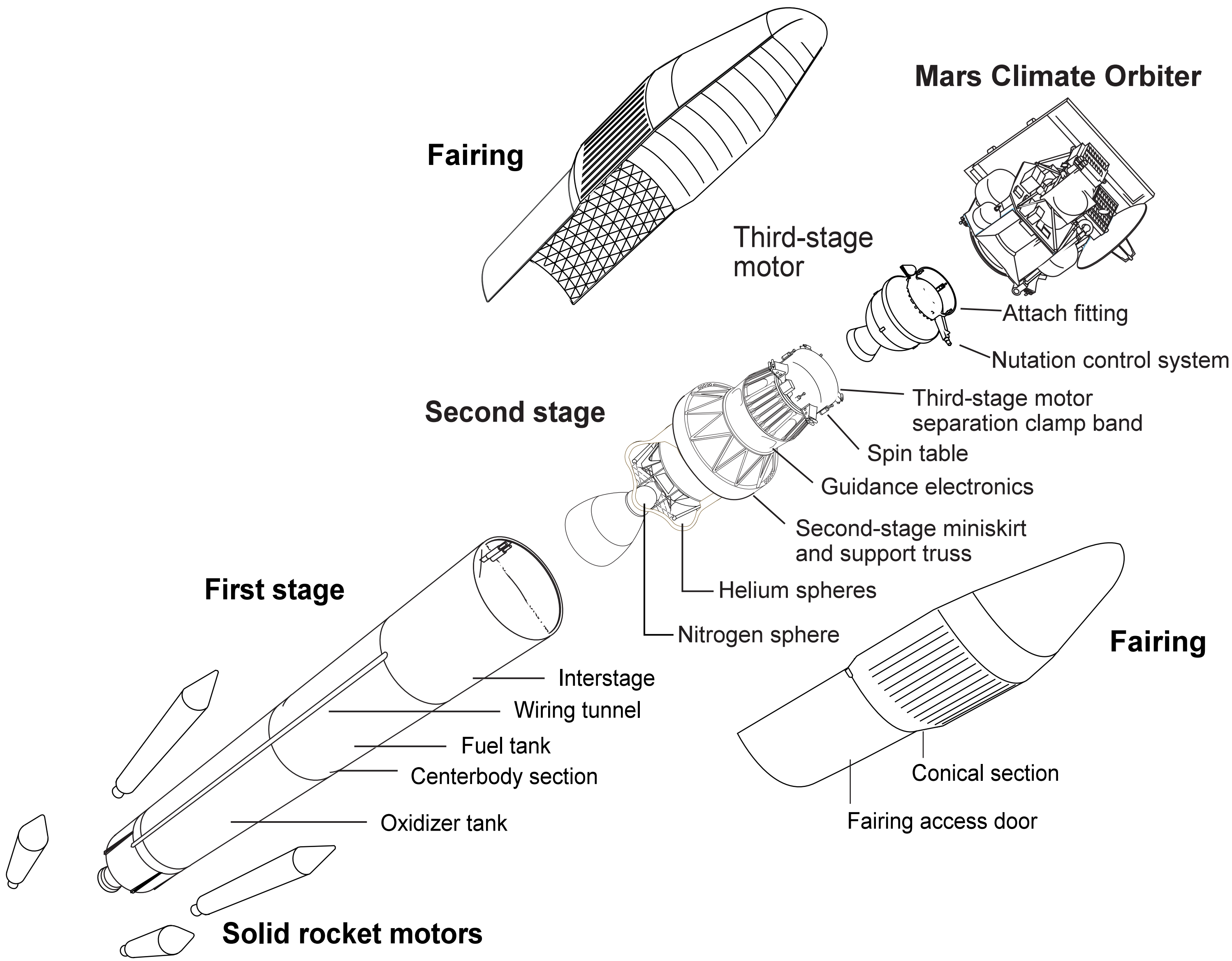
Each of the four solid rocket motors is 1 meter (3.28 feet) in diameter and 13 meters (42.6 feet) long; each contains 11,765 kilograms (25,937 pounds) of hydroxyl-terminated polybutadiene (HTPB) propellant and provides an average thrust of 446,023 newtons (100,270 pounds) at sea level. The casings on the solid rocket motors are made of lightweight graphite epoxy.

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

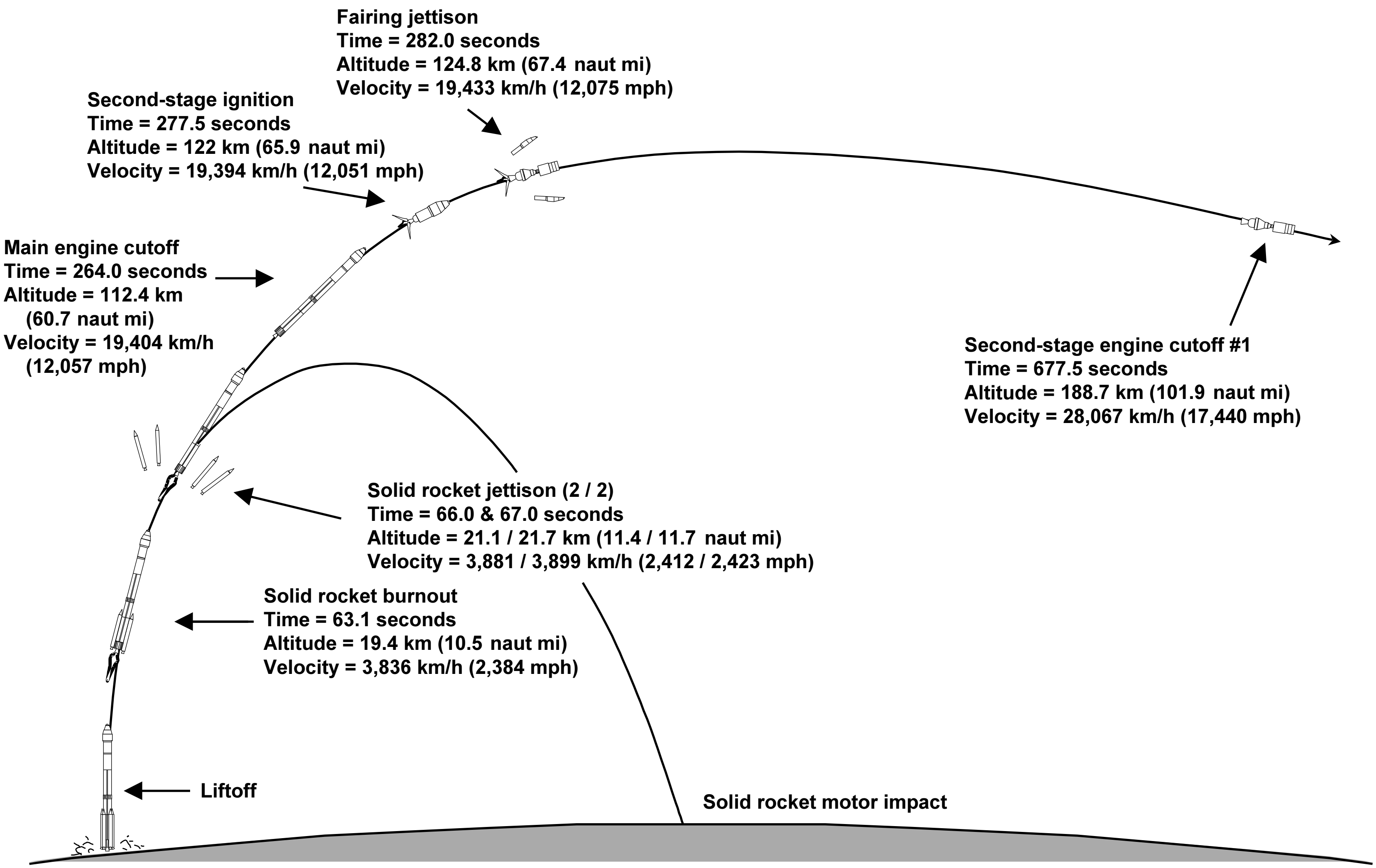
The second stage is 2.4 meters (8 feet) in diameter and 6 meters (19.7 feet) long, and is powered by an AJ10-118K engine. The propellant is 5,900 kilograms (13,000 pounds) of Aerozine 50 (A-50), a mixture of hydrazine and unsymmetrical dimethyl hydrazine (UDMH), and nitrogen tetroxide as the oxidizer.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

The third and final stage of the Delta 7425 is a Thiokol Star 48B booster, the same final stage used in the 1996 launch of Mars Global Surveyor. The Star 48B measures 2.12 meters (84 inches) long and 1.2 meters (4 feet) wide. Its motor carries solid propellant composed of a mixture of aluminum, ammonium perchlorate and hydroxyl-terminated polybutadiene (HTPB) solid propellant.

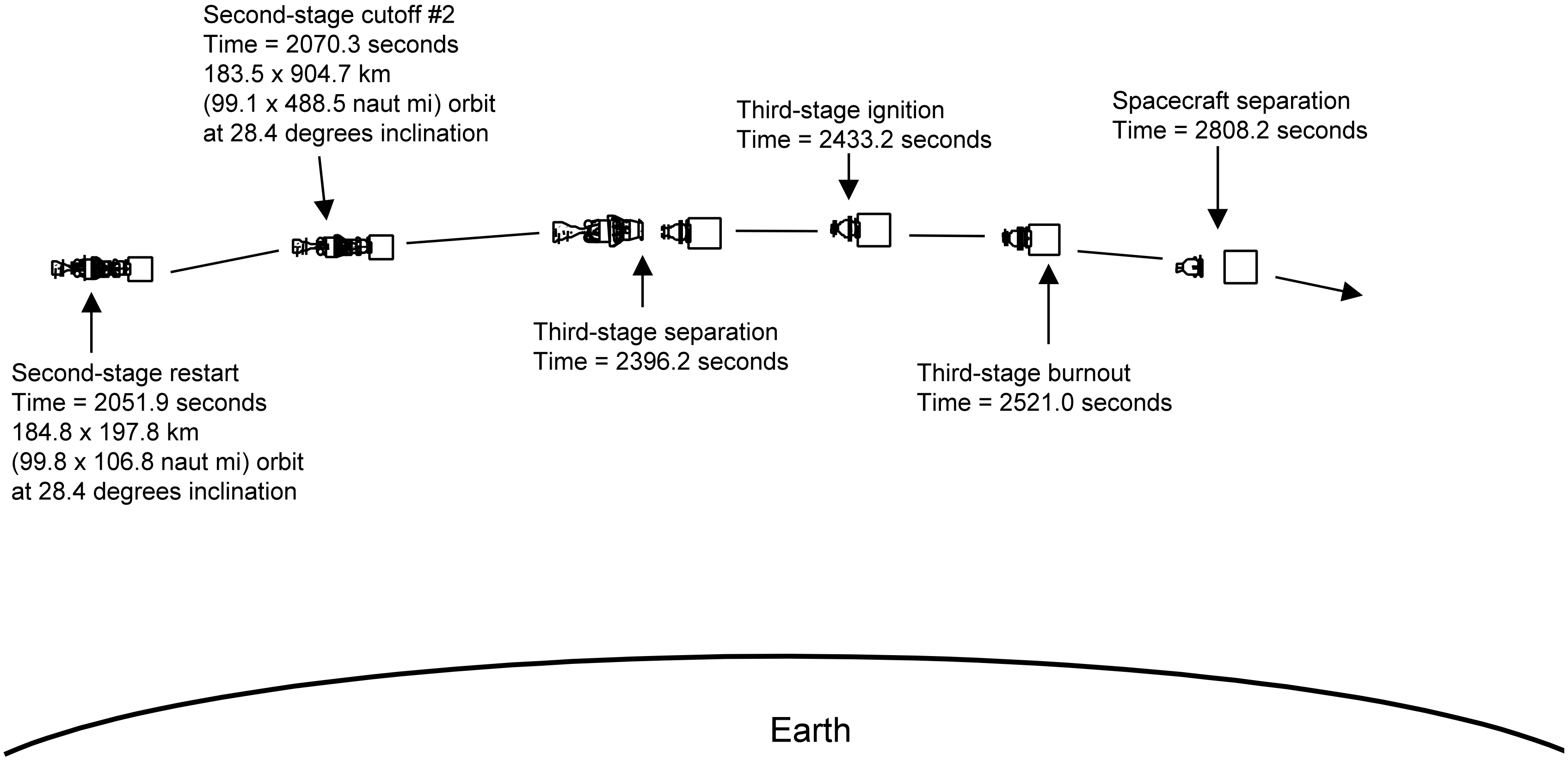
Launch period. The primary launch period is December 10-17, 1998, while a secondary period is open December 18-25. Launch during the primary period insures with greater probability that the orbiter will complete aerobraking before Mars Polar Lander lands. Launch during the secondary period results in a higher capture orbit upon Mars arrival, requiring more aerobraking to bring the spacecraft into a final science orbit. Launch past December 25 is pos-



Orbiter's Delta II launch vehicle



Orbiter launch boost phase



Orbiter launch injection phase

sible, but would result in an even higher capture orbit.

