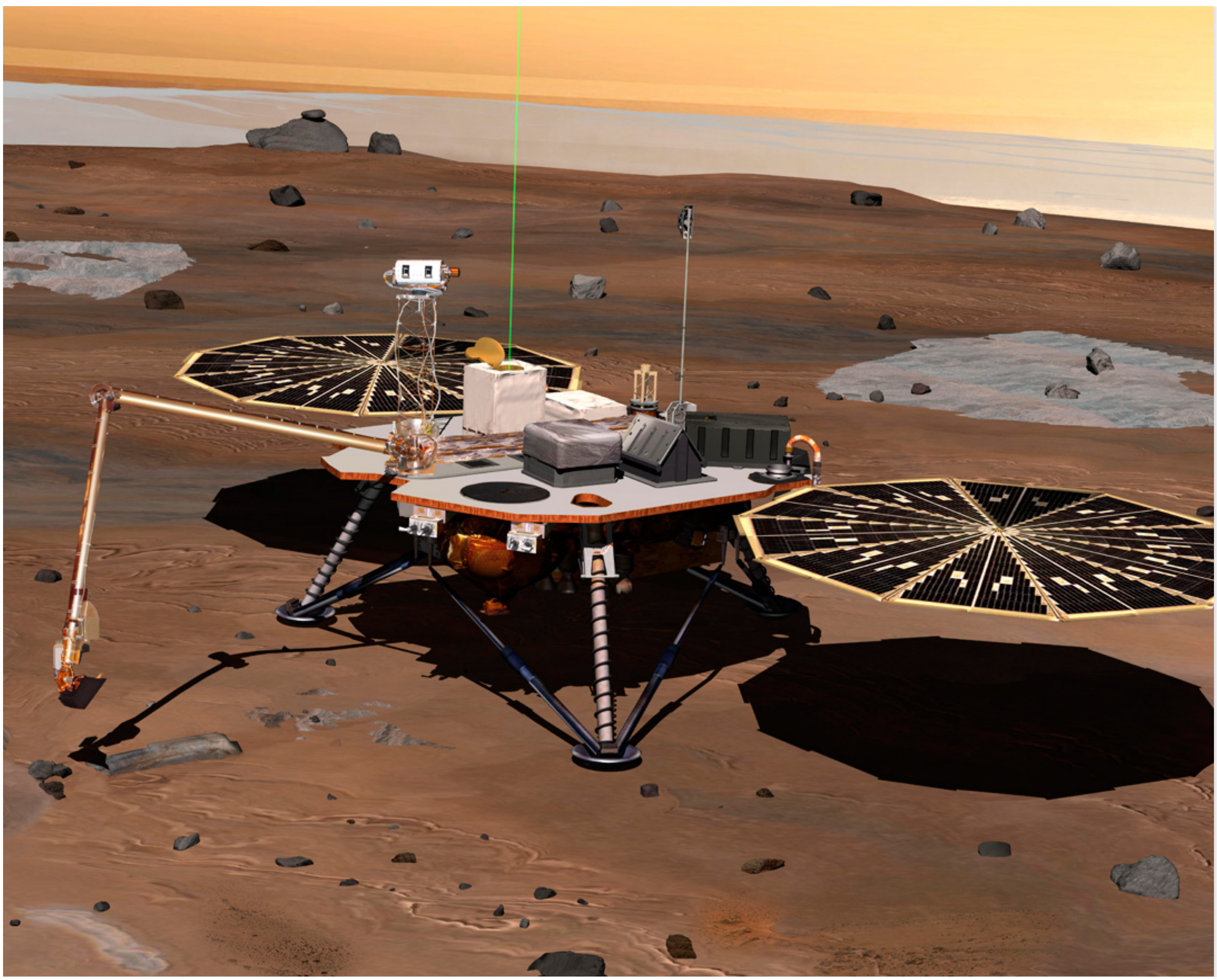
National Aeronautics and Space Administration

PRESS KIT/AUGUST 2007

Phoenix Launch
Mission to the Martian Polar North



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Media Services Information

NASA Television Transmission

The NASA TV Media Channel is available on an MPEG-2 digital C-band signal accessed via satellite AMC-6, at 72 degrees west longitude, transponder 17C, 4040 MHz, vertical polarization. In Alaska and Hawaii, it's available on AMC-7 at 137 degrees west longitude, transponder 18C, at 4060 MHz, horizontal polarization. A Digital Video Broadcast-compliant Integrated Receiver Decoder is required for reception. For digital downlink information for NASA TV's Media Channel, access to NASA TV's Public Channel on the Web and a schedule of programming for Phoenix Mars lander activities, visit **http://www.nasa.gov/ntv**.

Media Credentialing

News media representatives who would like to cover the launch in person must be accredited through the NASA Kennedy Space Center newsroom. Journalists may contact the newsroom at 321-867-2468 for more information.

Briefings

An overview of the mission will be presented in a news briefing broadcast on NASA Television originating from NASA Headquarters in Washington at 11:30 a.m. EDT July 9, 2007. A pre-launch briefing at Kennedy Space Center is scheduled at 1 p.m. EDT Aug. 1, 2007. Specific information about upcoming briefings, as they are scheduled, will be kept current on the Internet at **http://www.nasa.gov/phoenix**.

Live Feed

A live feed of video during key launch activities from the mission's control room at Cape Canaveral Air Force Station will be carried on NASA TV Media Channel between about 3:30 a.m. and 7 a.m. EDT on Aug. 3.

Internet Information

Information about NASA's Phoenix Mars Lander mission, including an electronic copy of this press kit, press releases, fact sheets, status reports, briefing schedule and images, is available at **http://www.nasa.gov/phoenix**. More detailed information on the mission is available at the Phoenix project Web site at **http://phoenix.lpl.arizona.edu**.

Quick Facts

Spacecraft

Cruise vehicle dimensions: Diameter 2.64 meters (8.66 feet), height 1.74 meters (5.71 feet); span of cruise solar arrays 3.6 meters (11.8 feet)

Lander dimensions: Height to top of meteorology mast 2.2 meters (7.2 feet), or slightly less depending on legs absorbing impact; span of deployed solar arrays 5.52 meters (18.1 feet); deck diameter 1.5 meters (4.9 feet); length of robotic arm 2.35 meters (7.71 feet)

Mass: 670 kilograms (1,477 pounds) total at launch, consisting of 350-kilogram (772-pound) lander plus cruise stage, aeroshell, parachute and propellant

Power: Solar panels and lithium-ion batteries

Science payload: 55 kilograms (121 pounds) consisting of robotic arm; robotic arm camera; surface stereoscopic imager; thermal and evolved-gas analyzer; microscopy, electrochemistry and conductivity analyzer; Mars descent imager; meteorological station

Launch Vehicle

Type: Delta II 7925 (three-stage)

Height with payload: 39.6 meters (130 feet)

Mass fully fueled: 231,126 kilograms (509,538 pounds)

Mission

Launch period: Aug. 3-24, 2007

Launch windows: Two nearly instantaneous windows daily; on Aug. 3, they are at 5:35 a.m. and 6:11 a.m. EDT

Launch site: Pad SLC-17A, Cape Canaveral Air Force Station, Florida

Earth-Mars distance on Aug. 3, 2007: 196 million kilometers (122 million miles)

Mars landing: If launched during first 15 days of launch period, landing May 25, 2008; if launched during last 7 days of launch period, landing June 5, 2008

Landing site: Leading candidate is at 68 degrees north latitude, 233 degrees east longitude, in Vastitas Borealis, the arctic plains of Mars

Earth-Mars distance on May 25, 2008: 276 million kilometers (171 million miles)

One-way radio transit time Mars to Earth on May 25, 2008: 15.3 minutes

Total distance traveled, Earth to Mars: About 680 million kilometers (423 million miles)

Primary mission: 90 Martian days, or “sols” (equivalent to 92 Earth days)

Expected near-surface atmospheric temperatures at landing site during primary mission: minus 73 C to minus 33 C (minus 100 F to minus 28 F)

Program

Cost: $420 million, including development, science instruments, launch and operations

Mars at a Glance

General

❑ One of five planets known to ancients; Mars was Roman god of war, agriculture and the state
❑ Yellowish brown to reddish color; occasionally the third brightest object in the night sky after the moon and Venus

Physical Characteristics

❑ Average diameter 6,780 kilometers (4,212 miles); about half the size of Earth, but twice the size of Earth's moon
❑ Same land area as Earth, reminiscent of a rocky desert
❑ 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 millions miles) to a maximum of 249.2 million kilometers (154.8 million miles); average is 227.7 million kilometers (141.5 million miles)
❑ Revolves around sun once every 687 Earth days
❑ Rotation period (length of day) 24 hours, 39 min, 35 sec (1.027 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), though expected no more than half that at Phoenix site
❑ 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

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

Science Investigations

The Phoenix Mars Lander will investigate a site in the far north of Mars to answer questions about that part of Mars, and to help resolve broader questions about the planet. The main questions concern water and conditions that could support life.

The landing region has water ice in soil close to the surface, which NASA's Mars Odyssey orbiter found to be the case for much of the high-latitude terrain in both the north and south hemispheres of Mars.

Phoenix will dig down to the icy layer. It will examine soil in place at the surface, at the icy layer and in between, and it will scoop up samples for analysis by its onboard instruments. One key instrument will check for water and carbon-containing compounds by heating soil samples in tiny ovens and examining the vapors that are given off. Another will test soil samples by adding water and analyzing the dissolution products. Cameras and microscopes will provide information on scales spanning 10 powers of 10, from features that could fit by the hundreds into the period at the end of this sentence to an aerial view taken during descent. A weather station will provide information about atmospheric processes in an arctic region where a coating of carbon-dioxide ice comes and goes with the seasons.

Mars is a vast desert where water is not found in liquid form on the surface, even in places where mid-day temperatures exceed the melting point of ice. One exception may be fleeting outbreaks that have been proposed to explain modern-day flows down some Martian gullies. Today's arid surface is not the whole story, though. Previous Mars missions have found that liquid water has persisted at times in Mars' past and that water ice near the surface remains plentiful today.

Water is a key to four of the most critical questions about Mars: Has Mars ever had life? How should humans prepare for exploring Mars? What can Mars teach us about climate change? How do geological processes differ on Mars and on Earth? Water is a prerequisite for life, a potential resource for human explorers and a major agent of climate and geology. That's why NASA has pursued a strategy of "follow the water" for investigating Mars. Orbiters and surface missions in recent years have provided many discoveries about the history and distribution of water on Mars -- such as minerals that formed in wet environments long ago and liquid flows that are still active today in hillside gullies.

The landing site and onboard toolkit of Phoenix position this mission to follow the water further. The mission's three main science objectives are:

1. Study the history of water in all its phases.

On a time scale of billions of years, ice near the surface where Phoenix will land might be the remnant of an ancient northern sea. Several types of evidence point to plentiful liquid water on ancient Mars, and the northern hemisphere is low and smooth compared to the southern hemisphere. Much of the water that could have remained liquid when ancient Mars had a thicker atmosphere may now be underground ice.

On a time scale of tens of thousands to a few million years, ice near the surface where Phoenix lands might periodically thaw during warmer periods of climate cycles. The tilt of Mars' axis wobbles more than Earth's, and the shape of Mars' orbit also cycles over time, from rounder to more elongated. Currently, Mars is about 20 percent farther from the sun during northern summer than during northern winter, so the summers are relatively cool in the north. As the orbit varies, the northern ice cap will enjoy warm winters on a 50,000-year cycle. The wobble of Mars' axis may also cause the climate to change on a time scale of 100,000 to millions of years.

On much shorter time scales, the arctic ground "breathes" every day and every season, converting tiny amounts of ice into water vapor on summer days and condensing tiny amounts of frost from the atmosphere at night or in winter. In this way, the ice table slowly rises and recedes as the climate changes.

Phoenix will collect information relevant for understanding processes affecting water at all these time scales, from the planet's distant past to its daily weather.

2. Determine if the Martian arctic soil could support life.

Life as we know it requires liquid water, but not necessarily its continuous presence. Phoenix will investigate a hypothesis that some ice in the soil of the landing site may become unfrozen and biologically available at times during the warmer parts of long-period climate cycles. Life might persist in some type of dormant microbial form for millions of years between thaws, if other conditions were right.

The spacecraft is not equipped to detect past or present life. However, in addition to studying the status and history of water at the site, Phoenix will look for other conditions favorable to life.

One condition considered essential for life as we know it is the presence of molecules that include carbon and hydrogen. These are known as organic compounds, whether they come from biological sources or not. They include the chemical building blocks of life, as well as substances that can serve as an energy source, or food, for life. Phoenix would be able to detect even very small amounts and identify them. Two Viking spacecraft that NASA landed on Mars in 1976 made the only previous tests for organic compounds in Martian soil, and they found none. Conditions at the surface may be harsh enough to break organic molecules apart and oxidize any carbon into carbon dioxide. Phoenix will assess some factors in those oxidizing conditions, and it will check for organic chemicals below the surface, as well as in the top layer. Organic chemicals would persist better in icy material sheltered from sunshine than in surface soil exposed to harsh ultraviolet radiation from the sun.

Phoenix will also be checking for other possible raw ingredients for life. It will examine how salty and how acidic or alkaline the environment is in samples from different layers. It will assess other types of chemicals, such as sulfates, that could be an energy source for microbes.

3. Study Martian weather from a polar perspective.

In Mars' polar regions, the amount of water vapor in the thin atmosphere -- the humidity -- varies significantly from season to season. Winds carrying water vapor can move water from place to place on the planet. The current understanding of these processes is based on observations from orbit and limited meteorological observations from earlier Mars landers closer to the equator. Phoenix will use an assortment of tools to directly monitor several weather variables in the lower atmosphere at an arctic site.

Phoenix will measure temperatures at ground level and three other heights to about 2 meters (7 feet) above ground. It will check the pressure, humidity and composition of the atmosphere at the surface. And it will identify the amounts, altitudes and movements of clouds and dust in the sky above.

Over the course of the mission, this unprecedented combination of Martian meteorological measurements will help researchers evaluate correlations such as whether southbound winds carry more humidity than northbound winds; whether drops in air pressure are associated with increased dust; and how the amount of water vapor at the bottom of the atmosphere changes from late spring to mid-summer or later.

Science Instruments

The Phoenix Mars Lander carries seven science instruments, three of which are suites of multiple tools.

❑ The **Robotic Arm** will allow Phoenix to explore vertically and to use instruments on the spacecraft deck to analyze samples of Martian soil and ice. The arm will dig trenches, position some arm-mounted tools for studying the soil in place, and deliver scooped-up samples to other instruments.

The aluminum and titanium arm is 2.35 meters (7.7 feet) long. One end is attached to the lander's deck. An elbow joint is in the middle. The other end has a scoop with blades for digging into the soil and a powered rasp for breaking up frozen soil. The arm moves like a backhoe, using four types of motion: up-and-down, side-to-side, back-and-forth and rotating.

The arm can reach far enough to dig about half a meter (20 inches) deep. However, the subsurface ice layer expected at the landing site may not lie that deep. Once the arm reaches the icy-soil layer, the powered rasp will be used to acquire samples.

Because the arm will be making direct contact with icy soil that is conceivably a habitat where microbes could survive, extra precaution has been taken with it to prevent introducing life from Earth. Before the arm was given a sterilizing heat treatment in March 2007, it was enclosed in a biological barrier wrap. This barrier is keeping microbes off the arm during the subsequent months before launch. It will not open until after Phoenix has landed on Mars.

The robotic arm uses design work for a similar arm flown on the 1999 Mars Polar Lander mission, with refinements including enhanced capability for collecting an icy sample.

A team led by Robert Bonitz at NASA's Jet Propulsion Laboratory, Pasadena, Calif., engineered and tested the Phoenix Robotic Arm. Alliance Spacesystems Inc., Pasadena, built it. Ray Arvidson of Washington University in St. Louis is the lead scientist for this instrument.

❑ The **Robotic Arm Camera** rides fastened to the arm just above the scoop. It will provide closeup color images of Martian soil at the landing site, of the floor and walls of trenches dug by the arm, and of soil and ice samples before and after they are in the scoop.

Information the camera reveals about soil textures will aid in selecting what to pick up as samples for analysis. Observations of trench walls will determine whether they show fine-scale layering, which could result from changes in the Martian climate.

The camera has a double Gauss lens system, a design commonly used in 35-millimeter cameras. Images are recorded by a charge-coupled device (CCD) similar to those in consumer digital cameras. The instrument includes sets of red, green and blue light-emitting diodes (LEDs) for illuminating the target area.

The focus can be adjusted by a motor, which is a first for a camera on an interplanetary spacecraft. The focus can be set as close as about 11 millimeters (half an inch) and out to infinity. With a resolution of 23 microns per pixel at the closest focus, this camera can show details much finer than the width of a human hair.

A team led by H. Uwe Keller at the Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany, and by Peter Smith at the University of Arizona originally built this camera for the Mars Surveyor 2001 Lander mission, which was canceled in 2000. It is similar to a camera on the robotic arm of the unsuccessful Mars Polar Lander spacecraft, though with an improved illumination system. For the Phoenix Robotic Arm Camera, Keller is the lead scientist and Chris Shinohara of the University of Arizona is the lead engineer.

❑ The **Surface Stereoscopic Imager** will record panoramic views of the surroundings from atop a mast on the lander. Its images from two cameras situated about as far apart as a pair of human eyes will provide three-dimensional information that the Phoenix team will use in choosing where to dig and in operating the robotic arm.

A choice of 12 different filters for each eye enables the instrument to produce images not only in full color, but in a several specific visual and infrared frequencies useful for interpreting geological and atmospheric properties. The multispectral and three-dimensional information will help scientists understand the geology of the landing area.

The twin cameras will be able to look in all directions from a perch about 2 meters (7 feet) above Martian ground level. They will see with about the same resolution as human eyes, capturing each view onto 1-megapixel charge-coupled devices (a 1,024-by-1,024-pixel CCD for each eye).

The instrument will sometimes point upward to assess how much dust and water vapor is in the atmosphere. When the robotic arm delivers soil and ice samples to deck-mounted instruments, the Surface Stereoscopic Imager will be able to look downward to inspect the samples. Views of the spacecraft's deck will also monitor dust accumulation, which is of scientific interest for inferences about Martian winds and of engineering interest for effects of the dust build-up on solar panels.

A University of Arizona team led by Chris Shinohara built the Phoenix Surface Stereoscopic Imager. Mark Lemmon of Texas A&M University, College Station, is lead scientist for this camera. The instrument closely resembles a stereo imager on Mars Polar Lander, which in turn used design features from the imager on Mars Pathfinder, which provided stereo views from the surface of Mars in July 1997.

❑ The **Thermal and Evolved-Gas Analyzer** will study substances that are converted to gases by heating samples delivered to the instrument by the robotic arm. It provides two types of information. One of its tools, called a differential scanning calorimeter, monitors how much power is required to increase the temperature of the sample at a constant rate. This reveals which temperatures are the transition points from solid to liquid to gas for ingredients in the sample. The gases that are released, or “evolved,” by this heating then go to a mass spectrometer, a tool that can identify the chemicals and measure their composition.

The mass spectrometer will determine whether the samples of soil and ice contain any organic compounds. It would be used to identify the types and amounts if any are present. Finding any would be an important result for interpreting the habitability of the site.

The instrument will also give information about water and carbon dioxide present as ices or bound to minerals. The amount of heat needed to drive off water or carbon dioxide that is bound to minerals is characteristically different for different minerals. The calorimeter’s information from that process can help identify minerals in the soil, including carbonates if they are present.

The mass spectrometer will measure the ratios of different isotopes of carbon, oxygen, hydrogen, argon and some other elements in the Martian samples. Isotopes are alternate forms of the same element with different atomic weights due to different numbers of neutrons. Ratios can be changed by the effects of long-term processes that act preferentially on lighter or heavier isotopes of the same element. For example, some of Mars’ original water was lost from the planet by processes at the top of the atmosphere, favoring the removal of lighter isotopes of hydrogen and oxygen and leaving modern Mars water with a raised ratio of heavier isotopes.

The instrument has eight tiny ovens for samples, each to be used only once. The ovens are about 1 centimeter (about half an inch) long and 2 millimeters (one-eighth inch) in diameter. At the start of an analysis, sample material is dropped into the oven through a screen. The oven closes after a light-beam detector senses that it is full. The experiment gradually heats samples to temperatures as high as 1,000 degrees Celsius (1,800 degrees Fahrenheit).The heating process drives off water and any other volatile ingredients as a stream of gases. Those gases are directed to the mass spectrometer.

One of the samples that the instrument will analyze will be a special material that the lander carries from Earth, specially prepared to be as free of carbon as possible. This will serve as an experimental control as the instrument analyzes samples excavated at Mars. The control material is made of a machinable glass ceramic substance named Macor, from Corning Inc. The arm will scrape some of it up and deliver it to the analyzer to get a reading showing how well the experiment can eliminate carbon carried from Earth. Carbon detected in assessments of Martian samples might be unavoidable traces of Earth carbon if the readings are no higher than the amount in this control sample.

The mass spectrometer part of the analyzer will examine samples of atmosphere at the landing site, in addition to the evolved gases from scooped-up samples. The atmospheric measurements will add information about humidity to the weather data monitored by the spacecraft’s Meteorological Station.

The Thermal and Evolved-Gas Analyzer was built by teams at the University of Arizona, led by William Boynton (science lead) and Heather Enos (project manager), and at the University of Texas, Dallas, led by John Hoffman. It is adapted from a similar instrument with the same name that flew on the Mars Polar Lander mission in 1999.

❑ The **Microscopy, Electrochemistry and Conductivity Analyzer** will use four tools to examine soil. It will assess characteristics that a gardener or farmer would learn from a soil test, plus several more. Three of the tools will analyze samples of soil scooped and delivered by the robotic arm -- a wet chemistry laboratory and two types of microscopes. The fourth tool is mounted near the end of the arm, and has a row of four small spikes that the arm will push into the ground to examine electrical conductivity and other properties of the soil.

The wet chemistry laboratory has four teacup-size beakers. Each will be used only once. Samples from Mars' surface and three lower depths may be analyzed and compared. The instrument will study soluble chemicals in the soil by mixing water with the sample to a soupy consistency and keeping it warm enough to remain liquid during the analysis.

On the inner surfaces of each beaker are 26 sensors, mostly electrodes behind selectively permeable membranes or gels. Some sensors will give information about the pH of the soil -- the degree to which it is acidic or alkaline. Soil pH is an important factor in what types of chemical reactions, or perhaps what types of microbes, a soil habitat would favor, and it is has never been measured on Mars. Other sensors will gauge concentrations of such ions as chlorides, bromides, magnesium, calcium and potassium, which form soluble salts in soil, and will record the level of the sample's oxidizing potential. One chemically important ion in soil, sulfate, cannot be directly sensed, so the analysis of each sample will end with a special process that determines the amount of sulfate by observing its reaction with barium. Comparisons of the concentrations of water-soluble ions in samples from different depths may provide clues to the history of water in the soil.

The wet chemistry setup has a built-in robotic laboratory technician that adds potions to each beaker in a choreographed two-day sequence. Before each soil sample goes in, about 25 cubic centimeters (nearly two tablespoons) of ice with dilute concentrations of several ions is slowly melted in a special container, a process that takes one to two hours. After the water is released into the beaker, the sensors make baseline measurements at this starting point. The first of five pill-size crucibles of prepared chemicals is then added to increase ion concentrations by a known amount in order to calibrate the measurements. Next, a drawer above the beaker extends to receive the soil sample, and the scoop on the robotic arm drops up to one cubic centimeter (one-fifth of a teaspoon) of soil into the drawer, which then retracts and dumps the sample into the beaker. A paddle stirs the soup for hours while the sensors take measurements. The next day, the second crucible adds nitrobenzoic acid to the beaker to test how ions from the soil react to increased acidity. The last three crucibles hold barium chloride. As they are added, one at a time, any sulfate from the soil reacts with the barium to make an insoluble compound, taking both the barium and the sulfate out of solution. The amount of sulfate in the soil sample is determined by measuring the amount of unreacted barium left behind.

The "microscopy" part of the Microscopy, Electrochemistry and Conductivity Analyzer will examine soil particles and possibly ice particles with both an optical microscope and an atomic force microscope. The robotic arm delivers soil samples to a wheel that rotates to present the samples to the microscopes. Along the perimeter of the wheel are substrates with different types of surfaces, such as magnets and sticky silicone. This allows the experiment to get information from the particles' interaction with the various surfaces, as well as from the sizes, shapes and colors of the particles themselves.

The biggest particles the optical microscope can view are about as long across as the thickness of a dime, just over a millimeter. The smallest it can see are about 500 times smaller

-- about 2 microns across. That would be the smallest scale ever seen on Mars, except that the atomic force microscope will image details down to another 20 times smaller than that -- as small as about 100 nanometers, one one-hundredth the width of a human hair.

The optical microscope obtains color information by illuminating the sample with any combination of four different light sources. The illumination comes from 12 light-emitting diodes shining in red, blue, green or ultraviolet parts of the spectrum. The atomic force microscope assembles an image of the surface shape of a particle by sensing it with a sharp tip at the end of a spring, which has a strain gauge indicating how far the spring flexes to follow the contour of the surface. The process is like a much smaller version of a phonograph needle tracking the bumpiness inside the groove of a vinyl record.

The shapes and the size distributions of soil particles may tell scientists about environmental conditions the material has experienced. Tumbling rounds the edges. Repeated wetting and freezing causes cracking. Clay minerals formed during long exposure to water have distinctive, plate-shaped particle shapes.

The "conductivity" part of the Microscopy, Electrochemistry and Conductivity Analyzer will assess how heat and electricity move through the soil from one spike to another of a four-spike electronic fork that will be pushed into the soil at different stages of digging by the arm. For example, a pulse of heat will be put onto one spike, and the rate at which the temperature rises on the nearby spike will be recorded, along with the rate at which the heated needle cools off. A little bit of ice in the soil can make a big difference in how well the soil conducts heat. Similarly, soil's electrical conductivity is a sensitive indicator of moisture in the soil. Soil moisture may have subtle stages intermediate between frozen solid and liquid, including warm ice and water films, which may be biologically available. The device, called the thermal and electrical conductivity probe, adapts technology used in commercial soil-moisture gauges for irrigation control systems.

The conductivity probe has an additional role besides soil analysis. It will serve as a humidity sensor when held in the air. Also, slight temperature changes from one spike to the next can allow it to estimate wind speed.

The Microscopy, Electrochemistry and Conductivity Analyzer is based on an instrument developed for the Mars Surveyor 2001 Lander mission, which was canceled in 2000. The instrument for Phoenix inherited many of the original electronic and structural components. The conductivity probe and other improvements have been added to the earlier design.

A team led by Michael Hecht at NASA's Jet Propulsion Laboratory, Pasadena, Calif., designed and built the analyzer. A consortium led by Urs Staufer of the University of Neuchatel, Switzerland, provided the atomic force microscope. The University of Arizona provided the optical microscope, equipped with an electronic detector (the same as in the Robotic Arm Camera) from the Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany. John Marshall of the SETI Institute, Mountain View, Calif., is lead scientist for the optical microscope. Transfer Engineering and Manufacturing Inc., Fremont, Calif. (formerly Surface/Interface Inc. of Mountain View, Calif.) designed the sample wheel for the microscopes. Aaron Zent of NASA Ames Research Center, Moffett Field, Calif., is science lead for the thermal and electrical conductivity probe, built by Decagon Devices Inc., Pullman, Wash. For the wet chemistry experiment, Thermo Fisher Scientific (formerly the Water Analysis Division of Thermo Corp., Beverly, Mass.) provided the chemical beakers; Starsys Research Corp., Boulder, Colo. provided the chemistry actuator assemblies and Tufts University, Medford, Mass., prepared the crucibles of reagents for mixing with the soil samples. Sam Kounaves of Tufts is lead scientist for the wet chemistry investigation.