Daily windows. Two nearly instantaneous launch opportunities occur each day during the launch period. On December 10, the first is at 1:56 p.m. Eastern Standard Time (EST) and the second is at 3:02 p.m. EST. The opportunities become earlier each day as the launch period progresses.

Liftoff. Liftoff will take place from Space Launch Complex 17A at Cape Canaveral Air Station, FL. Sixty-six seconds after liftoff, two of the four solid rocket strap-ons will be discarded. The remaining strap-on boosters will be jettisoned one second later, while the first stage continues to burn. About 4 minutes, 24 seconds after liftoff, the first stage will stop firing and be discarded eight seconds later. About five seconds later, the second stage engine ignites. The fairing or nose-cone enclosure of the launch vehicle will be discarded 4 minutes, 42 seconds after liftoff. The second-stage burn ends about 11 minutes, 22 seconds after liftoff.

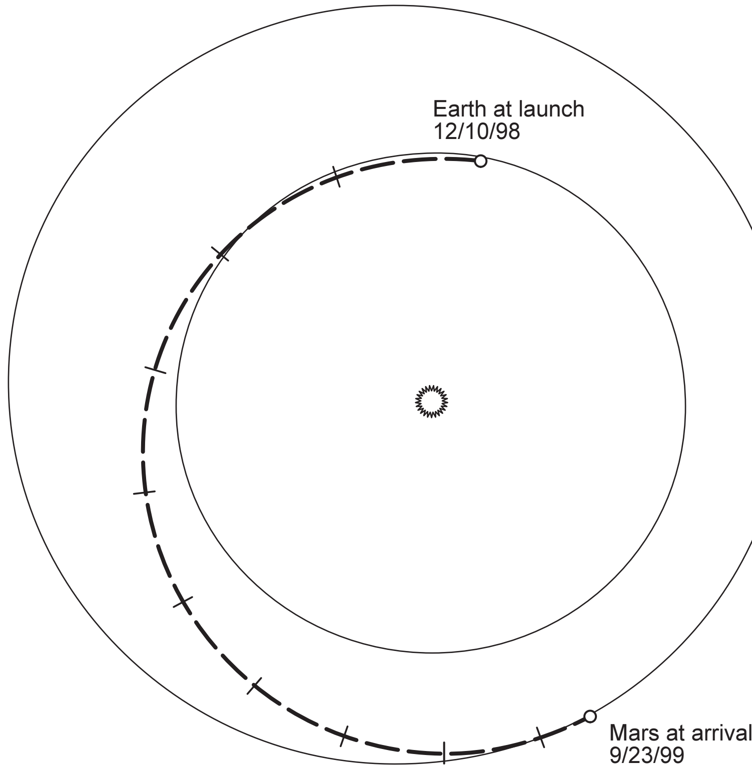
At this point, the vehicle will be in a low-Earth orbit at an altitude of 189 kilometers (117 miles). Depending on the actual launch date and time, the vehicle will then coast for 24 to 36 minutes. Once the vehicle is at the correct point in its orbit, the second stage will be restarted for a brief second burn.

Small rockets will then be fired to spin up the third stage on a turntable attached to the second stage. The third stage will separate and ignite its motor, sending the spacecraft out of Earth orbit. A nutation control system (a thruster on an arm mounted on the side of the third stage) will be used to maintain stability during this 88-second burn. After that, the spinning upper stage and the attached Mars Climate Orbiter must be despun so that the spacecraft can be separated and acquire its proper cruise orientation. This is accomplished by a set of weights that are reeled out from the side of the spinning vehicle on flexible lines, much as spinning ice skaters slow themselves by extending their arms. Approximately 43 to 56 minutes after liftoff, Mars Climate Orbiter will separate from the Delta's third stage. Any remaining spin will be removed using the orbiter's onboard thrusters.

Orbiter Daily Launch Opportunities

The orbiter has two near-instantaneous launch opportunities each day (all times EST)

Date	*First Opportunity*	*Second Opportunity*	*Date*	*First Opportunity*	*Second Opportunity*
12/10/98	1:56:38 pm	3:02:23 pm	12/18/98	12:10:27 pm	1:23:39 pm
12/11/98	1:45:51	2:52:00	12/19/98	11:51:05 am	1:05:54
12/12/98	1:34:08	2:40:49	12/20/98	11:28:12	12:45:54
12/13/98	1:22:24	2:29:58	12/21/98	11:00:21	12:22:48
12/14/98	1:10:12	2:18:35	12/22/98	10:57:14	12:19:24
12/15/98	12:57:26	2:06:27	12/23/98	10:55:23	12:16:56
12/16/98	12:43:33	1:53:20	12/24/98	10:54:41	12:15:29
12/17/98	12:28:21	1:39:02	12/25/98	10:55:05	12:14:54



Orbiter's interplanetary trajectory

About 7 to 12 minutes after third-stage separation, the spacecraft's solar array will be unfolded. An eight-minute onboard operation will orient the solar array toward the Sun for power. Shortly thereafter, the 34-meter-diameter (112-foot) antenna at the Deep Space Network complex near Canberra, Australia, will acquire Mars Climate Orbiter's signal.

Interplanetary cruise. Assuming launch on December 10, the spacecraft will take 286 days or about nine and a half months to reach Mars, entering orbit on September 23, 1999. The spacecraft's flight path is called a Type 2 trajectory because it will take the orbiter more than 180 degrees around the Sun; this will result in a slower speed at Mars arrival. 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 Climate Orbiter will fly slightly inward toward the Sun before spiralling out beyond Earth's orbit to Mars.

During the first phase of the cruise, the spacecraft will maintain contact with Earth using its low-gain or medium-gain antenna while keeping its solar arrays pointed at the Sun. For the first week, the spacecraft will be tracked 24 hours per day. During the second through fourth weeks after launch, the spacecraft will be tracked a minimum of 12 hours per day using 34-meter-diameter (112-foot) antennas of the Deep Space Network. During quiet periods of the interplanetary cruise, the orbiter will be tracked a minimum of four hours each day. The tracking rate will be increased again to 12 hours per day starting 45 days before the spacecraft reaches Mars.

Twelve days into flight, the radiator door on one of the science instruments, the Pressure Modulator Infrared Radiometer, will be moved to the vented position to acclimate the instrument's passive radiative cooler to the environment of space.

During interplanetary cruise, Mars Climate Orbiter is scheduled to fire its thrusters a total of four times to adjust its flight path. The first of these trajectory correction maneuvers will be carried out 10 days after launch. This maneuver, expected to be the largest and longest, will be used to correct launch injection errors and adjust the Mars arrival aimpoint. The maneuver is expected to take up to seven minutes to execute.

The remaining three trajectory correction maneuvers will be used to direct the spacecraft to the proper aimpoint at Mars. The maneuvers are scheduled 45 days after launch (January 25, assuming launch on December 10); 60 days before Mars arrival (approximately July 25); and 10 days before Mars arrival (approximately September 13).

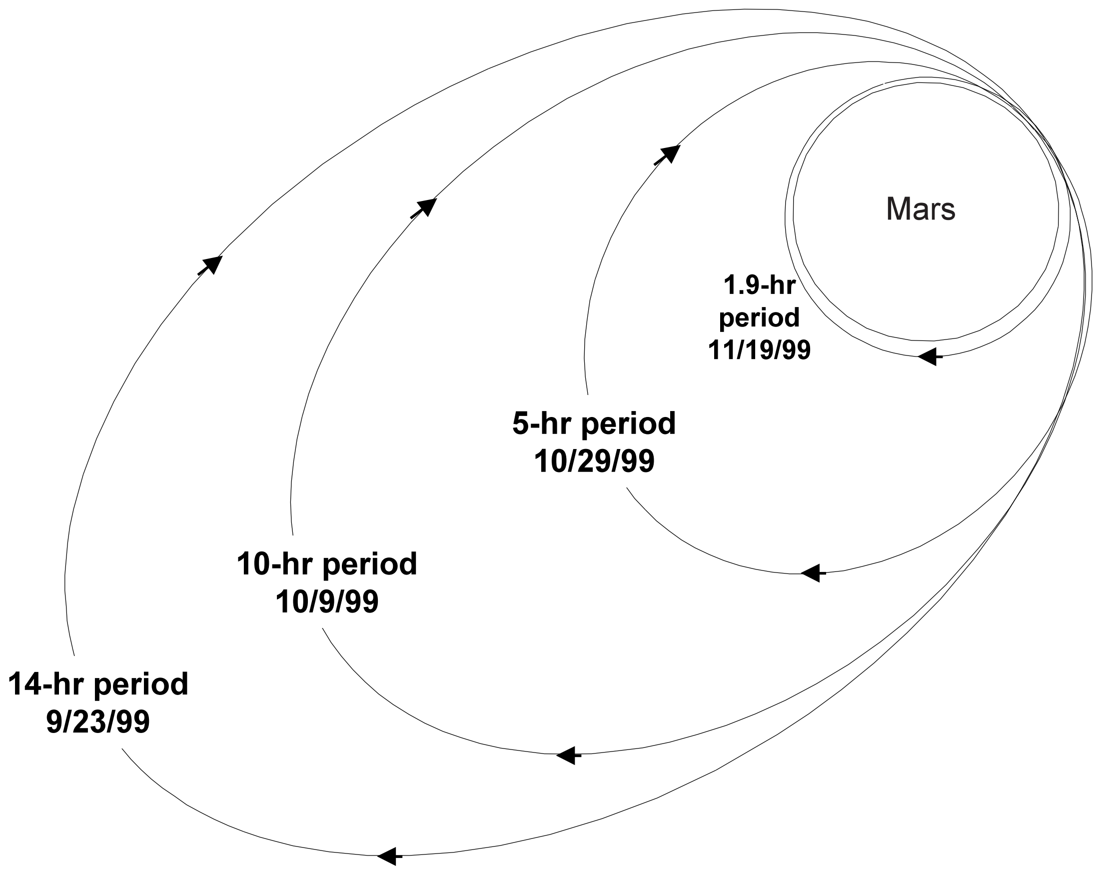
Science instruments will be powered on, tested and calibrated during cruise. The Pressure Modulator Infrared Radiometer and Mars Color Imager will be calibrated during a week-long checkout 80 days after launch. During this checkout activity, the Mars Color Imager will be commanded to turn and scan across a specific star cluster as part of a star calibration exercise.

Eighteen days before arrival, the imager will take pictures of Mars that will be transmitted to Earth over the following three days.

Mars orbit insertion. The orbiter will arrive at Mars on September 23, 1999. As it nears its closest point to the planet coming in over the northern hemisphere, the spacecraft will fire its 640-newton main engine for 16 to 17 minutes to brake into an elliptical capture orbit. Assuming launch on December 10, the spacecraft will loop around Mars roughly once every 12 to 17 hours. The period of the capture orbit will increase if launch takes place on a later date, due to an increasing arrival velocity. If launch takes place at the end of the launch period in late December, the capture orbit period would be approximately 20 hours.

About 22 minutes after completion of the burn, the spacecraft will be turned to point its high-gain antenna at Earth. During the first two days after orbit insertion, the spacecraft will communicate continuously with the Deep Space Network's 70-meter (230-foot) and 34-meter (112-foot) antennas.

Based on the details of the initial capture orbit, the spacecraft will fire its thrusters during its next closest pass by Mars to lower the orbit and reduce the orbit period by two to four hours. The flight team will work to achieve as low an orbit as possible to reduce the amount of time required for aerobraking.



Aerobraking orbits

Aerobraking. In aerobraking, a spacecraft is slowed down by frictional drag as it flies through the upper part of a planet's atmosphere. The technique was first tested by NASA's Magellan spacecraft at Venus at the end of its prime mission in 1994, and is being used by the currently orbiting Mars Global Surveyor. Mars Climate Orbiter will be starting from an orbit much lower than Mars Global Surveyor – with an orbit period only one-third as long – so it will require much less aerobraking. If Mars Climate Orbiter is launched within the first eight days of its launch period, it will be able to reach its final science-gathering orbit at least two weeks before Mars Polar Lander arrives.