❑ The **Meteorological Station** will track daily weather and seasonal changes using temperature and pressure sensors plus a laser-reflection instrument. The information collected by this first high-latitude weather station on Mars will aid understanding of how water is cycled seasonally between ice on the ground and vapor in the atmosphere.

The laser tool, called a lidar for "light detection and ranging," uses powerful laser pulses in a way comparable to radio pulses emitted by a radar instrument. The laser beam is emitted vertically into the atmosphere. Atmospheric dust and ice particles in the beam's path reflect the light, sending it in all directions, including straight downward. A telescope integrated into the instrument detects the downward-reflected light. Analysis of the strength and time-delay of the reflections reveals information about the sizes and altitudes of the particles. Tracking changes in these atmospheric particles' abundances and locations over time will help researchers study how clouds and dust plumes form and move.

The weather station includes a 1.2-meter (4-foot) mast bearing sensors at three heights to monitor how temperature varies with height near the surface. The temperature sensors are thin-wire thermocouples; they measure temperature by its effect on the flow of an electrical current through a closed circuit of two metals with different thermal properties. The thermocouples use the metals chromel (a nickel and chromium alloy) and constantan (a copper and nickel alloy). Also, hanging from the top of the mast is a wind telltale. This is a small tube that will be deflected by the wind. The science payload's stereo camera will record images of the telltale that will be used to determine wind direction and speed. The top of the meteorology mast, at 1.14 meters (3.75 feet) above the deck, is the highest point on the lander.

The Canadian Space Agency provided the Meteorological Station for Phoenix. Jim Whiteway of York University, Toronto, Ontario, leads the Canadian science team. The instrument construction was led by the Space Missions Group of MDA Ltd., Brampton, Ontario, with contributions from Optech Inc., Toronto, for the lidar. The Finnish Meteorological Institute provided the instrument for measuring atmospheric pressure. Aarhus University, Denmark, constructed the wind telltale.

❑ The **Mars Descent Imager** will take a downward-looking picture during the final moments before the spacecraft lands on Mars. This image will provide a bridge between orbiter-scale and lander-scale images. It is expected to show geological context helpful for planning the lander's activities and for interpreting other science instruments' observations and measurements. Conditions at the landing site have different implications if the site appears to be typical of a much broader area than if the site happens to be an unusual patch of ground unlike its surroundings.

This camera is mounted on the outer edge of the payload deck of the lander. It was designed to take several images, but the plan was altered to just one image after testing showed that a data-handling component elsewhere on the lander had a small possibility of triggering loss of some vital engineering data if it receives imaging data during a critical phase of final descent. The timing of the image will be planned to yield higher resolution of the landing area than currently possible from orbit.

The imager weighs just 480 grams (1 pound). The optics provide a field of view of 75.3 degrees. Exposure time is 4 milliseconds.. At that speed, some blurring may occur as the descent engines vibrate the spacecraft while the camera takes its image.

Future spacecraft to the surface of Mars may need capability for steering themselves to avoid hazards or to reach specific landing sites. Descent imaging could be an important component of the technology for accomplishing that.

A tiny microphone is riding on the descent camera. It might catch sounds around the spacecraft while the camera is taking its image. There are no plans to power the camera to take pictures or to record sounds after the landing.

The Mars Descent Imager that will fly on Phoenix was originally built for the Mars Surveyor 2001 Lander mission, by a team led by Michael Malin at Malin Space Science Systems, San Diego. A similar camera flew on Mars Polar Lander.

Research Strategy

The planned operational life of the Phoenix Mars lander after it reaches Mars is 90 Martian days. Each Martian day, often called a "sol," lasts about 40 minutes longer than an Earth day. That gives the Phoenix team three months to use the lander's instruments to address the water and habitat questions of the mission's science objectives. Planning and practice simulations before landing will prepare the team to make the best possible advantage of that time.

Observations made by orbiter spacecraft during the evaluation of candidate landing sites for Phoenix provide a starting-point base of knowledge about the area. After Phoenix has landed, views from the Surface Stereoscopic Imager, with added context from the Mars Descent Camera and closer looks with the Robotic Arm Camera, will be used for choosing where to collect the first soil sample for analysis.

The first samples fed into the lander's analyzers will come from the surface. Decisions about how much deeper to go before analyzing another sample will depend on results from the surface material and on what the robotic arm camera and stereo imager see in the soil. The Thermal and Evolved-Gas Analyzer can check for organics and other volatiles in up to eight samples. Researchers must be choosier with samples for the wet chemistry laboratory of the Microscopy, Electrochemistry and Conductivity Analyzer, which can examine four different samples. The microscopes and conductivity probe can analyze soil more frequently during the 90 sols. Meanwhile, the weather station and stereo imager will monitor changes in water and dust in the atmosphere throughout the mission. If the spacecraft remains functional longer than the 90-day prime mission, weather information might be collected during the approach of the northern hemisphere autumn on Mars, when dwindling sunlight will eventually make operations impossible, and buildup of carbon-dioxide frost will coat the spacecraft.

What types of findings would help answer questions about the history of water? If the microscopes find fine silty sediments or clay textures, that would be evidence supporting the hypothesis that the northern highlands of Mars once held an ocean. The presence of carbonates or other minerals that form in liquid water would be another. Rounded sand grains in the soil could suggest a history of flowing water.

The mass spectrometer will measure isotopic ratios. If there are differences between those ratios in subsurface ice and in atmospheric water, that could suggest the subsurface ice is ancient. A gradient in the concentrations of salts at different depths in the soil would support the hypothesis that climate cycles periodically thaw some subsurface ice. The conductivity probe's findings about thermal properties of the soil, combined with determination of the depth to an icy layer, could strengthen estimates for how much change in climate would be needed to melt the ice. The same ground-truth information will refine models of the ice's depth and of atmosphere-ice interactions in widespread areas of Mars that contain subsurface ice.

Using the microscopes and arm camera to learn about how porous and layered the soil is will help assess whether liquid water has come and gone. The conductivity probe will assess whether, even today, the soil may have thin films of unfrozen water. Atmospheric measurements as the season progresses through the Martian summer will aid the understanding of how water is seasonally cycled between solid and gas phases in the current Martian climate.

What types of findings would help answer questions about whether this site could formerly or still support microbial life? Three important factors in the suitability of a habitat for life are the availability of liquid water, the presence of carbon and access to energy. So evidence about the history of water will be one part of evaluating the habitat.

The Thermal and Evolved-Gas Analyzer has the dramatic job of checking for organic carbon molecules layer by layer as samples come from farther below the surface. Soluble sulfate minerals would be a possible source of energy that could sustain life. The wet chemistry lab of the Microscopy, Electrochemistry and Conductivity Analyzer can identify potential chemical-energy sources if they are present in soil samples. While the science payload of Phoenix is not designed for life detection, this mission is an important stepping stone in the search for whether Mars has life. Orbital observations indicate that areas with shallow subsurface ice make up at least a quarter of the red globe. Phoenix will be the first mission to visit such a site. Its findings about habitability could guide where a future spacecraft searching for life is sent.

Researchers have equipped Phoenix to look for answers to many questions posed in advance about water and habitat. However, if previous interplanetary missions are an indicator, some of the most important results from Phoenix may be surprises that raise new questions.

Mission Overview

NASA's Mars Phoenix Lander mission will travel to a site in the far northern plains of Mars where it will analyze components of the surface, subsurface and atmosphere. It will use a trench-digging arm and a set of analytical tools to study water believed to be frozen into the soil just below the surface. It will check for the presence of organic compounds as part of an evaluation of whether the site has been a favorable environment for microbial life. The mission will place the stationary lander on the ground using descent engines all the way to the surface. The lander will have a prime mission of three months on Mars during late spring to mid-summer at the landing site.

Launch Vehicle

A three-stage Delta II launch vehicle will loft the Phoenix spacecraft from pad SLC-17A of Cape Canaveral Air Force Station, Fla. Several earlier Mars missions -- Mars Odyssey, the twin Mars Exploration Rovers, Mars Pathfinder and Mars Global Surveyor -- have been among the more than 100 payloads carried by Delta II launches.

This mission will use the 7925 model of Delta II, which has a liquid-fueled first stage with nine strap-on solid-fuel boosters, a liquid-fueled second stage and a solid-fuel third stage. With its Phoenix payload on top, it stands 39.6 meters (130 feet) tall.

The first stage uses a Rocketdyne RS-27A main engine that will provide nearly 890,000 newtons (200,000 pounds) of thrust by reacting RP-1 fuel (thermally stable kerosene) with liquid oxygen. Hydraulic manipulation of the main engine's nozzle during the ascent will control the vehicle's pitch and yaw. The nine boosters, called graphite-epoxy motors, are each about 13 meters (43 feet) tall. They have enough hydroxyl-terminated polybutadiene solid propellant to add about 446,000 newtons (100,000 pounds) of thrust apiece.

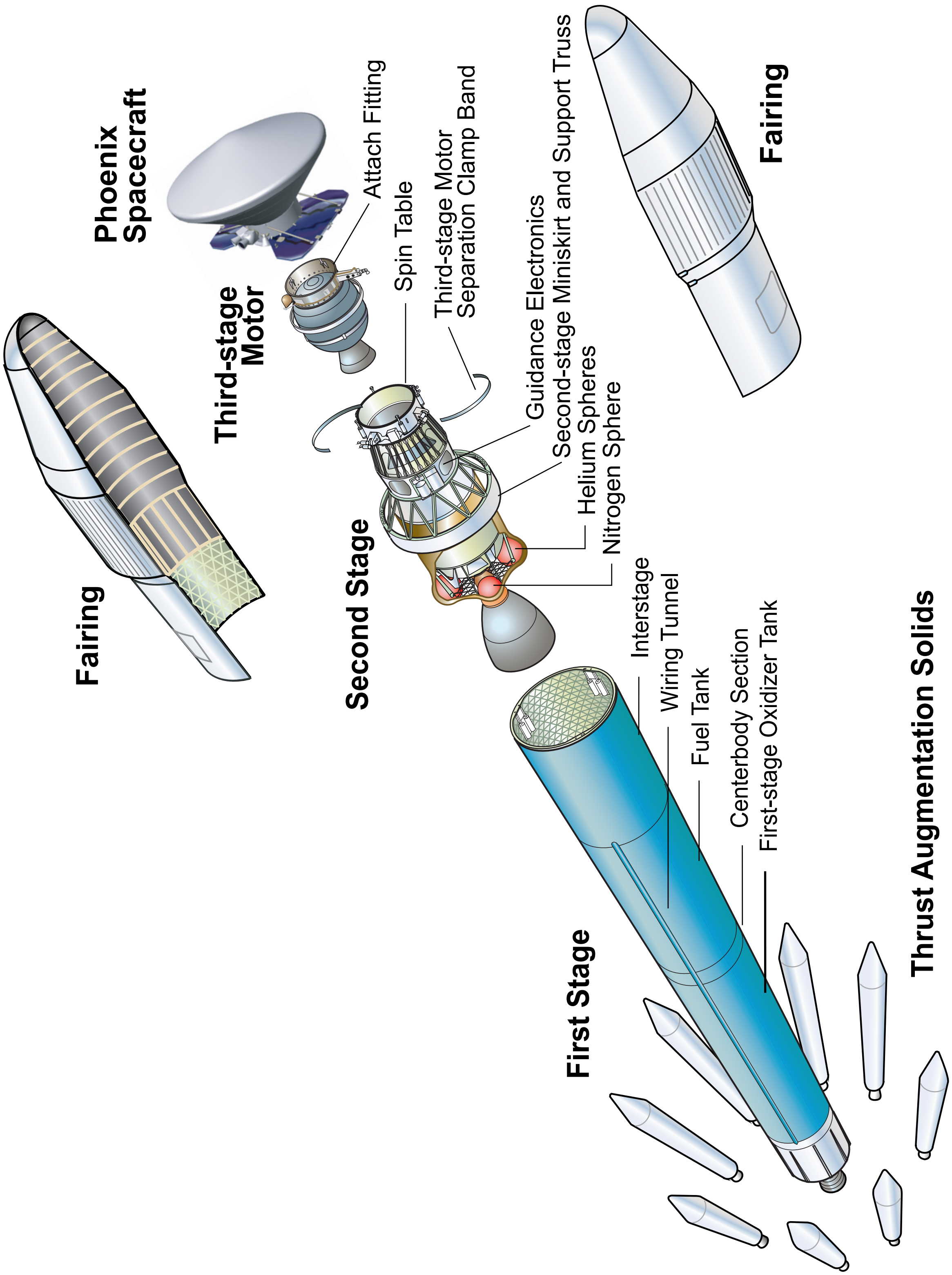
The Delta's second stage is powered by a restartable Aerojet AJ10-118K engine. The engine uses a fuel called Aerozine 50, which is a mixture of hydrazine and dimethyl hydrazine, reacted with nitrogen tetroxide as an oxidizer.

A Star-48B solid-fuel rocket made by Thiokol powers the third stage. Its propellant is made primarily of ammonium perchlorate and aluminum. During launch and ascent through the atmosphere, the Phoenix spacecraft and the third stage are shielded from aerodynamic forces by a payload fairing, or nose cone, that is 2.9 meters (9.5 feet) in diameter.

United Launch Alliance, a Denver-based joint venture of Boeing Co. and Lockheed Martin Corp., is providing the launch vehicle and related services for the Phoenix mission.