During each of its long, elliptical loops around Mars, the orbiter will pass through the upper layers of the atmosphere each time it makes its closest approach to the planet. Friction from the atmosphere on the spacecraft and its wing-like solar array will cause the spacecraft to lose some of its momentum during each close approach, known as an "aeropass." As the spacecraft slows during each close approach, the orbit will gradually lower and circularize.

Before the beginning of each aeropass, the orbiter's solar wing will be braced against the body of the spacecraft for mechanical stability. The spacecraft therefore will not receive any solar energy until after the aeropass is over and the solar array can be turned again toward the Sun.

Mars Climate Orbiter may begin aerobraking within a day after it enters Martian orbit. The first thruster firing to adjust the orbit for aerobraking may be performed as early as the first time the spacecraft swings away from the planet after entering orbit. During the next several days, the flight team will fire the thrusters each time the spacecraft reaches the point in its orbit most distant from the planet. This will bring the point of its closest approach to Mars down within the planet's upper atmosphere.

The main aerobraking phase will begin once the point of the spacecraft's closest approach to the planet – known as the orbit's periapsis – has been lowered to within about 100 kilometers (60 miles) above Mars' surface. As the spacecraft's orbit is reduced and circularized over approximately 200 aeropasses in 57 days, the periapsis will move northward from 34 degrees north latitude to 89 degrees north latitude, almost directly over Mars' north pole. Small thruster firings when the spacecraft is most distant from the planet will keep the aeropass altitude at the desired level to limit heating and dynamic pressure on the orbiter.

Although the orbiter's transmitter may be on continuously during aerobraking, contact with Earth will not be possible during the aeropasses or when the spacecraft passes behind Mars as seen from Earth. As a result, the spacecraft will be out of contact with Earth for 45 to 60 minutes per orbit. Mars Climate Orbiter will be monitored and tracked during each orbit, but will sometimes share Deep Space Network antenna time with Mars Global Surveyor. Concurrent observations of the planet by Mars Global Surveyor will provide early warning of dust storms and other atmospheric changes, which could affect Mars Climate Orbiter's aerobraking.

The most challenging part of aerobraking will occur during what the flight team calls the "end game": the last few days of aerobraking, when the period of the spacecraft's orbit is shortest. At that time, aeropasses will be occurring most frequently and lasting longer than previous aeropasses.

The final science orbit will be a "late afternoon" orbit that takes the spacecraft over the Martian equator at approximately 4:30 p.m. local mean solar time on the day side of the planet, and at 4:30 a.m. on the night side of the planet.

Lander approach navigation. Ground controllers will implement a program of near-simultaneous tracking of Mars Climate Orbiter and Mars Polar Lander to support precision approach navigation for the lander as it prepares for its entry, descent and landing on Mars. Beginning 30 days before lander arrival, the 34-meter-diameter (112-foot) antennas of the Deep Space Network will track the orbiter during sessions just before or after tracking the lander. This will allow engineers to reduce effects of errors from locations of ground stations, modeling of solar plasma and other sources. First demonstrated in 1997 with the Mars Pathfinder and Mars Global Surveyor spacecraft, the technique is expected to increase significantly the flight team's ability to control the entry angle of the lander and thus reduce the size of the landing footprint. Mars Global Surveyor also may be used as the navigation aid for the approaching lander.

Mapping orbit. The orbiter will fire its thrusters in two maneuvers at the end of aerobraking. The first and largest maneuver will raise the spacecraft's periapsis – the point in its orbit where it passes closest to the planet – out of the atmosphere. The second maneuver will place the spacecraft into an orbit designed to fine-tune the timing of the orbiter's passage over Mars Polar Lander's landing site. Shortly before the lander arrives, additional small maneuvers will be executed to place the orbiter into its final mapping orbit, a nearly circular, nearly Sun-synchronous orbit with an average altitude of about 421 kilometers (262 miles).

Once the spacecraft has reached the mapping orbit, its high-gain antenna will be deployed. The antenna, which was stowed during the nine-and-a-half-month trip to Mars and during aerobraking, may require testing to assess its performance in the deployed position.

Lander support. For the first three months after insertion into the mapping orbit, the orbiter's main task will be to act as a radio relay for Mars Polar Lander. During this time the orbiter will relay commands from Earth to the lander, as well as data from the lander to Earth. The orbiter may also spend a limited amount of time collecting science data and transmitting it to Earth during daily 10-hour communications sessions. The lander support is scheduled to last through the end of February 2000.

Mapping. From March 2000 through January 2002, the orbiter will carry out its primary mission making systematic observations of the atmosphere and surface of Mars using its two science instruments, the Pressure Modulator Infrared Radiometer and the Mars Color Imager. The length of the science mission was chosen to span one Martian year, or 687 Earth days, so that scientists can observe seasonal variations in the Martian weather. Data will be sent to Earth during daily 10-hour communications sessions.

Relay for future missions. Once its mapping mission is complete, the orbiter will be available for up to two years as a communications relay for future Mars landers. During this phase, the orbiter will fire its thrusters to increase its altitude. This maneuver fulfills planetary protection regulations by increasing the length of time the spacecraft remains in orbit before eventually entering the atmosphere, breaking up and crashing onto the planet's surface.

Spacecraft

Mars Climate Orbiter's main structure, or bus, is 2.1 meters (6.9 feet) tall, 1.6 meters (5.4 feet) wide and 2 meters (6.4 feet) deep. At launch it will weigh 629 kilograms (1,387 pounds), consisting of the 338-kilogram (745-pound) dry spacecraft plus 291 kilograms (642 pounds) of fuel.

The framework of the spacecraft bus is made of a combined graphite composite/aluminum honeycomb structure similar to that used in the construction of commercial aircraft.

Most systems on the spacecraft are fully redundant; for example, there are two onboard computers, two radio transmitter/receivers and so on, to compensate in case any device fails. The main exceptions are the electrical battery and the main engine used to brake the spacecraft into orbit upon arrival at Mars.

Onboard computer. The spacecraft's computer system is greatly simplified compared with computers on planetary spacecraft a few years ago. By the late 1980s, spacecraft boasted the equivalent of onboard local area networks, with a main computer communicating with other computers used to run various subsystems and science instruments. By contrast, the Mars '98 orbiter and lander have a single onboard computer that runs all spacecraft activities (the science instruments contain microprocessor chips but not complete computer systems).

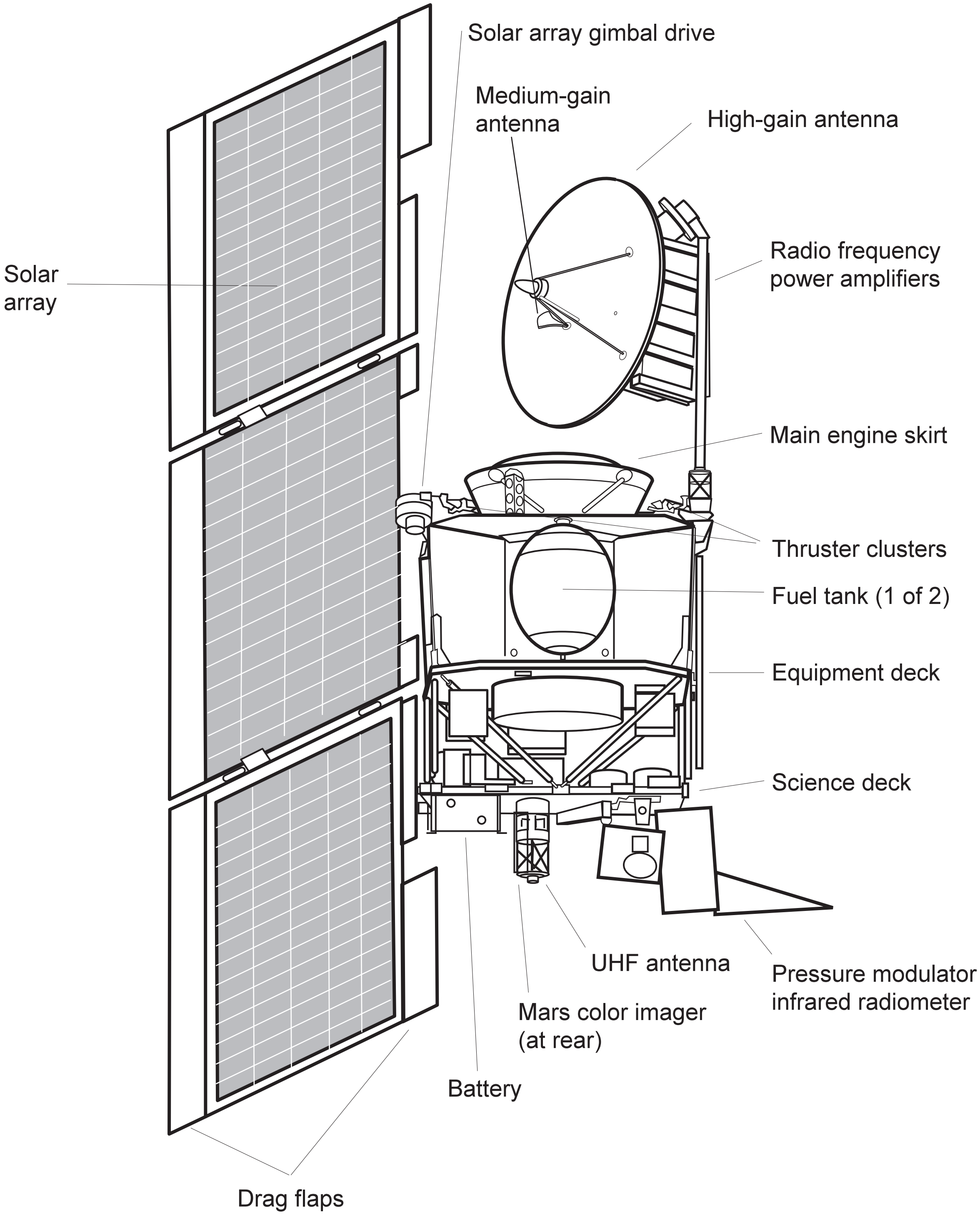
The spacecraft's computer uses a RAD6000 processor, a radiation-hardened version of the PowerPC chip used on some models of Macintosh computers. It can be switched between clock speeds of 5 MHz, 10 MHz or 20 MHz. The computer includes 128 megabytes of random-access memory (RAM); unlike many other spacecraft, the orbiter does not have an onboard tape recorder or solid-state data recorder, but instead stores data in its RAM for transmission to Earth. The computer also has 18 megabytes of "flash" memory that can store data even when the computer is powered off. Eight megabytes of the flash memory will be used to store triplicate copies of high-priority data; when the computer accesses the data later, it will check all three copies of each byte to make sure that information has not become corrupted.

Attitude control. The attitude control system manages the spacecraft's orientation, or "attitude." Like most planetary spacecraft, the orbiter is three-axis stabilized, meaning that its orientation is held fixed in relation to space, as opposed to spacecraft that stabilize themselves by spinning. The orbiter determines its orientation at any given time using a star camera, two Sun sensors and one of two inertial measurement units, each of which consists of three ring-laser gyroscopes and three accelerometers. The orientation is changed by firing thrusters or by using three reaction wheels, devices similar to flywheels.

During most of the interplanetary cruise, the spacecraft will be in "all stellar" mode, relying only on its star camera and Sun sensors for attitude determination without using the inertial measurement unit. To save wear and tear on their gyros, the inertial measurement units will be primarily used in Mars orbit.

Telecommunications. The spacecraft will communicate with Earth in the microwave X band, using a transponder (transmitter and receiver) based on a design used on the Cassini mission, along with a 15-watt radio frequency power amplifier. It uses a 1.3-meter-diameter (4.3-foot) dish-shaped high-gain antenna to transmit and receive, a medium-gain antenna with transmit-only capability and a receive-only low-gain antenna. A receiver and 15-watt transmitter in the UHF radio band will support two-way communications with Mars Polar Lander and future Mars landers.

Power. The spacecraft obtains its power from a solar array consisting of gallium arsenide solar cells mounted on three panels that form a single wing spanning 5.5 meters (18



Mars Climate Orbiter spacecraft

feet) from tip to tip. Shortly after launch, the solar array will provide up to 1,000 watts of power; in Mars orbit it will provide up to about 500 watts. Power is stored in a 12-cell, 16-amp-hour nickel-hydrogen battery. In addition to providing power, the solar array acts as the spacecraft's "brakes" during aerobraking. Wing flaps have been added to the array to increase the amount of surface area and improve aerobraking performance.

Thermal control. The thermal control system uses electrical heaters, thermal radiators and louvers to control the temperature inside the spacecraft. Multi-layer insulation, Kapton blankets and protective coatings are used to shield electronics from the harsh environment of space.

Propulsion. The propulsion system is similar to Mars Global Surveyor's, featuring both sets of small thrusters for maneuvers as well as a main engine that will fire to place the spacecraft in orbit around Mars. The main engine uses hydrazine propellant with nitrogen tetroxide as an oxidizer to produce 640 newtons (144 pounds) of thrust. The thrusters, which use hydrazine as a monopropellant, are divided into two sets. Four larger thrusters, each of which puts out 22 newtons (5 pounds) of thrust, will be used for trajectory correction maneuvers or turning the spacecraft. Four smaller thrusters producing 0.9 newton (0.2 pound) of thrust each will be used exclusively for attitude control.

Science Objectives

One of the chief scientific issues that Mars Climate Orbiter will study is the question of water distribution on Mars. On a planet with temperatures that rarely rise above freezing (0 C or 32 F) and plummet to lows of about -88C (-126 F), water ice and carbon dioxide ice remain year-round in its permanent polar caps.

Over time, some water has surely been lost to space; some has been added by the infall of comets and meteorites. Water is also likely to be stored in the ground, chemically and physically bound to soil particles and as ice. Models of subsurface temperatures indicate that ground ice should be near the surface in the polar regions.

Instruments onboard the orbiter and lander will analyze the composition of surface materials, characterize daily and seasonal weather patterns and frost deposits, and monitor surface and atmospheric interactions to better understand the planet as a global system.

Other major goals of the mission are:

❑ Study variations in atmospheric dust and volatile materials, such as carbon dioxide and water, in both their vapor and frozen forms. Mars Climate Orbiter will track these variations over a full Martian year (687 Earth days).

❑ Identify surface reservoirs of volatile material and dust, and observe their seasonal variations. The orbiter's imager and sounder will be able to characterize surface compositional boundaries and changes that might occur with time or seasons.

- Explore climate processes that stir up or quell regional and global dust storms, as well as atmospheric processes that transport volatiles such as water ice clouds and dust around the planet.

- Search for evidence of Mars' ancient climate, which some scientists believe was temperate and more Earth-like with a thicker atmosphere and abundant flowing water. Layered terrain in the polar regions suggests more recent, possibly cyclic, climate change. Studies of Mars' early climate compared with Earth's may explain whether internal or external factors (such as changes in Mars' orbit) are primary drivers of climate change.

The orbiter carries two science instruments, the Pressure Modulator Infrared Radiometer and the Mars Color Imager.

Pressure Modulator Infrared Radiometer. This instrument is a sounder that will scan Mars' thin atmosphere, measuring temperatures, dust, water vapor and condensate clouds. It can scan the planet's atmosphere at the horizon or straight down underneath the spacecraft.

The instrument detects radiation in a total of nine channels. One of them detects visible light, while the other eight detect various spectral bands of infrared radiation at wavelengths between 6 and 50 microns. These data will allow scientists to construct vertical profiles of the atmosphere from near the surface to as high as 80 kilometers (50 miles) above the surface. Bands of water vapor and carbon dioxide will be detected, for the first time, at a vertical resolution of 5 kilometers (3 miles). A radiative cooler will keep the detectors located on the instrument's focal plane assembly at temperatures of about -193 C (-315 F).

The instrument weighs 42 kilograms (93 pounds) and uses 41 watts of power. The main instrument box is 23 by 30 by 74 centimeters (9 by 12 by 29 inches); a smaller cooler attached to the instrument is 58 by 65 by 30 centimeters (23 by 26 by 12 inches).

The joint principal investigators of the Pressure Modulator Infrared Radiometer are Dr. Daniel McCleese of JPL and Dr. Vassili Moroz of the Space Research Institute (IKI), Moscow, Russia.

Mars Color Imager. The imager combines a wide-angle camera and a medium-angle camera. Both cameras are designed to snap a series of overlapping frames as the spacecraft sweeps over the planet. Each camera has a charge-coupled device (CCD) detector overlaid with spectral or color filter strips. The camera shutters are electronically controlled at intervals timed so that the spacecraft motion overlaps the filter strips in order to produce a series of color images covering the same surface area.

The wide-angle camera detects light in seven spectral bands – five in the visible spectrum from 425 to 750 nanometers, and two in the ultraviolet spectrum from 250 to 330 nanometers. The camera is capable of taking pictures with a resolution of up to about 1 kilometer (sixtenths of a mile) in Mars orbit when the data rate of the communications system allows sending large numbers of images. At other times, the camera will average adjacent pixels together to result in pictures with a resolution as low as 7.2 kilometers (4.5 miles) per pixel. The camera can also image the limb of the planet to detail the structure of clouds and hazes at a resolution of about 4 kilometers (2.5 miles) per pixel.

The medium-angle camera detects light in eight spectral bands from violet to near-infrared (425 to 930 nanometers wavelength). Pointed down at the planet, the camera will take pictures with a resolution of about 40 meters (130 feet) per pixel across a six-degree field-of-view covering 40 kilometers (25 miles).

Once the spacecraft is in its mapping orbit, the Mars Color Imager will provide daily global images of the Martian atmosphere and surface with the wide-angle camera, and monitor surface changes with the medium-angle camera when high downlink data rates are possible. Each of the imager’s two cameras is 6 by 6 by 12 centimeters (2.35 by 2.35 by 4.7 inches); together they weigh 2 kilograms (4.4 pounds). The imager uses 4 watts of power.

Principal investigator for the Mars Color Imager is Dr. Michael Malin of Malin Space Science Systems Inc., San Diego, CA.

Mars Polar Lander

Mars Polar Lander will send a lander to 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.

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 vehicle. The lander's Delta II launch vehicle is identical to the one that will launch Mars Climate Orbiter (see page 18).

Launch period. The primary launch period is January 3-10, 1999, while a secondary period is open January 11-16 and a contingency launch period exists January 17-27. Launch during the primary period insures that the spacecraft will land December 3, 1999, within the target area from 73 to 77 degrees south latitude near Mars' south pole. If launch is delayed past the primary period, the landing latitude moves northward, and the landing is delayed. Launch at the end of the contingency period would result in an arrival date no later than December 17, 1999, and a landing about 2 degrees further north.

Daily window. One nearly instantaneous launch opportunity occurs each day during the launch period. On January 3, the opportunity is at 3:21 p.m. Eastern Standard Time (EST). By January 27, the launch opportunity will be at 12:53 p.m. EST.

Liftoff. Liftoff will take place from Space Launch Complex 17B at Cape Canaveral Air Station, FL. Sixty-six seconds after liftoff, two of the four solid rocket strap-ons will be discarded. The remaining strap-on boosters will be jettisoned one second later, while the first stage continues to burn. About 4 minutes, 24 seconds after liftoff, the first stage will stop firing and be discarded eight seconds later. About five seconds later, the second stage engine ignites. The fairing or nose-cone enclosure of the launch vehicle will be discarded 4 minutes, 42 seconds after liftoff. The second-stage burn ends about 11 minutes, 22 seconds after liftoff.

At this point, the vehicle will be in a low-Earth orbit at an altitude of 191 kilometers (119 miles). Depending on the actual launch date, the vehicle will then coast for 23 to 26 minutes. Once the vehicle is at the correct point in its orbit, the second stage will be restarted for a brief second burn.

Small rockets will then be fired to spin up the third stage on a turntable attached to the second stage. The third stage will separate and ignite its motor, sending the spacecraft out of Earth orbit. A nutation control system (a thruster on an arm mounted on the side of the third stage) will be used to maintain stability during this 88-second burn. After that, the spinning upper stage and the attached Mars Polar Lander must be despun so that the spacecraft can be separated and acquire its proper cruise orientation. This is accomplished by a set of weights that are reeled out from the side of the spinning vehicle on flexible lines, much as spinning ice skaters slow themselves by extending their arms. Approximately 46 to 49 minutes after liftoff, Mars Polar Lander will separate from the Delta's third stage. Any remaining spin will be removed using the lander's onboard thrusters.

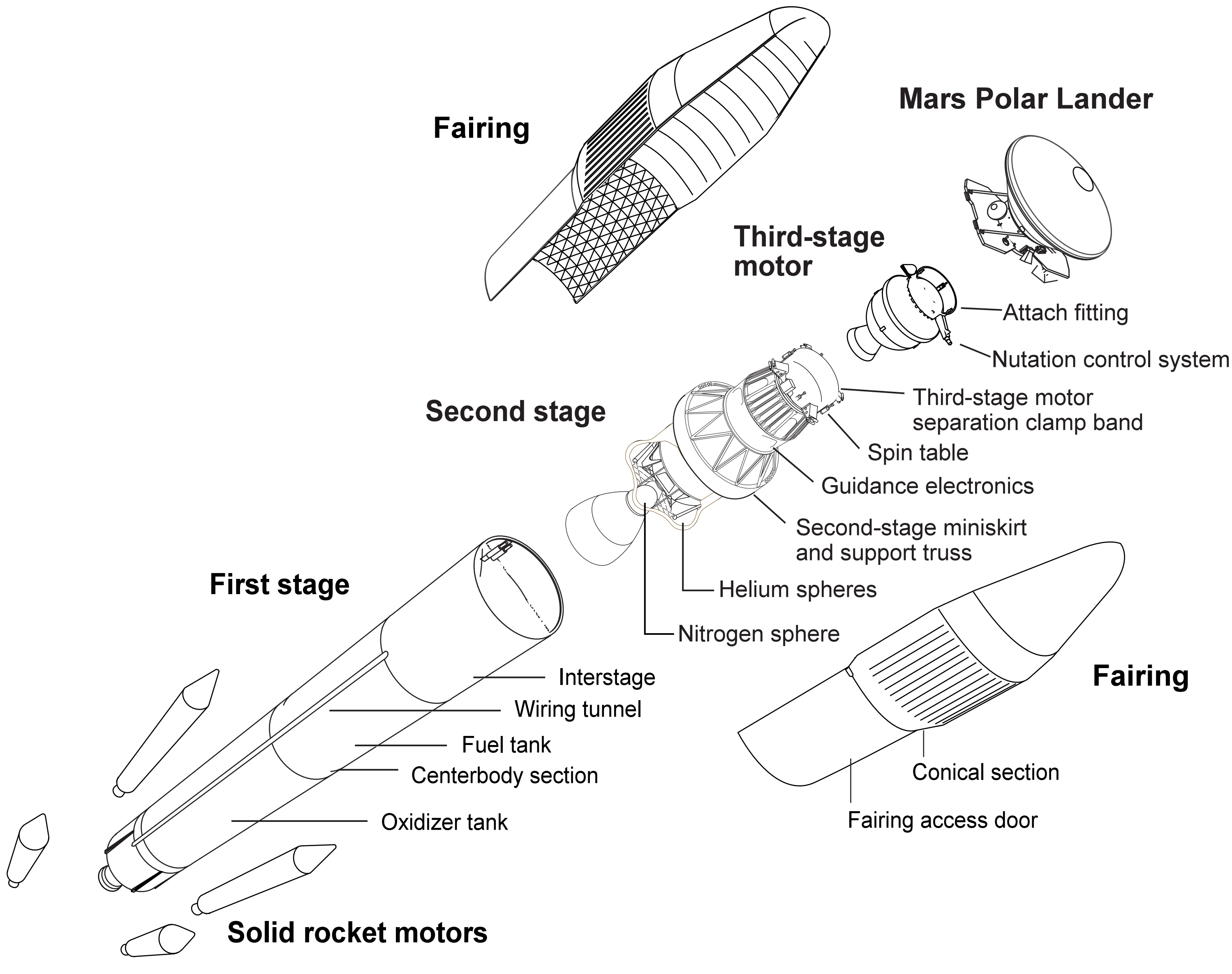
At the time of launch, the lander is encased within an aeroshell attached to a round platform called the cruise stage. Because the lander's solar panels are folded up within the aeroshell, a second set of solar panels is located on the cruise stage to power the spacecraft during its interplanetary cruise. About 50 to 55 minutes into flight, these hinged solar panels will unfold; the spacecraft will fire its thrusters to orient the solar panels toward the Sun. Around that time or shortly thereafter, the 34-meter-diameter (112-foot) antenna at the Deep Space Network complex in Canberra, Australia, will acquire Mars Polar Lander's signal.

Interplanetary cruise. Assuming launch during the primary period, Mars Polar Lander will spend 11 months in cruise, entering Mars' atmosphere December 3, 1999. The spacecraft's flight path is called a Type 2 trajectory because it will take 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 will fly slightly inward toward the Sun before spiralling out beyond Earth's orbit to Mars.