Launch Timing

As Earth and Mars race around the sun, with Earth on the inside track, Earth laps Mars about once every 26 months. The two planets come relatively close together at that point, which is called an opposition because Mars is temporarily on the opposite side of Earth from the sun. The best time to launch a mission to Mars, in terms of how much energy is required for the trip, is a few months before that happens. NASA has used every one of these Mars launch opportunities since 1996. During the 2007 opposition period, the closest approach of the two planets



Delta launch vehicle

will be on Dec. 18, 2007, when they will be 88 million kilometers (55 million miles) apart. That distance, the launch vehicle's power, the spacecraft's mass and the desired geometry for a high-latitude landing on Mars are all factors in determining the range of possible launch dates.

The possible launch dates for Phoenix are from Friday, Aug. 3, through Friday, Aug. 24. Each of the 22 days in that launch period has two nearly instantaneous launch opportunities ranging from about 36 minutes apart on Aug. 3 to 42 minutes apart on Aug. 24.

The first launch opportunity on Aug. 3 is for liftoff at 5:35 a.m. EDT. For each day later during the first two weeks of the launch period, the first liftoff opportunity shifts a few minutes earlier. On Aug. 17, it is at 2:38 a.m. For any of those first 15 dates in the launch period, the trajectory is planned for Phoenix to arrive at Mars on May 25, 2008. For the last 7 days of the launch period, Mars arrival date would be June 5, 2008. The first of the two launch opportunities on Aug. 18 is 3:16 a.m. Then the launch opportunity times again shift a few minutes earlier for each day later in the launch period.

Launch Sequences

When the Delta II launches, its first-stage engine and six of its nine strap-on boosters ignite at the moment of liftoff. The remaining three boosters will ignite following burnout of the first six. The spent casings of the first six boosters will be jettisoned about a minute after liftoff. The final three will be jettisoned about a minute later.

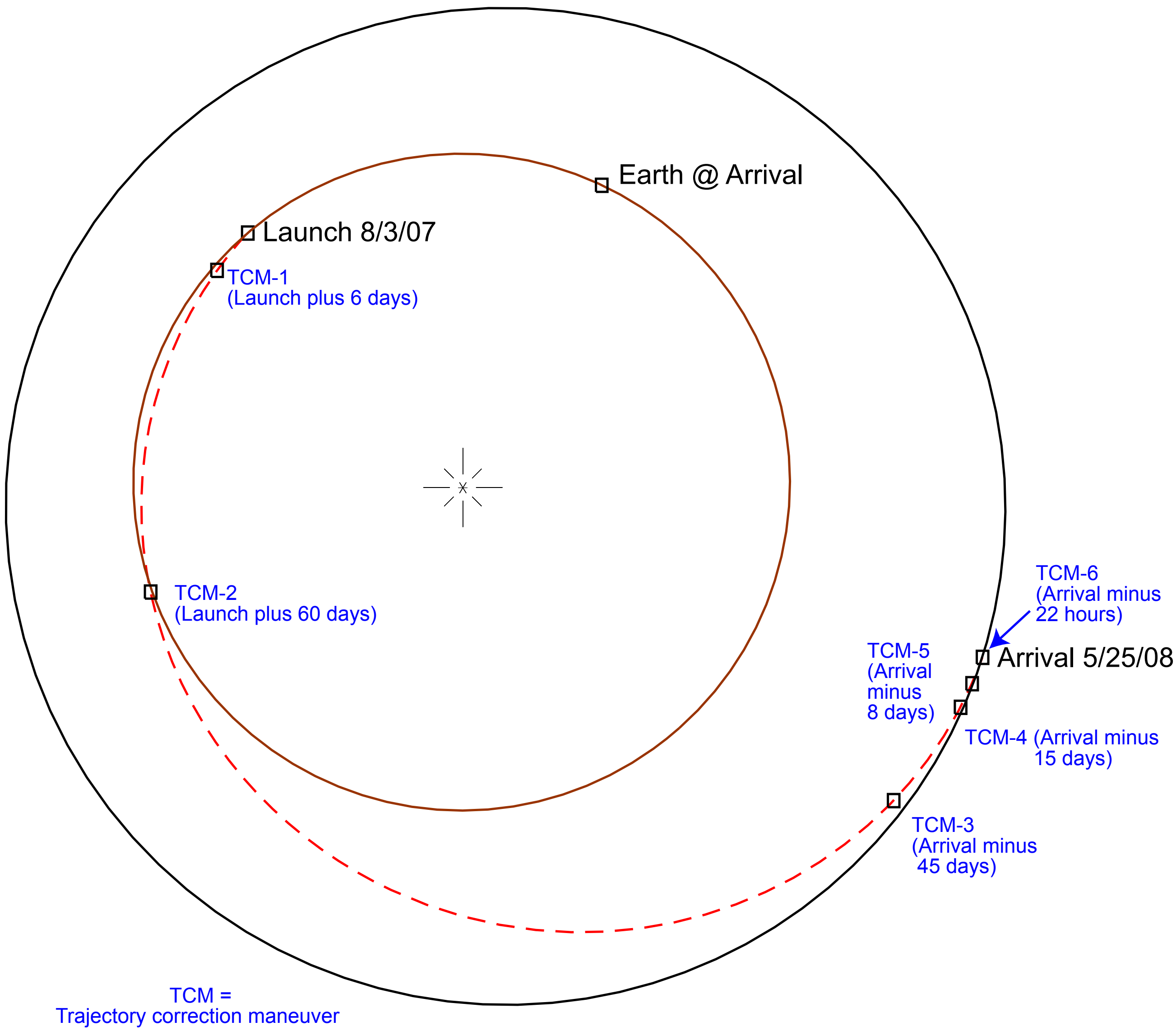
About 4 minutes, 23 seconds into the flight, at an altitude of about 111 kilometers (69 miles), the main engine will cut off. During the following 40 seconds, the first stage will separate from the second, the second stage will ignite, and the fairing will fall away from the payload. At about 9 minutes, 20 seconds after liftoff, the second-stage engine will temporarily stop firing.

At this point, the spacecraft with the second and third stages of the Delta still attached will be in a circular parking orbit 167 kilometers (104 miles) above Earth. Before completion of even one orbit, however, the Delta's second stage will reignite to begin pushing the spacecraft out onto its interplanetary trajectory toward Mars. The amount of time before the restart is different for different dates during the launch period, ranging from 72 minutes to 85 minutes after liftoff. This interval of coasting between the two engine burns by the second stage is longer than in any previous Delta II launch. The second burn of the Delta's second stage will last about 2 minutes.

Small rockets will be fired to spin the Delta's third stage to about 70 rotations per minute on a turntable attached to the second stage. The third stage will then separate from the second, firing its engine for about 87 seconds to finish putting the spacecraft on course for Mars. To reduce the spacecraft's spin rate after the third-stage engine finishes firing, a set of yo-yo-like weights will reel out on flexible lines. These work like a twirling ice-skater's arms, slowing the spin as they are extended.

If Phoenix launches at the first opportunity on Aug. 3, the spacecraft will shed the burned-out Delta third stage 84 minutes after liftoff. For other launch opportunities, the length of time between liftoff and spacecraft separation ranges from 82 minutes to 96 minutes.

Throughout the launch sequence, radio transmissions from the Delta will enable ground con-



Interplanetary trajectory

trollers to monitor critical events. However, communications with the Phoenix spacecraft cannot begin until after it separates from the Delta's third stage, exposing an antenna on the Phoenix craft. For launch opportunities early in August, the spacecraft at the time of separation will be in favorable position for communication with the Goldstone, Calif., antenna station of NASA's Deep Space Network, and controllers could acquire a signal from Phoenix within a few minutes. For launch opportunities later in the month, Phoenix will have passed out of range of Goldstone before separation, and acquisition of a signal via the Madrid, Spain, station of the Deep Space Network could take 15 minutes or more after separation. For these opportunities, Phoenix will have the support of the European Space Agency's antenna station in Kourou, French Guiana, to capture the signal from the spacecraft before it can be received at Madrid.

Initial events for the spacecraft after separation will include deploying the solar panels of the cruise stage, determining the direction toward the sun, and slewing to the best orientation to receive solar power and communicate with Earth.

Interplanetary Cruise and Approach to Mars

Phoenix will begin the portion of its mission called the cruise phase after the spacecraft has established radio communications with Earth and sent information that the cruise solar panels are generating electricity and spacecraft temperatures are stable. This phase will last until three hours before Phoenix enters the atmosphere of Mars, more than nine months later.

Phoenix will fly what is called a Type II trajectory to Mars, meaning the spacecraft will fly more than halfway around the sun while in transit from one planet to the other. This takes longer than the Type I trajectories flown by Mars Odyssey, Spirit, Opportunity and Mars Reconnaissance Orbiter.

During the cruise phase, the Phoenix lander will remain tucked inside the aeroshell, with the aeroshell attached to a cruise stage that will be jettisoned in the final minutes of flight.

Thrusters on the cruise stage will be fired to adjust the spacecraft's flight path up to six times during the cruise phase. These adjustments are called trajectory correction maneuvers. The first one is planned six days after launch. Additional opportunities for correction maneuvers, if judged to be needed based on assessments of actual and desired trajectories, are scheduled for 60 days after launch, 45 days before arrival, 15 days before arrival, 8 days before arrival and 22 hours before arrival (with a backup opportunity at 8 hours before arrival).

Navigators' assessments of the spacecraft's trajectory will use three types of tracking information from ground antennas of NASA's Deep Space Network at Goldstone, Madrid and Canberra, Australia. One traditional method is ranging, which measures the distance to the spacecraft by timing precisely how long it takes for a radio signal to travel to the spacecraft and back. A second traditional method is Doppler, which measures the spacecraft's speed relative to Earth by the amount of shift in the pitch of a radio signal from the craft.

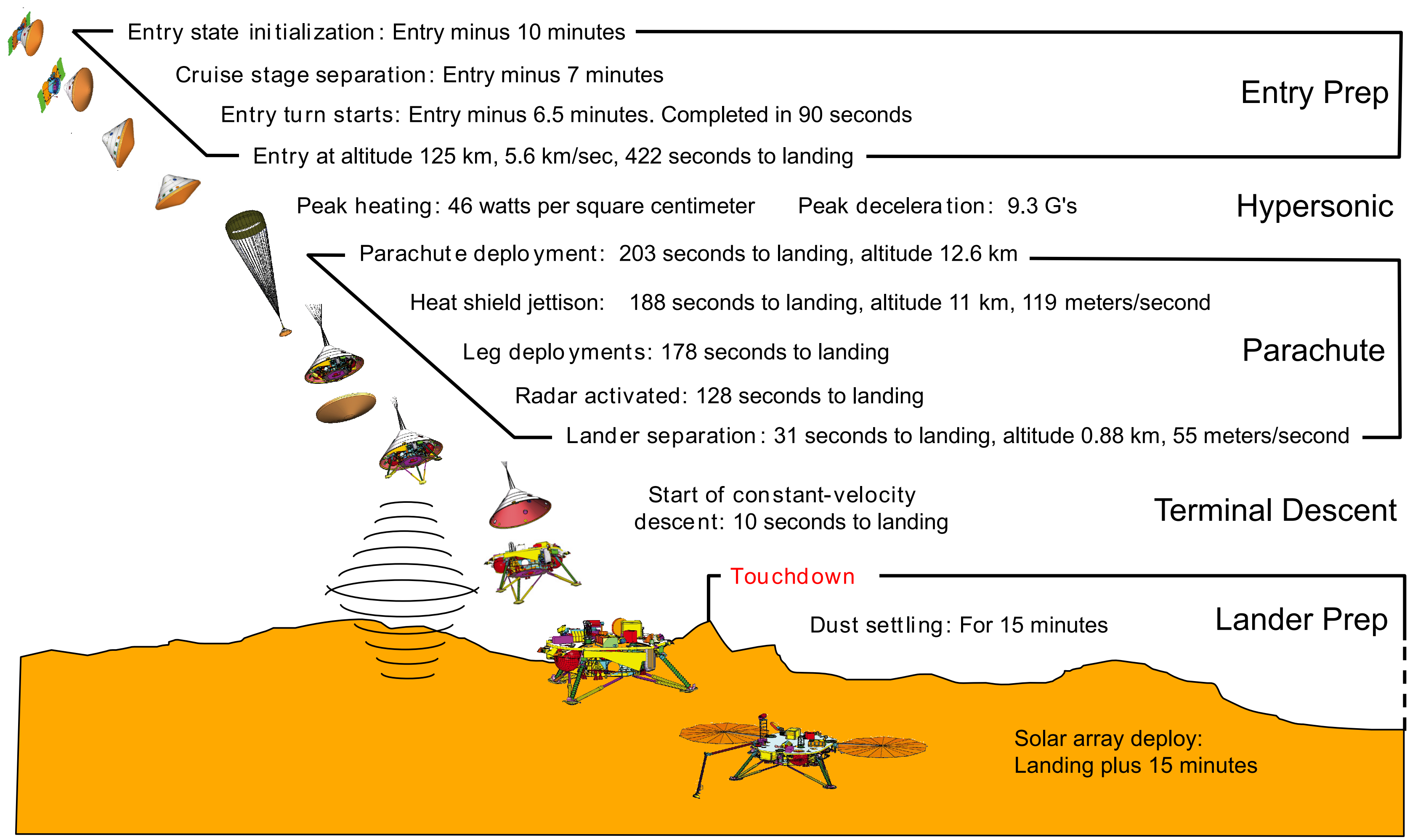
A newer method, called delta differential one-way range measurement, adds information about the location of the spacecraft in directions perpendicular to the line of sight. Pairs of antennas on different continents simultaneously receive signals from the spacecraft, and then the same antennas observe natural radio waves from a known celestial reference point, such as a quasar. European Space Agency antenna stations in New Norcia, Australia, and in Cebreros, Spain, will supplement the Deep Space Network stations in providing the delta differential one-way range measurements.

The months of the cruise phase will also provide time for testing critical procedures, equipment and software in preparation for the spacecraft's arrival at Mars.

Entry, Descent and Landing

The intense period from three hours before the spacecraft enters Mars' atmosphere until it reaches the ground safely is the mission phase called entry, descent and landing. The craft will hit the top of the atmosphere at a speed of 5.7 kilometers per second (12,750 miles per hour). Within the next six and a half minutes, it will use heat-generating atmospheric friction, then a parachute, then firings of descent thrusters, to bring that velocity down to about 2.4 meters per second (5.4 miles per hour) just before touchdown.

The entry, descent and landing system for Phoenix weighs less than the systems for earlier



Entry, descent and landing

Mars missions, such as the airbags that cushioned the impacts for Mars Pathfinder and the Spirit and Opportunity rovers. This helps give Phoenix a higher ratio of science-instrument payload (55 kilograms or 121 pounds) to total launch weight (680 kilograms or 1,469 pounds) than any spacecraft that has previously landed on Mars.

Like NASA's twin Viking landers in 1976, Phoenix will use descent thrusters in the final seconds down to the surface and will set down onto three legs. However, compared to the Vikings, Phoenix uses leaner components, such as thrusters controlled by pulse firing instead of throttle-controlled, and more complex interdependence among the components. The calculated tradeoff is more science payload for less leeway to recover if any stage of descent and landing goes awry. The system on Phoenix resembles Mars Polar Lander's more than Viking's. Mars Polar Lander reached Mars in 1999 but did not land successfully. Engineers for Phoenix have remedied all the vulnerabilities identified in reviews of Mars Polar Lander, and have also identified and addressed dozens of other potential issues.

Timing for the complex sequence of events during the final minutes before landing is subject to change before May 2008 from the following description, based on plans a year earlier. Seven minutes before it reaches the top of Mars' atmosphere, Phoenix will jettison the cruise stage hardware that it has relied on during the long flight from Earth to Mars. Half a minute later, the spacecraft will begin a 90-second process of pivoting to turn its heat shield forward. Five minutes after completing that turn, Phoenix will start sensing the top of the atmosphere, at an altitude of about 125 kilometers (78 miles). Friction from the atmosphere during the next three minutes will take most of the velocity out of the descent. At about 13 kilometers (8 miles) in altitude and a velocity about 1.7 times the speed of sound, Phoenix will deploy its parachute, which is attached to the back shell.

The spacecraft will descend on the parachute for about three minutes. During the first 25 seconds of that, Phoenix will jettison its heat shield and extend its three legs. About 75 seconds after the parachute opens and 130 seconds before landing, the spacecraft will start using its radar to sense the distance to the ground. Descent speed will have slowed to about 55 meters per second (123 miles per hour) by the time the lander separates from the back shell and parachute, about 900 meters (3,000 feet) above the ground. The descent thrusters will begin firing three seconds after the parachute has been released and about 30 seconds before landing. With input from the radar, they will finish slowing the spacecraft for a soft touchdown, then shut off when sensors on the footpads detect contact with the ground.

Mars Surface Operations

The surface operations phase of the mission will last from about a minute after touchdown until the end of the mission. The prime mission is planned for three months of surface operations, which is expected to be long enough to dig to the icy layer and analyze material collected from it. Those three months will extend from late spring to mid-summer in the northern hemisphere of Mars.

When Phoenix sets its three legs onto the surface, the time of day at the landing site will be afternoon. A Martian day, or "sol," lasts 39 minutes and 35.244 seconds longer than an Earth day. The landing sol is designated as Sol 0 of the mission, a change from the practice of the Mars Exploration Rover missions, which designated landing sols as Sol 1.

Phoenix will rely on battery-stored energy as it descends through the atmosphere until the lander's solar arrays can be opened after touchdown, so deploying the arrays is a high priority. However, Phoenix will first wait 15 minutes to let any dust from the landing settle, in order to avoid having that dust settle onto the array's photovoltaic cells. Any rock more than about half a meter (20 inches) high within the area covered by the opened arrays could be trouble for this essential deployment.

Next, the meteorology mast and camera mast will extend upwards. The stereo camera will take its first images of the Martian surface at the landing site.

Over the next several sols, a series of checkouts will characterize the performance and readiness of the lander's subsystems and science instruments. Data collected during the entry, descent and landing and during the first day on the surface will be transmitted, making memory space available for other data, including more images.

After verification of the lander's fitness to proceed, Phoenix will begin its digging phase, with a decision from the science operations team about where to dig. The team will be based at the University of Arizona's Spacecraft Operations Center in Tucson, which has a functional near-twin of the Phoenix lander installed for testing of commands. The team will be working on "Mars time" -- a schedule organized around the longer Martian day -- in order to maximize the amount of time available to review each day's downlinked data before creating the next day's uplinked commands.

Through the 90-sol prime mission, the science operations team will use Phoenix to analyze soil and ice from different layers and to monitor changes in the atmosphere.

If electrical output from the solar panels remains adequate and other subsystems are functioning, the mission for Phoenix might be extended for an additional month or two, into late summer or early fall at the landing site. Factors in how long the lander can keep getting adequate solar power include whether it lands with a southward tilt and how quickly dust accumulates on the solar panels. However, Phoenix will not be capable of outliving its prime mission several times over, as other recent Mars missions have done. Mission planners anticipate that by about Sol 150, a combination of less sunlight per day and accumulated dust on the solar panels will shrink electrical output below the amount needed for heating to keep Phoenix operating. Within a few more months, carbon dioxide frost will heavily coat the region of the landing site and the spacecraft itself.

Communications Strategy

Like all of NASA's interplanetary missions, Phoenix will rely on the agency's Deep Space Network to track and communicate with the spacecraft. The network has groups of antennas at three locations: at Goldstone in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. These locations are about one-third of the way around the world from each other so that, whatever time of day it is on Earth, at least one of them will have the spacecraft in view. Each complex is equipped with one antenna 70 meters (230 feet) in diameter, at least two antennas 34 meters (112 feet) in diameter, and smaller antennas. All three complexes communicate directly with the control hub at NASA's Jet Propulsion Laboratory, Pasadena, Calif.

Phoenix will communicate directly with Earth using the X-band portion of the radio spectrum (8 to 12 gigahertz) throughout the cruise phase of the mission and for its initial communication after separating from the third stage of the launch vehicle. The cruise stage carries two copies of its communications equipment, providing redundancy in case of a problem with one of them.

The mission will use ultra high frequency (UHF) links (300 megahertz to 1,000 megahertz), relayed through Mars orbiters during the entry, descent and landing phase and while operating on the surface of Mars. A UHF antenna on the back shell will transmit for about six minutes between the time the cruise stage is jettisoned and the time the back shell is jettisoned. From then on, a UHF antenna on the lander deck will handle outgoing and incoming communications. The UHF system on Phoenix is compatible with relay capabilities of NASA's Mars Odyssey and Mars Reconnaissance Orbiter, and with the European Space Agency's Mars Express. Phoenix communication relays via orbiters will take advantage of the development of an international standard, called the Proximity-1 protocol, for the data transfer. This protocol was developed by the Consultative Committee for Space Data Systems in an international partnership for standardizing techniques used for handling space data. The Phoenix spacecraft's UHF signal might also be receivable directly via the Green Bank Telescope in West Virginia.

Data transmission is most difficult during the critical sequence of entry, descent and landing activities, but communication from the spacecraft is required during this period in order to diagnose any potential problems that may occur. An antenna on the back shell will transmit during entry and descent. Another, on the lander deck, will transmit and receive during the final moments of descent and throughout the surface operations phase of the mission.

Planetary Protection

In the study of whether Mars has had environments conducive to life, precautions must be taken to avoid introduction of microbes from Earth. Consistent with this, the United States is a signatory to an international treaty stipulating that exploration must be conducted in a manner that avoids harmful contamination of celestial bodies. "Planetary protection" is the collection of rules and practices used to avoid biological contamination in the process of exploration. NASA has a planetary protection office responsible for establishing and enforcing planetary protection regulations. Spacecraft missions are responsible for implementing measures to comply with the regulations. In compliance with the treaty and NASA regulations, the Phoenix flight hardware has been designed and built to meet planetary protection requirements.

NASA's primary strategy for preventing contamination of Mars with Earth organisms is to be sure that all hardware going to the planet is clean. One of the requirements for the Phoenix mission is that the exposed interior and exterior surfaces of the landed system, which includes the lander, parachute and back shell, must not carry a total number of bacterial spores greater than 300,000, with the average spore density not exceeding 300 spores per square meter (about 11 square feet) so that biological load is not concentrated in one place. Spore-forming bacteria have been the focus of planetary protection standards because these bacteria can survive harsh conditions for many years as inactive spores.

The standard of cleanliness is much higher for hardware that will touch parts of Mars thought to have potential for sustaining life. This applies to the soil containing water ice, which scientists believe lies just below the surface where Phoenix will land. The robotic arm is the only part of the spacecraft that will touch Mars' icy subsurface layer. Consistent with the higher cleanliness standards for subsurface contact, the robotic arm was designed and built to stricter cleanliness requirements than the rest of the lander. It must comply with a standard that allows less than one spore per square meter on the arm's total surface area.

The three primary methods used for reducing the number of spores on the spacecraft are precision cleaning, dry heat microbial reduction and protection behind high-efficiency filters. For the arm, an innovative biological barrier wrapping was also developed to supplement the dry heat treatment. This biobarrier is essentially a customized enclosure to protect the arm from recontamination before it is put to use at Mars.

Technicians assembling the spacecraft and preparing it for launch have routinely cleaned surfaces by wiping them with alcohol or other solvent. Components tolerant of high temperature were heated to reduce spore burden according to NASA specification, at temperatures ranging from 110 to 146 degrees Celsius (230 to 295 degrees Fahrenheit) for durations up to 50 hours. The planetary protection team carefully sampled the surfaces and performed microbiological tests to demonstrate that the spacecraft meets requirements for biological cleanliness. Whenever possible, hardware was contained within a sealed container vented through high-efficiency filters.

The most distinctive feature of planetary protection on Phoenix, the biobarrier sealing the robotic arm, is constructed of a film that holds up to baking, like a turkey basting bag. Workers sealed the arm inside the biobarrier before beginning heat treatment to reduce spores on the arm. The biobarrier will remain sealed until the lander reaches the Martian surface. It prevents any new spores from getting onto the arm during final preparations for launch and in the subsequent launch and cruise environments. The film is Tedlar, a trademarked polyvinylflouride material with commercial uses ranging from durable surfaces of airline cabin furnishings to backing sheets for photovoltaic panels. The biobarrier film is supported by a skeleton of spring-loaded, aluminum-tube ribs to maintain its shape. On the Martian surface, the springs retract the ribs and the film, allowing the arm to deploy.

Another way of making sure Phoenix doesn’t transport Earth life to Mars is to ensure that any hardware not meeting cleanliness standards does not go to Mars accidentally. When the Delta launch vehicle’s third stage separates from the spacecraft, the two objects are traveling on nearly identical trajectories. To prevent the possibility of the third stage hitting Mars, that shared flight path is deliberately set so that the spacecraft would miss Mars if not for its first trajectory correction maneuver, 6 days later. By design, the third stage is never aimed at Mars. For hardware expected to impact Mars, such as the cruise stage after lander separation, a detailed thermal analysis was conducted to make sure that plunging through Mars atmosphere gets it sufficiently hot that few to no spores survive.

Spacecraft

The Phoenix Mars lander has a science payload and systems that enable the payload to do its job and send home the results. The spacecraft also includes systems to convey the lander during transit from Earth and to deliver it safely to the surface of Mars.

The lander's main structure was built for the Mars Surveyor 2001 program, and then kept in a protective, controlled environment after the lander portion of that program was cancelled. Several modifications have been made to the inherited lander, some to meet return-to-flight recommendations from review of Mars mission failures in 1999 and some to adapt to the specific goals and plans for the Phoenix mission.

Some of the subsystems and features of the Phoenix spacecraft are propulsion, power, command and data handling, telecommunications, navigation, thermal control and flight software.