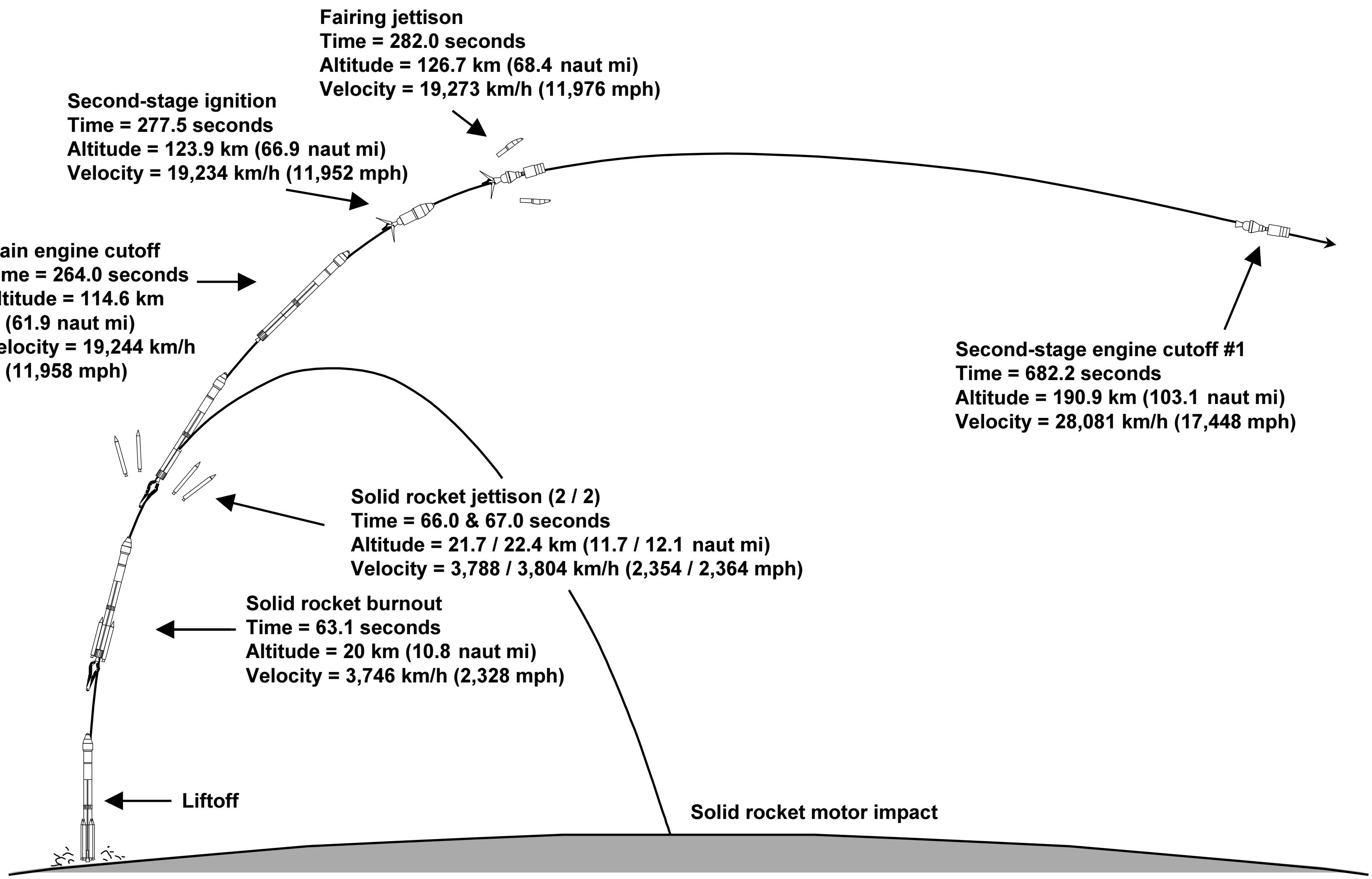
Lander Daily Launch Opportunity

The lander has one near-instantaneous launch opportunity each day (all times EST)

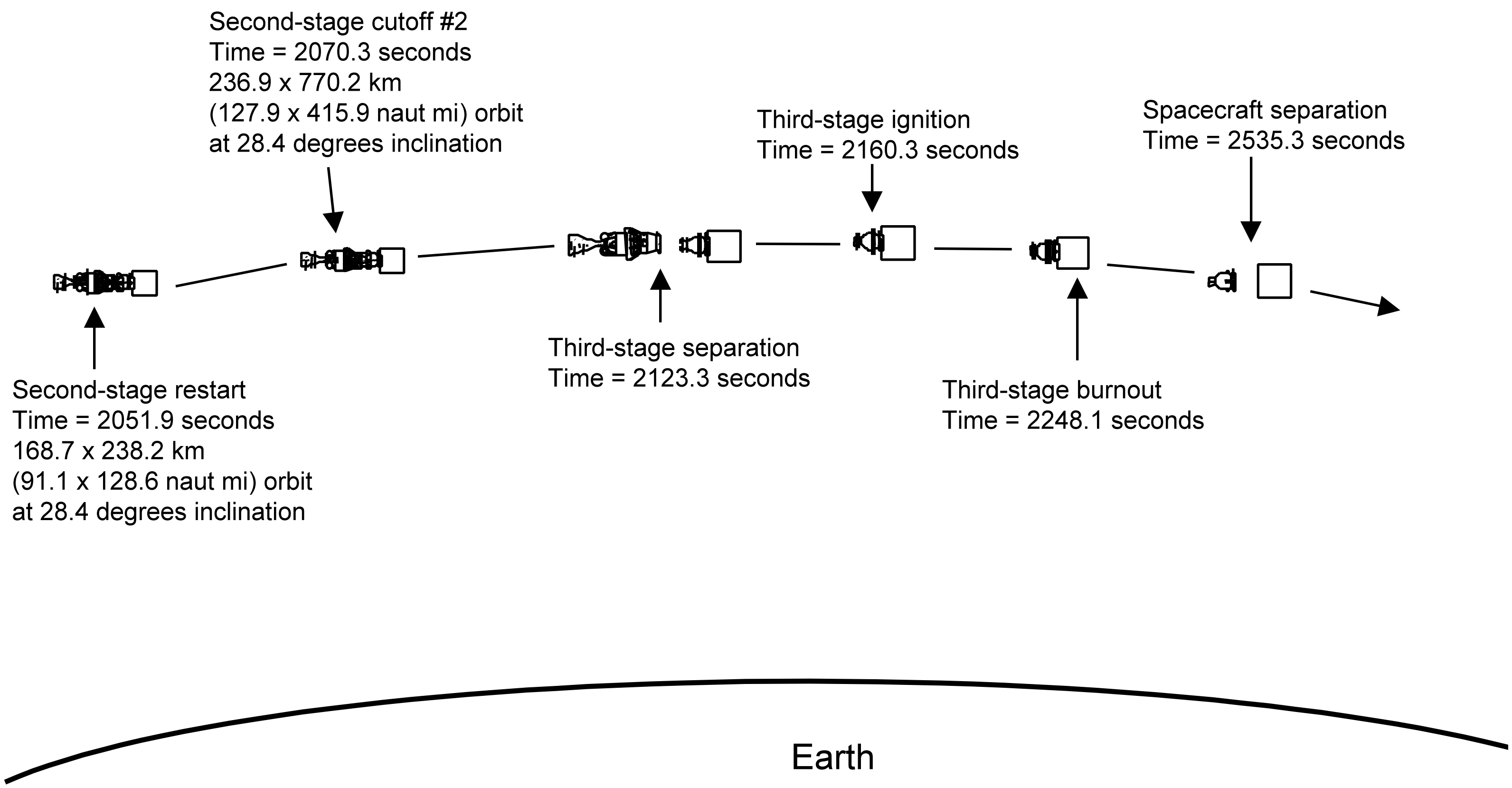
Date	*Opportunity*	*Date*	*Opportunity*
1/3/99	3:21:10 pm	1/16/99	2:35:07 pm
1/4/99	3:13:34	1/17/99	2:25:28
1/5/99	3:05:42	1/18/99	2:15:32
1/6/99	2:57:33	1/19/99	2:05:15
1/7/99	2:49:03	1/20/99	1:54:44
1/8/99	2:40:03	1/21/99	1:51:40
1/9/99	2:30:05	1/22/99	1:41:11
1/10/99	2:19:08	1/23/99	1:30:17
1/11/99	2:22:03	1/24/99	1:19:18
1/12/99	2:25:59	1/25/99	1:08:05
1/13/99	2:43:06	1/26/99	12:56:41
1/14/99	2:47:10	1/27/99	12:53:45
1/15/99	2:37:55		