Propulsion

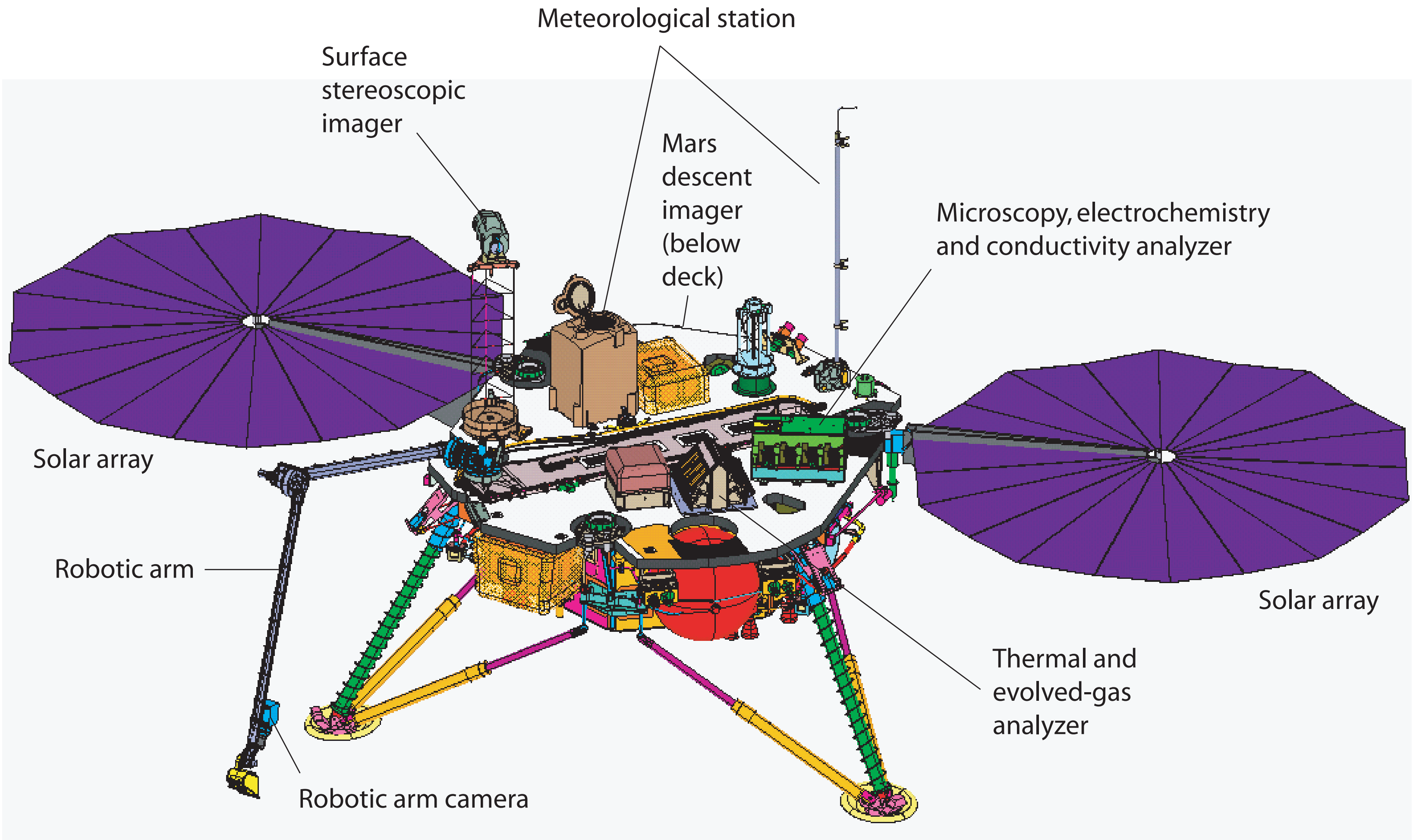
Nearly all of the shove that propels Phoenix to Mars comes from the launch vehicle rather than the spacecraft itself, but Phoenix carries thrusters to adjust its trajectory while it coasts, to control its orientation and to slow its final descent to the surface of Mars. All 20 of these thrusters use hydrazine, a propellant that does not require an oxygen source. Hydrazine is a corrosive liquid compound of nitrogen and hydrogen that decomposes explosively into expanding gases when exposed to a catalyst in the thrusters.

Twelve thrusters mounted around the bottom edge of the lander will slow the descent during the last half-minute before the legs touch the surface. These can each pulse on and off for fine-tuning the velocity and for maintaining the lander's stability -- controlling its pitch, yaw and roll -- as it approaches touchdown. They each provide about 293 newtons (65.9 pounds) of thrust.

Eight smaller thrusters have jobs during the cruise phase of the mission, while the lander is enclosed in a protective aeroshell. These eight are also mounted on the lander, but extend through cutaways in the in the back shell. Four are used during the six trajectory correction maneuvers during cruise. These trajectory correction thrusters each deliver about 15.6 newtons (3.5 pounds) of force. The other four are used for changing the spacecraft's orientation, or "attitude," such as for pivoting the spacecraft so the heat shield faces forward during entry into Mars' atmosphere. Their thrust capacity is about 4.4 newtons (1 pound) apiece.

Electric Power

On the surface of Mars, the lander's power will come from a two-wing solar array converting solar radiation to electricity. The array is shaped as two nearly circular decagons extending from opposite sides of the lander, with a total of 4.2 square meters (45 square feet) of functional surface area on flexible, lightweight substrate. A pair of rechargeable 25-amp-hour lithium-ion batteries will provide power storage. The spacecraft's cruise stage carries its own solar array, as the lander's array will stay folded inside the aeroshell until Phoenix reaches Mars.



Phoenix lander

Command and Data Handling

The spacecraft's computing functions are performed by the command and data handling subsystem. The heart of this subsystem is a RAD6000 microprocessor, a version of the PowerPC chip once used on many models of Macintosh computers, but enhanced to endure the natural radiation and other rigors of a space environment. The RAD6000 can operate at three speeds: 5 million, 10 million or 20 million clock cycles per second. Computer memory available to the command and data handling subsystem includes more than 74 megabytes of dynamic random access memory, plus flash memory, which allows the system to maintain data even without power.

Telecommunications

From the surface of Mars, Phoenix will use the ultrahigh frequency (UHF) radio band for communications (300 megahertz to 1,000 megahertz). Communications to and from Earth will be relayed by Mars orbiters. NASA's Mars Odyssey orbiter and Mars Reconnaissance Orbiter will be the main relay assets for Phoenix. The system is also compatible with relay capabilities of the European Space Agency's Mars Express orbiter.

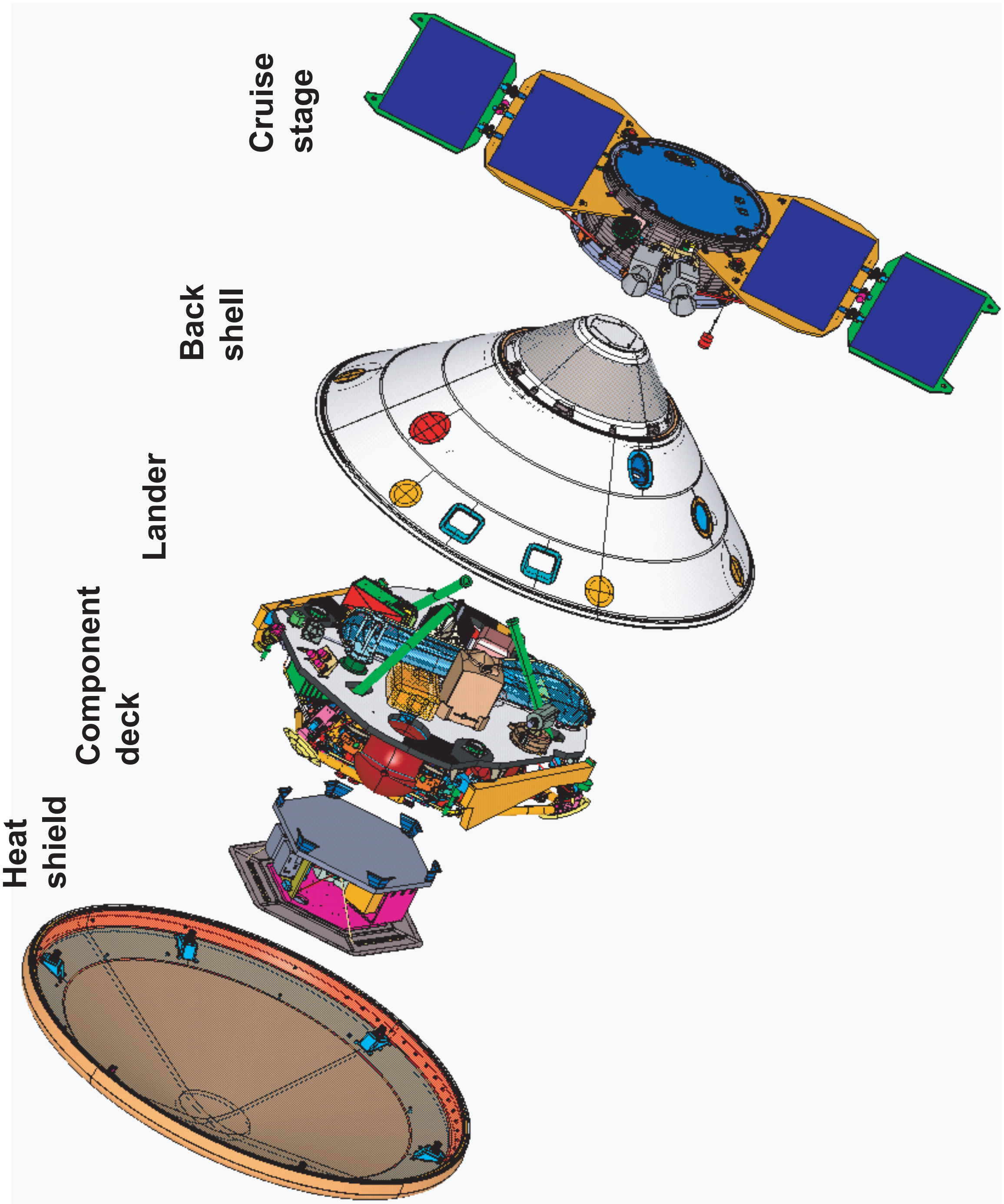
A helical UHF antenna mounted on the lander deck will send and receive all communications starting with the final half-minute of descent. The helical antenna and a monopole UHF antenna, also mounted on the deck, will be used for relay telecommunications during the months of operation after landing. The lander can send data at rates of 8,000 bits per second, 32,000 bits per second or 128,000 bits per second. The lower two speeds are the choices for receiving commands relayed to Phoenix from an orbiter. The UHF part of the telecommunications subsystem also includes a wrap-around UHF antenna on the back shell. This antenna will handle communications during a period beginning when the cruise stage is released about five minutes before landing, and ending when the helical antenna begins working, just after the lander separates from the back shell.

During the voyage from Earth to Mars, Phoenix will use a different set of communications equipment. It will be able to communicate directly with Earth in radio's X band (8 to 12 gigahertz). A medium-gain X-band antenna mounted on the cruise stage can both transmit and receive. Two low-gain antennas provide backup redundancy, one to transmit and the other to receive. The redundancy also extends to a pair of transponders and a pair of amplifiers. In X-band, Phoenix will be able to transmit at date rates up to 2,100 bits per second and to receive data at up to 2,000 bits per second.

Guidance, Navigation and Control

Phoenix will be able to keep oriented as it flies toward Mars by using a star tracker and pair of sun sensors mounted on the cruise stage. The same type of star tracker is used on Mars Odyssey, a camera that takes pictures of the sky and has computer power to compare the images with a catalog of star positions and recognize which part of the sky it is facing.

During its descent through Mars' atmosphere, the spacecraft's knowledge of its movement and position will come from inertial measurement units, which sense changes in velocity, and a downward-pointing radar to assess the distance to the ground. Each inertial measurement unit includes accelerometers to measure changes in the spacecraft's velocity in any direction, and ring-laser gyroscopes to measure how fast the spacecraft's orientation is changing.



Flight system

Thermal Control

Thermal controls use a combination of electrical heaters, thermostats, temperature sensors, blanketing and thermal coatings. The deck of the Phoenix lander doubles as an insulation layer by its honeycomb-composite interior structure and a low-thermal-conductivity surface layer.

At the Phoenix landing site, the main challenge is to prevent components from getting too cold and to prevent the large daily swings in temperature from doing any damage. En route from Earth to Mars, overheating is also a concern. The thermal control subsystem conducts heat away from electronics susceptible to becoming too hot.

Flight Software

The flight software on Phoenix will coordinate the spacecraft's execution of commands and organize data to be transmitted to Earth. It will protect the spacecraft by checking commands for faults, monitoring the health of subsystems and being ready to take corrective steps when it detects irregularities.

'Visions of Mars' Disc

A miniature digital videodisc attached to the deck of the Phoenix lander contains the names of about 250,000 people from more than 70 nations, plus selections of Mars-related literature, art and music.

The "Visions of Mars" mini-DVD features works by Percival Lowell, H.G. Wells, Isaac Asimov, Ray Bradbury and many others. It is made of silica glass for durability and positioned where it will show up in images of a calibration target on the lander. The Planetary Society, Pasadena, Calif., provided the disc and invited the public to submit names for it via the Internet.

Phoenix Landing Site

Phoenix will land in an arctic plain comparable in latitude to central Greenland or northern Alaska. Favorable opportunities to launch missions to Mars come about every 26 months, but the 2007 launch opportunity is the best in several years for sending a surface mission so far north on Mars. NASA's Mars Odyssey orbiter found evidence in early 2002 that this region shelters high concentrations of water ice mixed with the soil just beneath the surface.

The Phoenix mission was developed to take advantage of the 2007 launch opportunity by sending a payload of science instruments particularly appropriate for examining an environment of ice and soil. The landing region has been a key factor in defining the mission. The region has expanses with little variation on the surface, but a key attraction within arm's reach underground. This robotic-armed, stationary lander was made for just such a place.

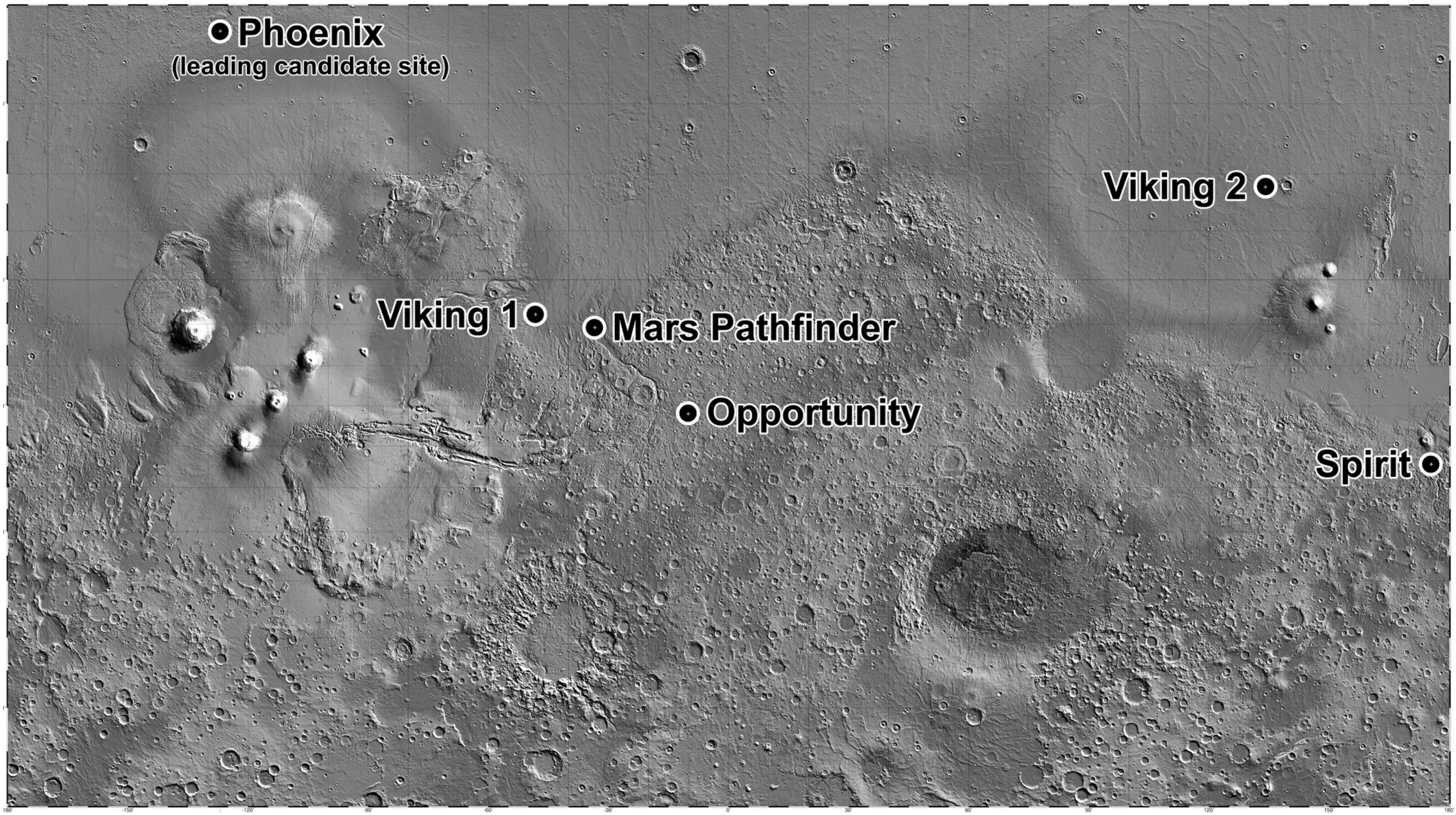
A working group of Mars researchers from many states used observations from Mars orbiters to evaluate many possible landing sites from latitudes of 65 degrees to 72 degrees north, within the arctic plains called Vastitas Borealis. Scientists and engineers examined the factors that could add hazards to landing, such as slopes and rock abundance. Images in visible-light and infrared wavelengths from NASA's Mars Global Surveyor and Mars Odyssey orbiters revealed many characteristics about sites under consideration.

In mid-2006, the front-running candidate was in an area between 120 to 140 degrees east longitude, called Region B by the landing site working group. However, the team received higher-resolution images of the site in October 2006 from NASA's Mars Reconnaissance Orbiter, which had just arrived at Mars. Mars Reconnaissance Orbiter saw that Region B was characterized by clustered boulder fields, with many rocks larger than the 35- to 45-centimeter (14- to 18-inch) clearance height underneath the lander. The high frequency of rocks posed an unacceptable risk to the lander.

Fortunately, examination of a region from 230 to 250 degrees east, called Region D, found areas with fewer rocks. Assessments of rock abundance included nighttime infrared imaging by Mars Odyssey's Thermal Emission Imaging System, as well as views from Mars Reconnaissance Orbiter's High Resolution Imaging Science Experiment camera and Context Camera. Nighttime infrared images can give information about rocks too small to be discerned individually because, hours after sundown, even rocks the minimum size of concern for Phoenix are warmer than pebbles or smaller particles.

The favored area for Phoenix to land (subject to final NASA review of a specific target ellipse shortly before launch) lies at 68.35 degrees north latitude, 233.0 degrees east longitude. Topographical mapping by Mars Global Surveyor's laser altimeter indicates a broad, shallow valley about 50 kilometers (about 30 miles) wide and only about 250 meters (about 800 feet) deep. The ground texture shows polygonal cracking, a pattern seen widely in Mars' high latitudes and also observed in permafrost terrains on Earth. It lies in mapped geological units named Scandia and Vastitas Borealis Marginal.

During northern hemisphere winter, this area is covered with carbon-dioxide frost. Phoenix will land in late spring, when the frost is gone and the sun stays up long into the night, a boon for the lander's solar-powered operations.



Mars mission landing sites

Mars Science: Following the Water

As the world in 1965 eagerly awaited results of the first spacecraft flyby of Mars, everything we knew about the Red Planet was based on what sparse details could be gleaned by peering at it from telescopes on Earth. Since the early 1900s, popular culture had been enlivened by the notion of a habitable neighboring world crisscrossed by canals and, possibly, inhabited by advanced life forms that might have built them -- whether friendly or not. Astronomers were highly skeptical about the canals, which looked more dubious the closer they looked. About the only hard information they had on Mars was that they could see it had seasons with ice caps that waxed and waned, along with seasonally changing surface markings. By breaking down the light from Mars into colors, they learned that its atmosphere was thin and dominated by an unbreathable gas, carbon dioxide.

The past four decades have revolutionized that view. First, hopes of a lush, Earth-like world were deflated when Mariner 4's flyby on July 15, 1965, revealed large impact craters, like craters that cover Earth's barren, lifeless moon. Those holding out for Martians were further discouraged when NASA's two Viking landers were sent to the surface in 1976 equipped with a suite of chemistry experiments that turned up no conclusive sign of biological activity. Mars as we came to know it was cold, nearly airless and bombarded by hostile radiation from both the sun and from deep space.

Since then, however, new possibilities of a more hospitable Martian past have emerged. Mars is a much more complex body than Earth's moon. Scientists scrutinizing pictures from the orbiters of the 1970s detected surface features potentially shaped by liquid water, perhaps even the shoreline of an ancient ocean. Seven successful Mars missions since the mid-1990s have advanced the story. Accumulated evidence shows that the surface of Mars appears to be shaped by flowing water in hundreds of places; that some Mars rocks formed in water; that significant amounts of water as ice or hydrated minerals still make up a fraction of the top surface layer of Mars in many areas; and that gully-cutting fluid, probably water, still occasionally emerges from the ground to flow briefly before freezing or evaporating.

Although it appears unlikely that complex organisms similar to advanced life on Earth could have existed on Mars' comparatively hostile surface, scientists are intrigued by the possibility that life in some form -- perhaps very simple microbes -- may have gained a foothold in ancient times when Mars was warmer and wetter. It is not unthinkable that life in some form could persist today in underground springs warmed by heat vents around smoldering volcanoes, or even beneath the thick ice caps. To investigate those possibilities, the most promising strategy is to learn more about the history of water on Mars: How much was there? How long did it last? Where were the formerly wet environments that make the best destinations for seeking evidence of past life? Where might there be wet environments capable of sustaining life today?

The consensus strategy for answering those questions uses a balance of examining selected sites in great detail while also conducting planet-wide surveys to provide context for interpreting the selected sites. This enables researchers to extrapolate from the intensively investigated sites to regional and global patterns, and to identify which specific sites make the best candidates for targeted examination.

One way this balance works is in the combination punch of orbital and surface missions. Mineral mapping by NASA's orbiting Mars Global Surveyor identified the hematite deposit that made

Meridiani Planum one of the top-priority targets selected as landing sites for NASA's Mars Exploration Rovers. The hematite suggested a possible water history. The rover Opportunity's intensive examination of the composition and fine structure of rocks where it landed confirmed that the site had had surface and underground water, and added details about the acidity of the water and the alternation of wet and dry periods at the site. This "ground truthing" by the rover improves interpretation of current orbiters' observations of the surrounding region; the orbiters' observations add context for understanding how the environment that the landing-site rocks reveal about a particular place and time fits into a broader history.

The Phoenix lander will also investigate a site with intriguing characteristics discovered from orbit. Spectrometers on NASA's Mars Odyssey orbiter found evidence of copious water ice within the top meter (3 feet) of the surface in high-latitude and some mid-latitude regions. Phoenix will go to one site in a region of buried ice detected by Odyssey. There it will analyze the icy soil and any layers of soil on top of the ice, checking for organic chemicals, evidence of periodic meltings and other indicators of a possible past or present habitat for microbes. Odyssey and other orbiters provided information to evaluate the safety of the candidate landing sites, as well as their scientific appeal.

Myths and Reality

Mars 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 Mars convinced him that the canals were dug by intelligent beings -- a view that he energetically promoted for many years.

By the turn of the last century, popular songs envisioned sending messages between worlds 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 1965 flyby of Mariner 4 and the 1969 flybys of Mariner 6 and 7 showed a desolate world, pocked with impact craters similar to those seen on Earth's moon. Mariner 9 arrived in 1971 to orbit Mars for the first time, but showed up just as an enormous dust storm was engulfing the entire planet. When the storm died down, Mariner 9 revealed a world that, while partly crater-pocked like Earth's moon, was much more geologically complex, complete with gigantic canyons, volcanoes, dune fields and polar ice caps. This first wave of Mars exploration culminated in the Viking mission, which sent two orbiters and two landers to the planet in 1975. The landers carried a suite of experiments that conducted chemical tests to detect life. Most scientists interpreted the results of these tests as negative, deflating hopes of identifying another world on where life might be or have been widespread. However, Viking left a huge legacy of information about Mars that fed a hungry science community for two decades.

The science community had many other reasons for being interested in Mars, apart from the direct search for life; the next mission on the drawing boards concentrated on a study of the planet's geology and climate using advanced orbital reconnaissance. Over the next 20 years, however, new findings in laboratories and in extreme environments 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 and NASA's Johnson Space Center that a meteorite believed to have originated on Mars contained what might be the fossils of ancient bacteria. This rock and other Mars meteorites discovered on several continents on Earth appear to have been blasted off Mars by asteroid or comet impacts. The evidence that they are from Mars comes from gases trapped in them that unmistakably match the composition of Mars' atmosphere as measured by the Viking landers. Many scientists have questioned the conclusions of the team announcing the discovery of possible life in one Martian meteorite, but if nothing else the mere presence of organic compounds in the meteorites increases the odds of life forming at an earlier time on a wetter Mars. The debate has also focused attention on what types of experiments would be most useful for assessing whether an extraterrestrial site or sample has ever held anything alive.

Another development shaping ideas about extraterrestrial life was a string of spectacular findings on how and where life thrives on Earth. The fundamental requirements for life as we know it today are liquid water, organic compounds and an energy source for synthesizing complex organic molecules. In recent years, it has become increasingly clear that life can thrive in settings much harsher than what we as humans can experience.

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 deduce that life on Earth may have begun at hot vents far under the ocean's surface.

This in turn had its effect on how scientists thought about Mars. Martian life might not be so widespread that it would be readily found at the foot of a lander spacecraft, but it may have thrived billions of years ago in an underground thermal spring or other hospitable environment. Or it might still exist in some form in niches below the currently frigid, dry, windswept surface, perhaps shielded in ice or in liquid water aquifers.

Each successful Mars mission reads more pages of the planet's story. After years of studying pictures from the Viking orbiters, scientists gradually came to conclude that many features they saw suggested that Mars may have been warm and wet in an earlier era.

Two decades after Viking, NASA's Mars Pathfinder observed rounded pebbles and sockets in larger rocks, suggesting conglomerates that formed in running water. Mars Global Surveyor's camera detected possible evidence for recent liquid water in many settings, including hundreds of hillside gullies. That orbiter's longevity even allowed before-and-after imaging that showed fresh gully-flow deposits in 2005 that had not been present earlier in the mission. Observations by Global Surveyor and Odyssey have also been interpreted as evidence that Mars is still adjusting from a recent ice age as part of a repeating cycle of global climate change.

NASA's Mars Exploration Rover Opportunity established that rocks in at least one part of Mars were formed under flowing surface water. Minerals present indicate the ancient water was very acidic. Halfway around the planet, Opportunity's twin, Spirit, has also found rocks extensively altered by water.

The European Space Agency's Mars Express has identified exposures of clay minerals that probably formed in long-lasting, less-acidic wet conditions even earlier in Mars history than the conditions that produced the minerals examined by Opportunity. Mars Express and telescopic studies from Earth have found traces of atmospheric methane at Mars that might come from volcanic or biological sources. A radar instrument co-sponsored by NASA and the Italian Space Agency on the European orbiter has assessed the thickness and water content of icy layers covering Mars' south polar region, yielding an estimate that the quantity of water frozen into those icy layers is equivalent to an 11-meter-thick (36-foot-thick) coating of the whole planet.

The newest robot at Mars, NASA's Mars Reconnaissance Orbiter, has returned additional details of the clay-mineral deposits. As seen at the highest resolution yet, these confirm a story of alteration by water early in Martian history. Other observations early in this orbiter's two-year primary science phase, which began in November 2006, have shown where underground flows of water through crevices altered adjacent minerals and have revealed details of layering in exposed canyon walls. A new radar, which probes the near-surface layers, shows that these layers extend throughout the permanent polar caps, not just at where canyons expose them.

Three Ages of Mars

Based on what they have learned from spacecraft missions, scientists view Mars as the "in-between" planet of the inner solar system. Small rocky planetary bodies such as Mercury and Earth's moon apparently did not have enough internal heat to drive the motion of tectonic plates, so their crusts grew cold and static relatively soon after they formed when the solar system condensed into planets about 4.6 billion years ago. Devoid of atmospheres, they are riddled with craters that are relics of impacts during a period of bombardment when the inner planets were sweeping up remnants of small rocky bodies that failed to "make it as planets" in the solar system's early times.