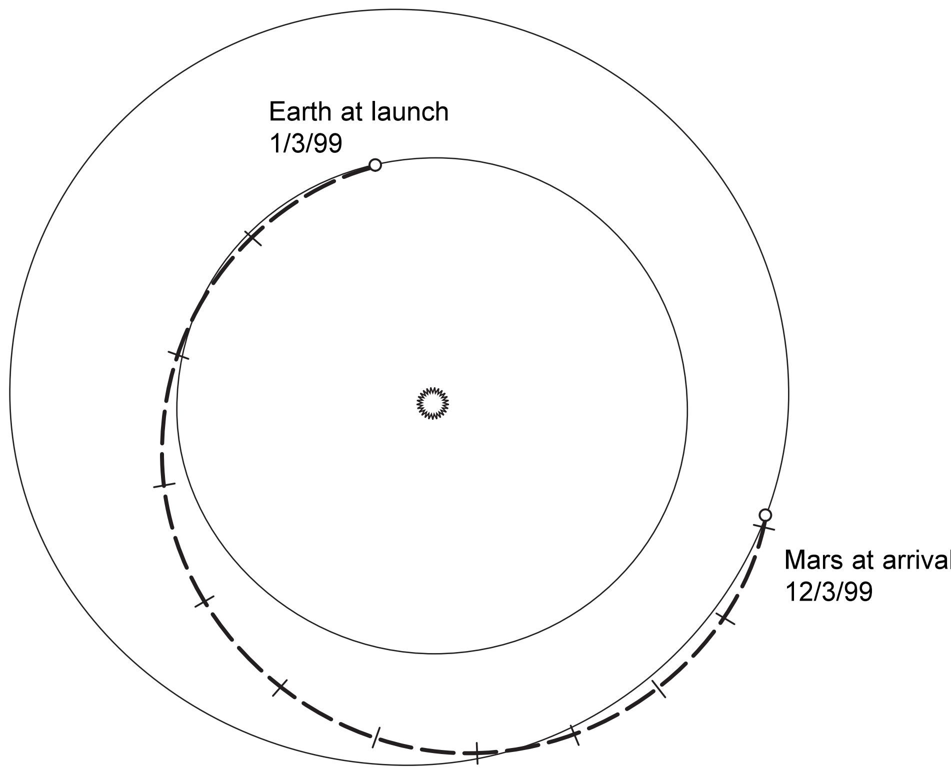
Lander's Delta II launch vehicle



Lander launch boost phase



Lander launch injection phase



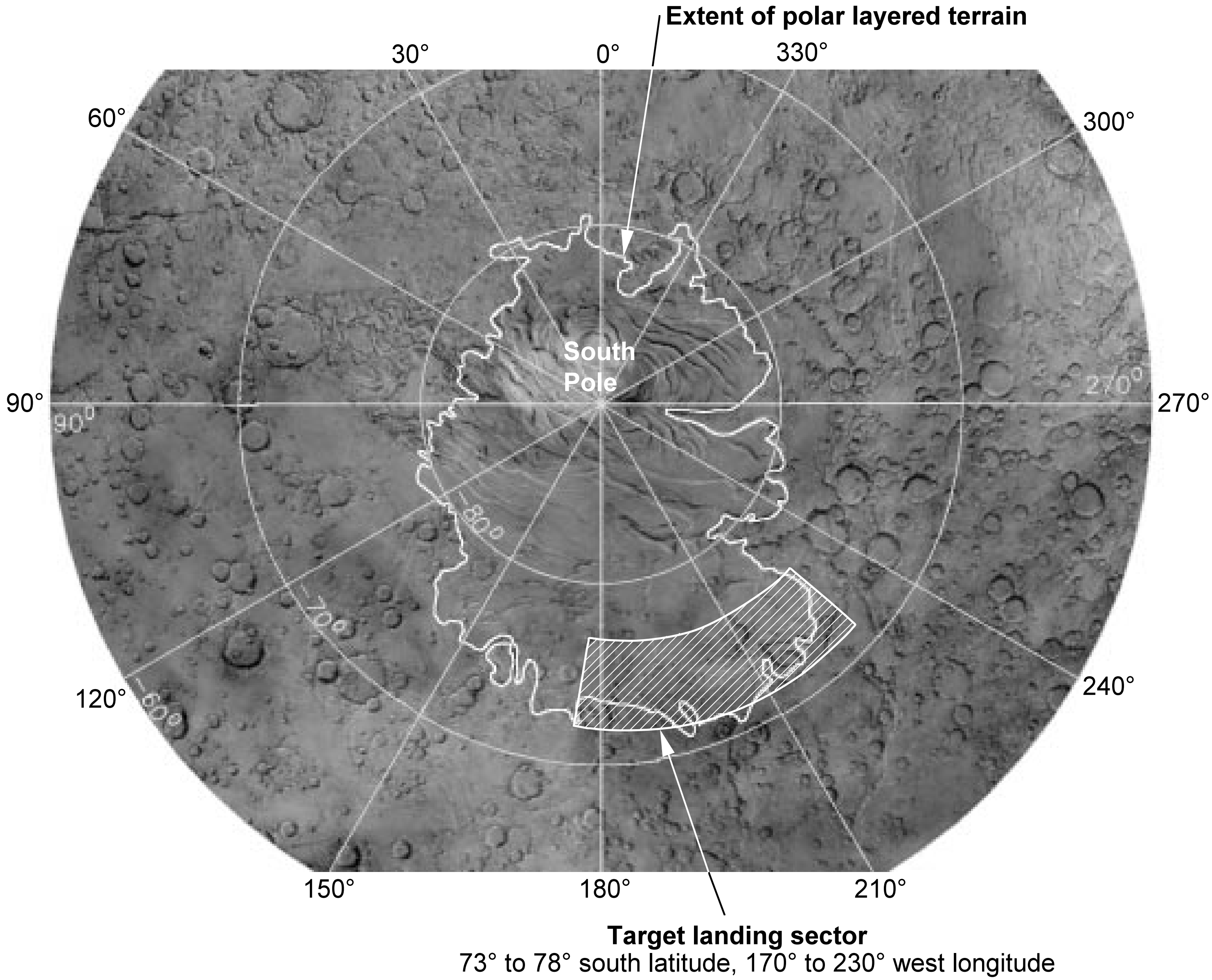
Lander's interplanetary trajectory

Toward the end of cruise, it will fly slightly out past the orbit of Mars before returning inward to intersect the planet's orbit.

Throughout cruise, the spacecraft will communicate 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 will be 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 will be conducted.

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

During interplanetary cruise, Mars Polar Lander is scheduled to fire its thrusters in up to six maneuvers to adjust its flight path. The first of these trajectory correction maneuvers will be carried out 15 days after launch. This maneuver, expected to be the largest and longest, will correct for injection errors and adjust the Mars arrival aimpoint. The maneuver is expected to take up to five minutes to execute.



Lander's target landing sector

The remaining trajectory correction maneuvers are expected to be smaller. They are scheduled 45 days after launch (February 17, assuming launch on January 3); 60 days before Mars arrival (about October 4); and 10 days before arrival (about November 23). A final contingency maneuver can be conducted if necessary from three days to seven hours before the spacecraft hits the upper atmosphere of Mars.

Science instruments will be tested and calibrated during two week-long periods scheduled during cruise. The first is planned 40 days after launch (February 12, assuming launch on January 3). The second is scheduled 90 days before arrival (about September 4).

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

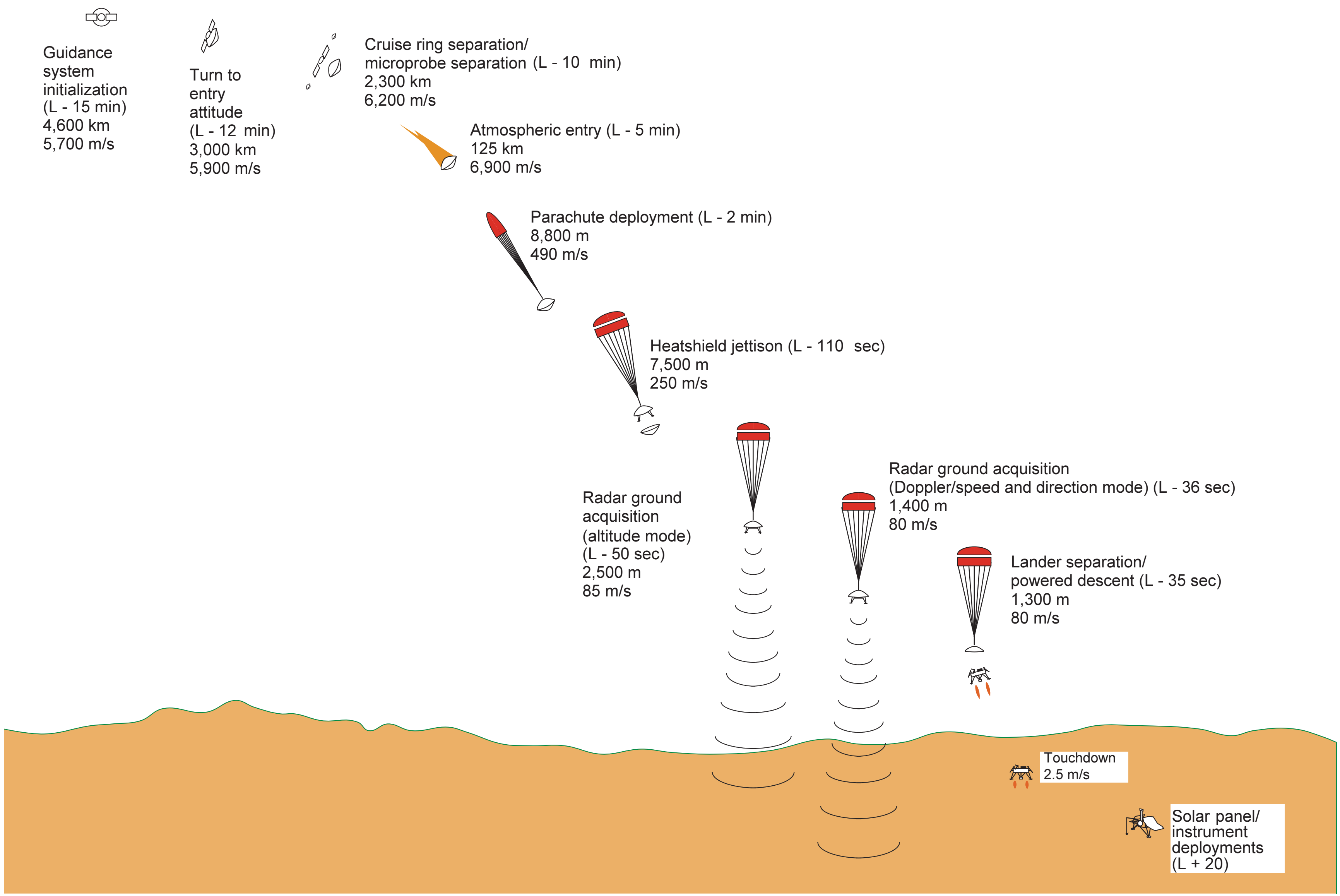
The meteorological package's pressure transducer will be powered on for a few minutes each month during cruise for calibration. The surface stereo imager will twice take images of dark space inside the lander's aeroshell during cruise to calibrate its charge-coupled device (CCD) detectors.

Pre-entry events. Preparations for the lander's entry into the Martian atmosphere will begin 14 hours in advance, when the final four-hour tracking session of the cruise period begins. This will be the final opportunity for ground controllers to gather navigation data before entry. About 12 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.

At seven hours and 25 minutes before entry, a 30-minute tracking session will begin. If a final trajectory correction maneuver is required to fine-tune the spacecraft's flight path, computer commands for that thruster firing could be sent to the spacecraft during this session. The maneuver would be executed as late as seven hours before entry.

A one-hour tracking session will begin five hours before entry. This session will be used to monitor spacecraft health and status and perform tracking after the final thruster firing. During this tracking session, at four hours and 40 minutes before entry, a series of valves will open to vent the descent engines. A pyro valve will fire at four hours and 30 minutes before entry to pressurize the descent engines.

Final contact with the spacecraft will begin 25 minutes before entry and will last 15 minutes. During this tracking session, the spacecraft team will receive information on the status of the propulsion system. Starting about 20 minutes before entry, heaters on the lander's thrusters will be turned on. Fifteen minutes before entry, software controlling the Mars Descent Imager will be initialized.



Entry, descent and landing

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 fire its thrusters for 80 seconds to turn it to its entry orientation. Five minutes before entry and 10 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 6.8 kilometers per second (15,400 miles per hour), 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 no more than 4 minutes and 33 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 1650 C (3000 F).

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 493 meters per second (1,100 miles per hour) some 7.3 kilometers (4.5 miles) 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 jettisoned. The first descent image will be taken 0.3 seconds before heat-shield separation. The imager will take a total of about 10 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 2.5 kilometers (1.5 miles) above the surface.

Shortly after radar ground acquisition, when the spacecraft is traveling at about 80 meters per second (180 miles per hour) some 1.4 kilometers (4,600 feet) 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 40 meters (130 feet) above the surface, and the spacecraft will fall back on its gyros and accelerometers for inertial guidance as it lands.

Once the spacecraft reaches either an altitude of 12 meters (40 feet) or a velocity of 2.4 meters per second (5.4 miles per hour), 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 5:00 a.m. local solar time (1:03 p.m. Pacific Standard Time). At this time, software which puts the spacecraft in safe mode in reaction to unexpected events will be reenabled. The clock rate of the computer's processor chip, which was set to 20 megahertz one minute before atmospheric entry, will be reset to 10 megahertz to save power. The descent imager will be turned off 60 seconds after landing.

After waiting two minutes to allow for dust kicked up by the landing to settle, the lander's solar arrays will be unfolded. Five 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.

Initial surface operations. A two-way direct Mars-to-Earth communication link will be established using the medium-gain antenna approximately 20 minutes after landing. The dish-shaped medium-gain antenna may not be pointed at Earth until the meteorological mast on the lander's deck is deployed.

During this session, data will be received from the lander on a 70-meter (230-foot) Deep Space Network antenna. During the 20-minute session, the lander will transmit data on spacecraft health; data from accelerometers during entry, descent and landing; post-landing meteorological data; and possibly some pictures. Once the direct communications session is finished, the lander will be configured to listen using its low-gain antenna.

The lander's meteorological package will take temperature and pressure readings throughout the Martian morning and into the afternoon. Observations by the lidar instrument will begin at 9 a.m. local Mars time.

At some point after the direct communications link with Earth is concluded, the lander will send data at a high rate over its UHF transmitter to Mars Climate Orbiter. The first opportunity for a high-speed communication link between the lander and orbiter will occur no later than two hours after landing, with a duration of 4.5 to 8 minutes. Data relayed during this session will include engineering telemetry, meteorological data, some Mars Descent Imager pictures and, possibly, pictures from the surface stereo imager.

Two additional sessions transmitting science data via the UHF transmitter to Mars Climate orbiter for relay will occur at 1 p.m. and 3 p.m. local Mars time. The highest priority of the afternoon will be returning the remaining pictures from the Mars Descent Imager, some of which will have been transmitted during the morning communications sessions.

High-priority data from the surface stereo imager and meteorological experiment will also be returned during the afternoon sessions. Some commands for the lander may be relayed back through the orbiter.

At some point during late afternoon activities, the medium-gain antenna will be positioned to support a direct Mars-to-Earth link the next day. At about 3:50 p.m., the lander will be placed in a reduced-power sleep mode for nighttime operations. About 30 minutes before power down, any data remaining in the spacecraft's random access memory will be automatically transferred to its "flash" memory – non-volatile memory that will be used to store data when the main computer is off – for transmission during the next day's direct communications links.

For mission planning purposes, engineers refer to Martian days, or "sols," each of which is 24 hours, 37 minutes in length. Activities in the afternoon of landing day, or "sol 0," will depend on the health of the lander. The flight team will use monitoring data to determine the depth of charge of the battery, the power output of the solar arrays, the tilt of the lander deck and temperatures onboard the spacecraft. If an unfavorable power or thermal environment exists, the lander will enter a "no frills" mode of operation, in which minimal science is performed or, under extreme conditions, the lander would switch to sleep mode.

The schedule of activities after landing, in fact, depends greatly on the condition of the spacecraft. If everything is operating very well, a highly optimistic scenario might include landing and getting basic spacecraft operations going on sol 0, sending to Earth entry, descent and landing data from the descent imager and other science instruments on sol 1, and then perhaps exercising the robotic arm for the first time on sol 2. If the flight team has to deal with any spacecraft anomalies, however, science operations such as exercising the robotic arm might be delayed up to perhaps a week.

Initial science operations will 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. Hourly 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.

Nighttime activities. The lander's onboard computer and meteorological package will be activated several times during the Martian nights. 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.

Sol 1. The lander will be powered up for the next day's activities at about 9 a.m. local Mars time. The microprocessor will run at a clock rate of 20 megahertz for two minutes to configure the spacecraft, then switch to 5 megahertz to save power. The highest priority will be transmitting any remaining pictures from the Mars Descent Imager. Primary data relay and commanding will occur as Mars Climate Orbiter passes overhead the lander, but a one-hour direct-to-Earth link is also planned in the afternoon. Science activities during sol 1 will include regular meteorological temperature and pressure observations.

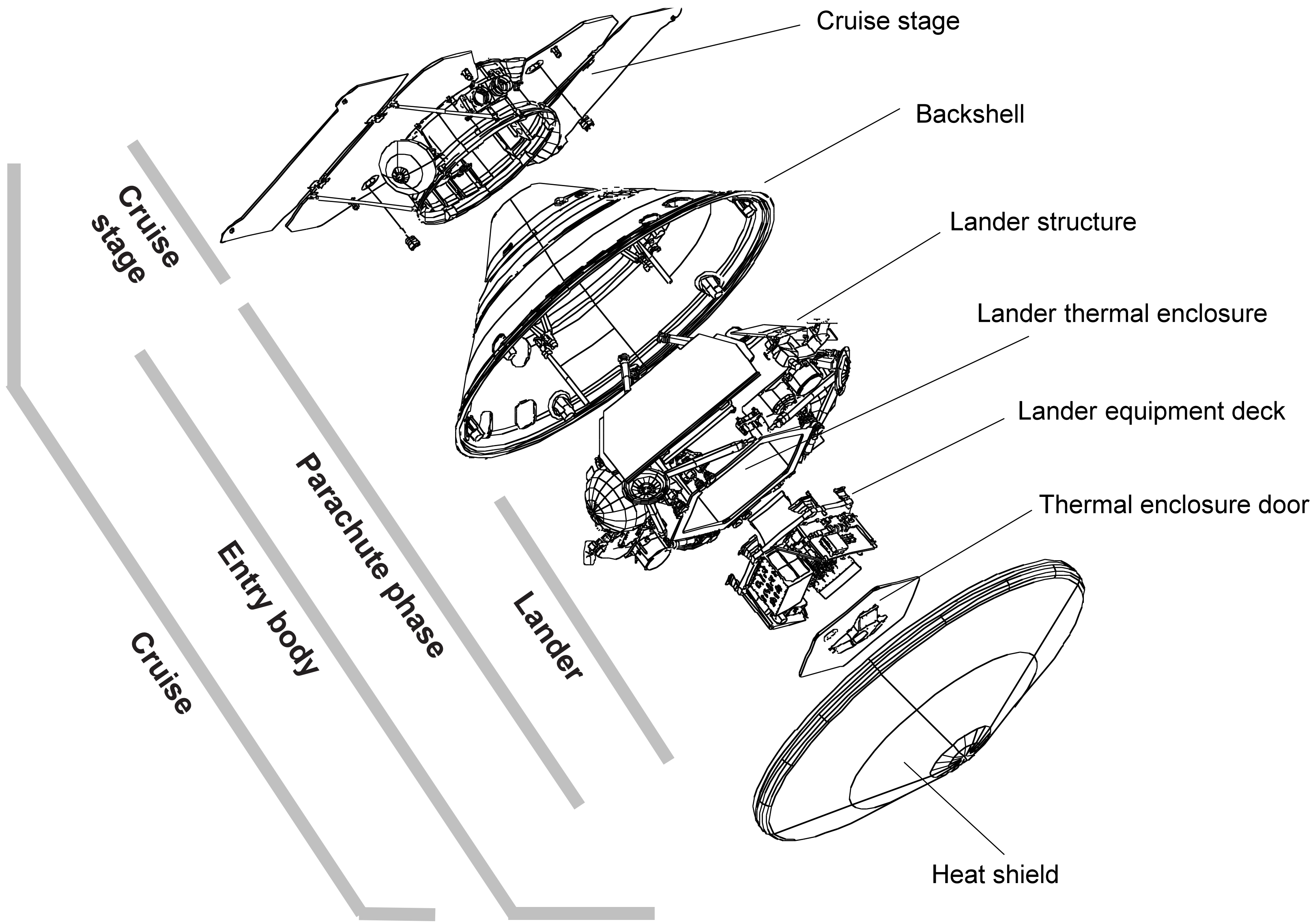
Payload activities. When the flight team concludes that the lander is ready to begin science operations, the spacecraft's robotic arm will be turned on and instructed to dig a shallow trench a few centimeters deep. The arm will probably take two days to complete this excavation of a few additional centimeters (or inches). While the arm is working, the thermal and evolved gas analyzer will be powered on for warm-up and calibration. A sample of the Martian soil will be scooped up, 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 27 C (80 F) will begin. 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. 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 1,027 C (1,880 F).

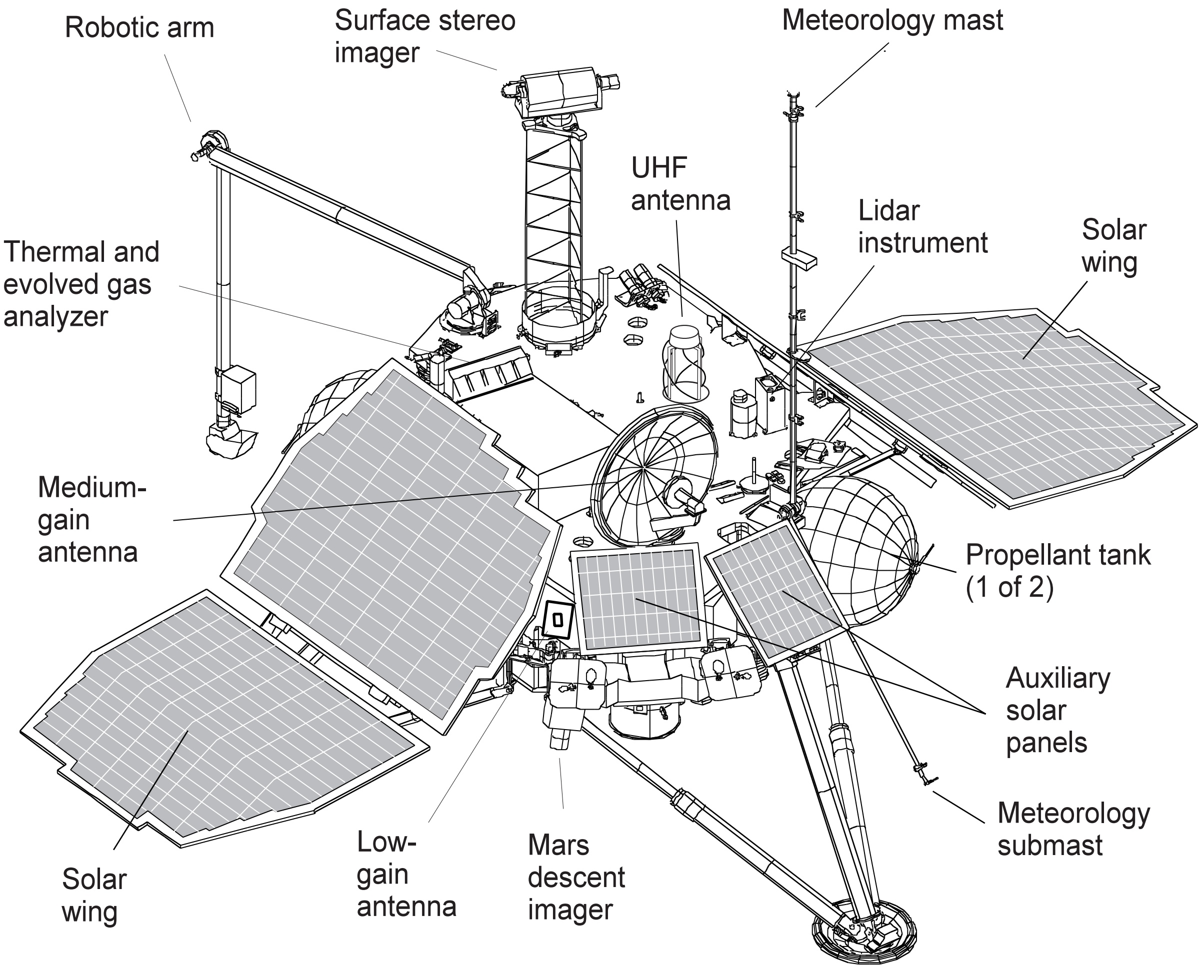
The meteorological package will take weather measurements throughout each day. Lidar observations are also planned. Throughout the 90-day primary mission, science experiments will collect data on atmospheric conditions and weather patterns, observe changes in the landscape and search for evidence of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

Telecommunications modes. Spacecraft operators will be able to take advantage of several different modes to communicate with Earth. Most data will be sent and commands received via a UHF radio link to Mars Climate Orbiter, which will use an X-band radio to communicate with Earth. The lander can also send data (but not receive commands) via Mars Global Survyeor. In addition, the lander is able to communicate directly with Earth – either sending data or receiving commands – using its own X-band radio and medium-gain antenna. The lander could also relay its science data through one of the orbiters while receiving commands on its X-band radio directly from Earth. The lander can communicate directly with Earth via X-band at 5,700 bits per second over the Deep Space Network's 70-meter (230-foot) antennas, or at 1,400 bits per second over 34-meter (112-foot) antennas. Using Mars Climate Orbiter or Mars Global Surveyor as a relay, the lander can send data at 128,000 bits per second.

At the beginning of the lander science mission, the spacecraft will have three or four



Lander flight system



Mars Polar Lander spacecraft

opportunities each day to transmit engineering and science data to Mars Climate Orbiter as it passes over the landing site. These lander-to-orbiter sessions must be scheduled when the orbiter is at least 20 degrees above the Martian horizon.

Each of these relay sessions is called a “hybrid” command/telemetry pass because each communications pass will be divided between a session sending commands to the lander and a session receiving data from the lander.

Spacecraft engineering data will be delivered to the lander 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 via the spacecraft team.

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.

Spacecraft

The lander stands 1.06 meters (3-1/2 feet) tall from the ground to the top of the science deck and measures 3.6 meters (12 feet) wide. The dry spacecraft weighs 512 kilograms (1,129 pounds); loaded with propellant, the weight is 576 kilograms (1,270 pounds). 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 3.6 meters (12 feet) when fully deployed. They are expected to provide up to 200 watts of 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 is 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 2.4-meter-diameter (7.9-foot) 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 8.4-meter-diameter (27-foot) 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 22 newtons (5 pounds) of force and one small thruster providing 4.4 newtons (1 pound) of force. The lander's final descent will be controlled by 12 descent engines, or retro-rockets, each delivering 266 newtons (60 pounds) of force, arranged in three groups on the underside of the lander. Two spherical propellant tanks underneath the lander's solar arrays carry 64 kilograms (141 pounds) 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 -30 C (-22 F)) during -80 C (-110 F) 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 Climate Orbiter or Mars Global Surveyor when one of the orbiters 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 74 to 77 degrees south. The lander is the only spacecraft planned by any space agency to study an area of Mars this far south or north.

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 and help determine whether it 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 characterize 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.

Images acquired in December 1997 by the currently orbiting Mars Global Surveyor reveal that the layered terrain in the area near Mars Polar Lander's landing site exhibits a range of brightnesses and contrasts, reflecting varying composition and erosional patterns. Bright areas are believed to contain surface ice, while dark areas may be partially frosted or frost-free ground.

The brighter areas appear "fuzzy," possibly the result of water-ice fog in the atmosphere immediately above the surface. The dark areas display textures that may be due to the intrinsic darkness of the material or to shadowing caused by topographic variations, perhaps eroded by wind.

The images, acquired at a range of more than 4,000 kilometers (2,500 miles) from the polar surface, cover an area slightly south of, or poleward from, Mars Polar Lander's landing site. The area of the landing site will be observed by Mars Global Surveyor in June 1999 after that orbiter begins its science mapping mission. Mission managers expect to fine-tune Mars Polar Lander's landing site by August 1999 – still four months before arrival – based on those new data.

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 1.5-meter (5-foot) 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 2-meter (6-1/2-foot) 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 1.2-meter (4-foot) 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 0.9-meter (3-foot) 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 10 to 15 centimeters (4 to 6 inches) 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 1,027 C (1,880 F). The heater is able to achieve this heat with the limited power of the solar-powered spacecraft because the sample chamber holds only 0.1 gram (1/300th of an ounce) 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 10 pictures as the lander descends toward Mars' surface, beginning just before heat-shield ejection at an altitude of about 8 kilometers (5 miles) and continuing until landing. The first pictures will show areas of Mars 9 kilometers (5.6 miles) square with a resolution of 7.5 meters (25 feet) per pixel, while the final pictures will show an area 9 meters (30 feet) square with a resolution of 9 mm (1/3 inch) 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 2 to 3 kilometers (1 to 2 miles)). 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 5 by 5 by 1 centimeters (2 by 2 by 1/2 inches), weighs less than 50 grams (1.8 ounces) 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 300 spores per square meter (about 250 spores per square yard) 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 110 C (230 F). 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 300 spores per square meter (250 spores per square yard).

A final inspection and spore count will be performed at NASA's Kennedy Space Center, FL, before the spacecraft is integrated with the Delta II launch vehicle. Results of that final total spore count by direct assay and by analysis should yield less than 300,000 spores.

Deep Space 2

The Deep Space 2 project is sending two 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 1 meter (three feet) 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

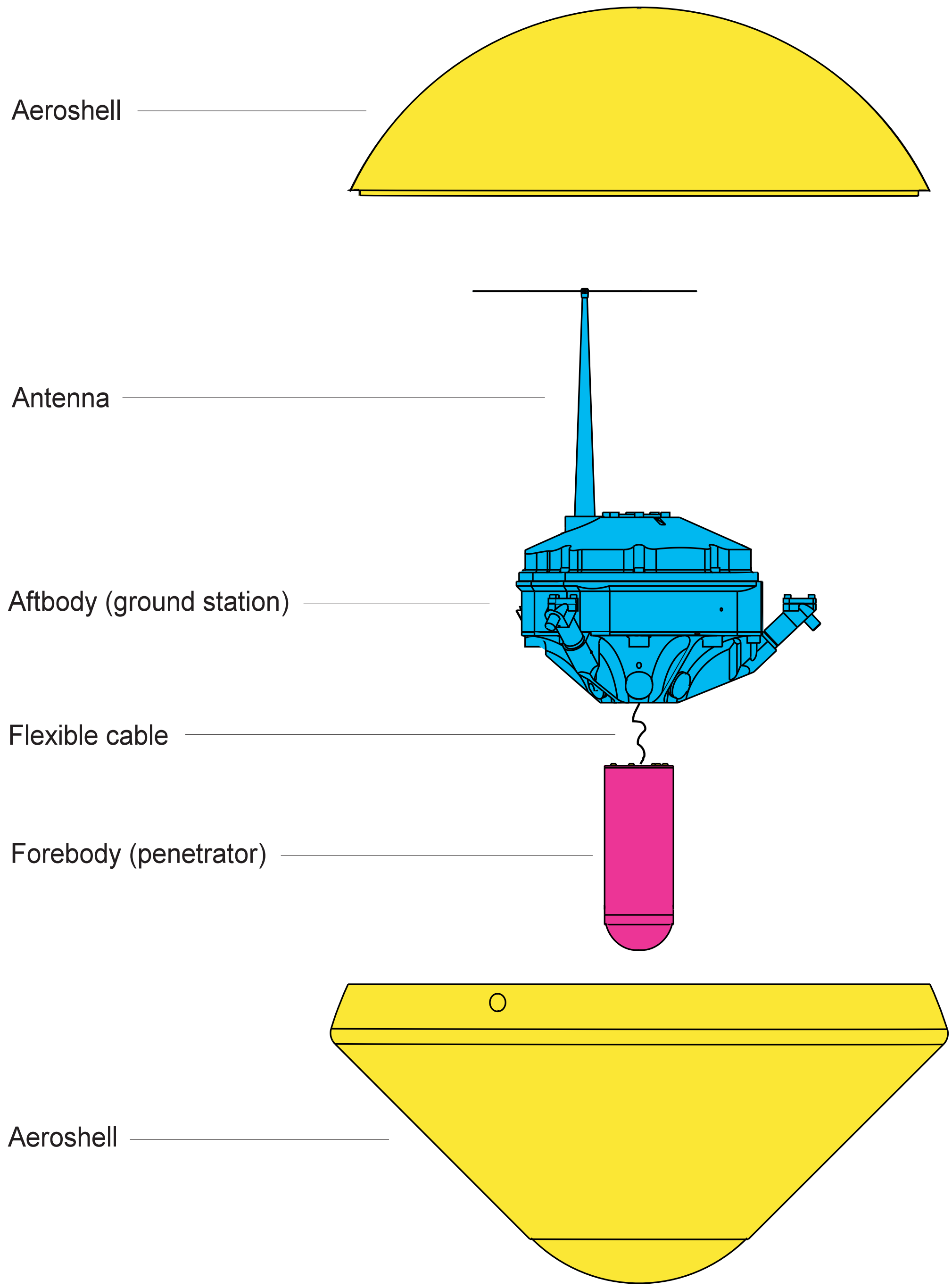
At the time of launch, the two Deep Space 2 probes are attached to the cruise stage on the Mars Polar Lander spacecraft. To simplify hardware and operations, there are no electrical interfaces between the probes and the lander's cruise stage. The probes are powered off during cruise, so there is no communication 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 with a softball-size probe inside.

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 50 to 85 seconds before Mars Polar Lander's landing some 100 kilometers (60 miles) 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 1 meter (3 feet) 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.



Deep Space 2 flight system

Unlike any spacecraft before, the Deep Space 2 probes smash into the planet at speeds of up to 200 meters per second (400 miles per hour). The probe's electrical and mechanical systems must withstand this crushing impact. This is achieved by using 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 forebody buried in the Martian soil must withstand temperatures as low as -120 C (-184 F), while the aftbody that remains on the surface is exposed to an environment as low as -80 C (-112 F).

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 six hours after impact. Data collection will continue until the probe batteries are depleted in about one to three days.

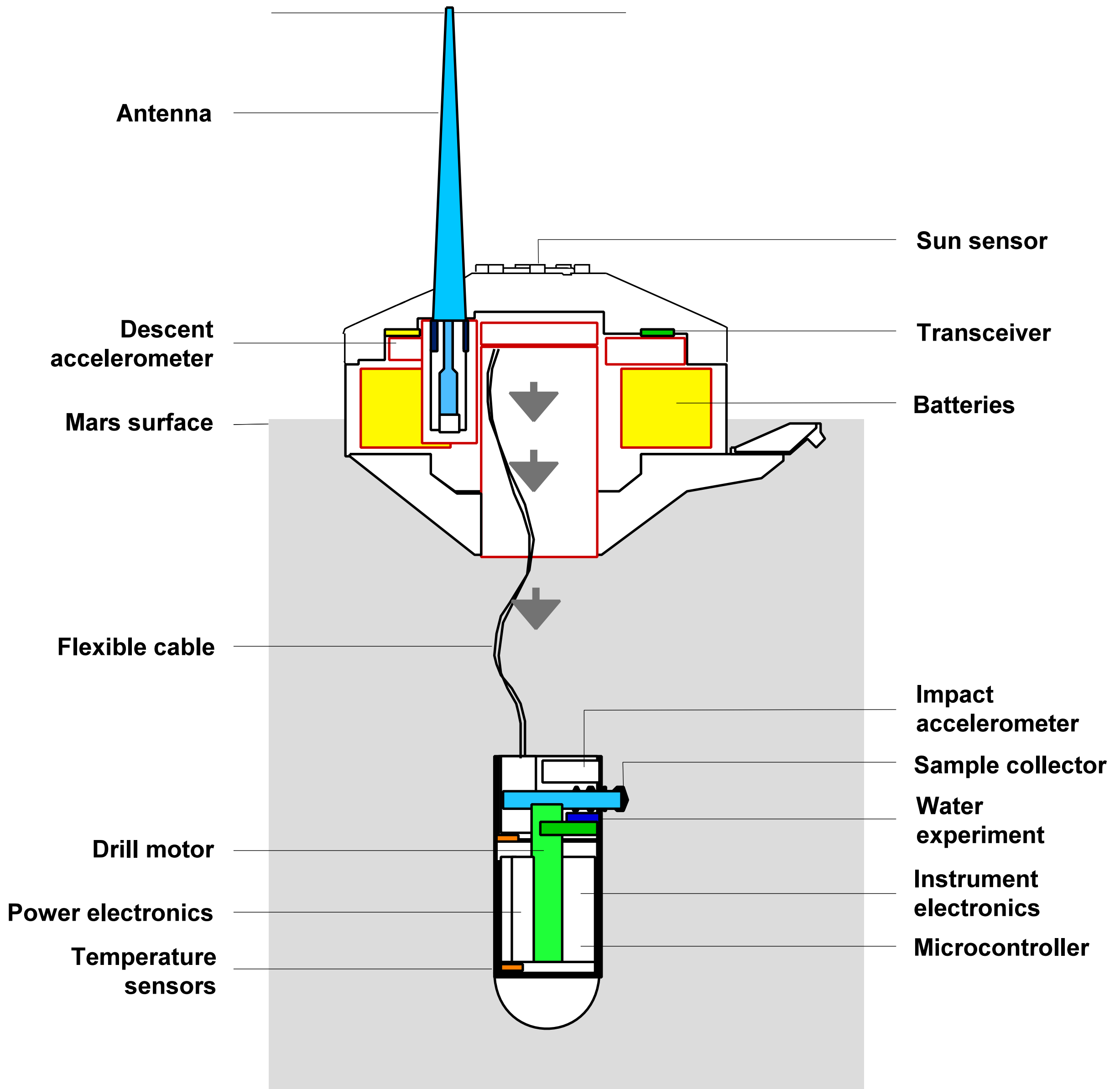
Each probe will transmit data to the orbiting Mars Global Surveyor using a radio in the UHF band (at frequencies near the upper channels of a conventional TV set) at a rate of 7,000 bits per second. The first such communications session is expected within two hours after impact. Normally each probe will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

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 conductivity and potential water content of the subsurface soil surrounding the bullet-like probe forebody.

Within six hours after impact, a micromotor will drive 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 two 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 until their batteries are depleted.



Deep Space 2 probe

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 performed 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 C (-40 F) while the heat shield surface experiences temperatures of up to 2,000 C (3,500 F). 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 3 kilometers (2 miles) high. Silicon carbide, the same material used in sandpaper, was selected as the material for the aeroshells, each of which weighs less than 1.2 kilogram (2.6 pounds). 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 200 meters per second (400 miles per hour).

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 200 meters per second (400 miles per hour) 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 microminiaturized radio transmitter and receiver system weighing less than 50 grams (1-3/4 ounces), 64 square centimeters (9.9 square inches) 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 -80 C (-112 F). 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 40 grams (1.4 ounce) 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 5 grams (1/5th of an ounce), has a volume of 5.6 cubic centimeters (one-third cubic inch) 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 (2.2 cubic centimeters (0.13 cubic inch)) and mass (3.2 grams (1/10th of an ounce)). 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 Kapton and copper traces. Kapton, a trade name for 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 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 100 milligrams (1/250th of an ounce) 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 11 cubic centimeters (1 cubic inch) in size and weighs less than 50 grams (1.6 ounce). The instrument electronics is about 4.8 cubic centimeters (one-third cubic inch) in size and weighs less than 10 grams (one-third ounce). The tunable diode laser is about 0.3 cubic centimeter (1/50th of a cubic inch) in size and weighs less than 1 gram (1/30th of an ounce). 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 5.5-meter-long (18-foot), 15-centimeter-diameter (6-inch) 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 200 meters per second (400 miles per hour). More than 63 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 6 meters (20 feet) long and 38 centimeters (15 inches) 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 supersonic 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 on 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.

Science objectives for Deep Space 2 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 tens of centimeters (many inches to a few feet).

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 100 kilometers (60 miles) 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, and Dr. James R. Murphy of New Mexico State University in Las Cruces.

❑ **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

The Mars ’98 and Deep Space 2 projects 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 acting 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 senior program executive of the Mission and Payload Development Division. Joseph Boyce is Mars ’98 program scientist, and Dr. Michael Meyer is Deep Space 2 program scientist.

At the Jet Propulsion Laboratory, Norman Haynes is director of the Mars Exploration Directorate, and Dr. Daniel McCleese is chief scientist for the Mars Exploration Directorate. For Mars ’98, Dr. John McNamee is project manager and Dr. Richard Zurek is project scientist. Mars Climate Orbiter and Mars Polar Lander will be operated after launch by JPL’s Mars Surveyor Operations Project; Glenn E. Cunningham is project manager and Dr. Sam Thurman is Mars ’98 flight operations manager. At Lockheed Martin Astronautics, Denver, CO, Dr. Edward A. Euler is the company’s Mars ’98 program director.

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.

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