Earth and Venus, by contrast, are larger planets with substantial internal heat sources and significant atmospheres. Earth's surface is continually reshaped by tectonic plates sliding under and against each other and by materials spouting forth from active volcanoes where plates are ripped apart. Both Earth and Venus have been paved over so recently that both lack any discernible record of cratering from the era of bombardment in the early solar system.

On the basis of current yet evolving knowledge, Mars appears to stand between those sets of worlds. Like Earth and Venus, it possesses many volcanoes, although they probably did not remain active as long as counterparts on Earth and Venus. On Earth, a single "hot spot" or plume might form a chain of middling-sized islands such as the Hawaiian Islands as a tectonic plate slowly slides over it. On Mars there are apparently no such tectonic plates, at least as far as we know today, so when volcanoes formed in place they had the time to become much more enormous than the rapidly moving volcanoes on Earth. Overall Mars appears to be neither as dead as Mercury and our moon, nor as active as Earth and Venus. As one scientist quips, "Mars is a warm corpse, if not a fire-breathing dragon." Thanks to the ongoing observations by current missions, however, this view of Mars is still evolving.

Mars almost resembles two different worlds that have been glued together. From latitudes around the equator to the south are ancient highlands pockmarked with craters from the solar system's early era, yet riddled with channels that attest to the flow of water. The northern third of the planet, however, overall is sunken and much smoother at kilometer (mile) scales. There is as yet no general agreement on how the northern plains got to be that way. At one end of the spectrum is the theory that it is the floor of an ancient sea; at the other, the notion that it is merely the end product of innumerable lava flows. Some scientists believe a giant ice sheet may be buried under much of the relatively smooth northern plains. It is also possible that some unusual internal process not yet fully understood may have caused the northern plains to sink to relatively low elevations in relation to the southern uplands.

Scientists today view Mars as having had three broad ages, each named for a geographic area that typifies it:

❑ The **Noachian Era** is the name given to the time spanning roughly the first billion years of Mars' existence after the planet was formed 4.6 billion years ago. In this era, scientists suspect that Mars was quite active with periods of warm and wet environment, erupting volcanoes and some degree of tectonic activity. The planet may have had a thicker atmosphere to support running water, and it may have rained and snowed.

❑ In the **Hesperian Era**, which lasted for about the next 500 million to 1.5 billion years, geologic activity was slowing down and near-surface water perhaps was freezing to form surface and buried ice masses. Plunging temperatures probably caused water pooled underground to erupt when heated by impacts in catastrophic floods that surged across vast stretches of the surface -- floods so powerful that they unleashed the force of thousands of Mississippi Rivers. Eventually, water became locked up as permafrost or subsurface ice, or was partially lost into outer space.

❑ The **Amazonian Era** is the current age that began around 2 billion to 3 billion years ago. The planet is now a dry, desiccating environment with only a modest atmosphere in relation to Earth. In fact, the atmosphere is so thin that water exposed to it can be stable only as a solid or a gas, not as a liquid. The climate and perhaps the stability of water at the surface may vary on scales of thousands to millions of years as the tilt of the planet and its distance from the sun waver cyclically.

Apart from that broad outline, there is lively debate and disagreement on the details of Mars' history. How wet was the planet, and how long ago? What eventually happened to all of the water? That is all a story that is still being written.

Even if we ultimately learn that Mars never harbored life as we know it here on Earth, scientific exploration of the red planet can assist in understanding the history and evolution of life on our own home world. Much if not all of the evidence for the origin of life here on Earth has been obliterated by the rapid pace of weathering and global tectonics that have operated over billions of years. Mars, by comparison, is a composite world with some regions that may have histories similar to Earth's crust, while others serve as a frozen gallery of the solar system's early days.

Thus, even if life never developed on Mars -- something that we cannot answer just yet -- scientific exploration of the planet may yield critical information unobtainable by any other means about the pre-biotic chemistry that led to life on Earth. Mars as a fossil graveyard of the chemical conditions that fostered life on Earth is an intriguing possibility.

NASA's Mars Scout Missions

In 2001, NASA announced a new series of competitively proposed and selected missions to Mars. This series, named the Mars Scouts, opens the door for qualified teams to submit proposals for innovative, moderate-cost missions. Scout missions supplement the sequence of larger, "facility-class" strategic missions of NASA's Mars Exploration Program.

The Phoenix Mars Lander mission, now in final stages of preparation for an August 2007 launch, was selected in August 2003 from the first round of Mars Scout proposals.

NASA solicited a second round of Mars Scout proposals in 2006, for a mission to be launched in 2011. In January 2007, the agency selected two proposed orbital missions to receive $2 million for nine-month feasibility studies leading to final selection of one mission in late 2007 or early 2008.

The Mars Scout missions follow the model of other NASA initiatives that tap into the broadest possible base of creative research ideas by openly soliciting proposals for missions. The competitive Discovery Program for solar system exploration, for example, has selected 10 spacecraft missions, including Near Earth Asteroid Rendezvous, which orbited and landed on asteroid Eros; Stardust, which flew through the tail of comet Wild 2 and brought sample particles from the comet back to Earth; and Messenger, now flying to Mercury. Current missions of NASA's competitive Earth System Science Pathfinder program include the Gravity Recovery and Climate Experiment, studying changes in Earth's water resources, and CloudSat, studying the vertical structure of clouds.

Space exploration requires many types of expertise. Each team that submits a proposal for one of NASA's competitive-mission programs is headed by an individual principal investigator, but many proposals combine efforts of people at universities, aerospace corporations and NASA centers, often with international partners.

Twenty-five teams submitted proposals in August 2002 to develop and operate the first NASA Mars Scout mission. The four selected in December 2002 for detailed mission-concept studies illustrate the diversity of proposals. One team proposed a spacecraft that would loop through Mars' atmosphere once, then head back to Earth with collected samples of dust and gas. Another proposed to release a winged aircraft that would study Mars' atmosphere while descending through it. A proposed orbiter would search Mars for gaseous signs of life or hydrothermal activity. The other finalist was Phoenix, a stationary lander to dig into icy soil and analyze it.

The May 2006 announcement of opportunity for NASA's second Scout Mission drew 26 proposals. The two mission proposals funded for further study are:

❑ **Mars Atmosphere and Volatile Evolution** mission, or Maven. This orbiter would provide first-of-its-kind measurements and address key questions about Mars climate and habitability and improve understanding of dynamic processes in the upper Martian atmosphere and ionosphere. The principal investigator is Bruce Jakosky, University of Colorado, Boulder. NASA's Goddard Space Flight Center, Greenbelt, Md., would provide project management.

❑ The **Great Escape** mission. This orbiter would directly determine the basic processes in Martian atmospheric evolution by measuring the structure and dynamics of the upper atmosphere. In addition, potentially biogenic atmospheric constituents such as methane would be measured. The principal investigator is James L. Burch, Southwest Research Institute, San Antonio, Texas. Southwest Research Institute would also provide project management.

In addition to proposals for complete missions, NASA solicited Mars Scout proposals for investigations to fly on a mission other than a NASA Mars Exploration Program mission.

Alian Wang of Washington University, St. Louis, was selected for funding to study the chemistry, mineralogy and astrobiology of Mars as a member of the science team for a European instrument intended for the payload of the European Space Agency's ExoMars mission, which is planned for launch in 2013.

NASA also selected two proposals for technology development studies that may lead to further NASA contributions to ExoMars or other Mars missions. The two technology development studies are:

❑ **Urey Mars Organic and Oxidant Detector**. This instrument would investigate organics and oxidant materials on Mars using three complementary detection systems. The principal investigator is Jeffrey Bada, University of California at San Diego.

❑ **Mars Organic Molecule Analyzer**. This instrument would investigate organic molecular signatures and the environment in which they exist using a mass spectrometer and gas chromatograph. The principal investigator is Luann Becker, University of California at Santa Barbara.

If selected for flight, a 2011 Scout mission will be cost-capped at a budget of up to $475 million in 2006 dollars. If an instrument is selected for flight, each will be cost-capped at no more than $35 million.

Scout missions are led by the principal investigators, reporting to the Mars Exploration Program managed for NASA by the Jet Propulsion Laboratory. Further information about the program is available online at **http://mars-scout.larc.nasa.gov** .

Recent, Current and Upcoming Missions

Building on scientific discoveries and lessons from past and ongoing missions, NASA's Mars Exploration Program is working to establish a sustained observational presence at Mars. This includes orbiters that view the planet from above and act as telecommunications relays; surface-based mobile laboratories; robots that probe below the planet's surface; and, ultimately, missions that return soil and rock samples to Earth and prepare for human landing.

With international cooperation, the long-term program is guided by compelling questions about Mars and developing technologies to make missions possible within available resources. The program's strategy is to seek to uncover profound insights into Mars' past environment, the roles and abundance of water, and the potential for past or present habitats suitable for the existence of life.

As part of the NASA's Vision for Space Exploration, these missions of discovery foresee human exploration of the moon, Mars and beyond in coming decades, and take early measurements necessary for human landing and habitation.

The following are the most recently completed, ongoing and near-term future Mars missions of exploration by NASA and its international partners:

❑ **Mars Pathfinder** (December 1996 - March 1998): The first completed mission in NASA's Discovery Program of low-cost planetary missions with highly focused scientific goals, Mars Pathfinder set ambitious objectives and surpassed them. This lander released its Sojourner rover on the Martian surface and returned 2.3 billion bits of information from instruments on the lander and the rover. The information included more than 17,000 images, more than 15 chemical analyses of rocks and soil, and extensive data on winds and other aspects of weather. The observations suggest that early Mars may have been more Earth-like with liquid water on its surface and a thicker atmosphere than it has today. The mission functioned on the Martian surface for about three months, well beyond the planned lifetimes of 30 days for the lander and seven days for the rover.

❑ **Mars Global Surveyor** (November 1996 - November 2006): During its primary mapping mission from March 1999 through January 2001, NASA's Mars Global Surveyor collected more information than any previous Mars project. The orbiter continued to examine Mars' surface and monitor its global weather patterns through three mission extensions, successfully operating longer than any other spacecraft sent to Mars. It had begun a fourth extension and was five days shy of the 10th anniversary of its launch when it last communicated with Earth. Mars Global Surveyor returned more than 240,000 camera images, 206 million spectrometer measurements and 671 million laser-altimeter shots. Some of the mission's most significant findings include: discovery of gullies that bear evidence of modern activity by liquid water; identifying concentrations of a mineral that often forms under wet conditions, leading to selection of one large deposit as the landing area for NASA's Mars Exploration Rover Opportunity; laser-altimeter mapping of many eroded or buried craters too subtle for previous observation; compiling extensive evidence for the role of dust in reshaping the recent Martian environment; and detection of localized remnant magnetic fields, indicating that Mars once had a global magnetic field like Earth's, shielding the surface from deadly cosmic rays. This orbiter provided details used to evaluate the risks and attractions of potential landing sites for Phoenix, as well as for the Mars Exploration Rover missions. It also served as a communications relay for the Mars Exploration Rovers during and after their landings.

❑ **Mars Odyssey** (April 2001 - present): This NASA orbiter's prime mapping mission began in March 2002. Its suite of gamma-ray spectrometer instruments soon provided strong evidence for large quantities of frozen water mixed into the top layer of soil in the 20 percent of the planet near its north and south poles. Subsequently, a site in this permafrost terrain became the destination for Phoenix. Odyssey's camera system, which examines the planet in both visible-light and infrared wavelengths, has identified minerals in rocks and soils and has compiled the highest-resolution global map of Mars. Nighttime infrared imaging provides information about how quickly or slowly surface features cool off after sunset, which gives an indication of where the surface is rocky and where it is dusty. Odyssey's observations helped evaluate potential landing sites for the Mars Exploration Rovers and for Phoenix. Relays via this orbiter have been the rovers' main way of sending information to Earth and are planned for use by Phoenix.

❑ **Mars Exploration Rover Spirit** (June 2003 - present): Spirit and its twin, Opportunity, are mobile robotic field geologists sent to examine geological clues about the environmental history -- particularly the history of water -- at carefully selected sites. Together, they make up NASA's Mars Exploration Rover project. Spirit is exploring inside Gusev Crater, a bowl 150 kilometers (95 miles) in diameter. Orbital images suggest Gusev may have once held a lake fed by inflow from a large valley network that channels into the crater from highlands to the south. Spirit landed in January 2004 in a level plain pocked with small craters and strewn with loose rocks. The rover found that the rocks on the plain are volcanic with only slight alteration by exposure to moisture. By June 2004, Spirit had driven to a range of hills about 2.6 kilometers (1.6 miles) from the landing site in a quest to find exposed bedrock. Exploring in the hills since then, Spirit has discovered a profusion of rocks and soils bearing evidence of extensive exposure to water, including the iron-oxide-hydroxide mineral goethite and hydrated sulfate salts.

❑ **Mars Exploration Rover Opportunity** (July 2003 - present): This rover was sent to a flat region named Meridiani Planum, where the spectrometer on Mars Global Surveyor had discovered a large exposure of the mineral hematite -- which often forms in the presence of water. In January 2004, Opportunity landed inside a crater only 22 meters (72 feet) in diameter and immediately saw exposed bedrock in the crater's inner slope. During the next few weeks, the rover's examination of that outcrop settled the long-running debate about whether Mars ever had sustained liquid water on its surface. Composition and textures showed that the rocks not only had been saturated with water, but had actually been laid down under gently flowing surface water. For six months beginning in June 2004, Opportunity examined deeper layers of rock inside a stadium-sized crater about 700 meters (half a mile) from the landing site. The rocks had all soaked in water, but textures in some showed that periods of dry, wind-blown deposition alternated with periods when water covered the surface. After examining its own jettisoned heat shield and a nickel-iron meteorite near this crater, Opportunity drove more than 6 kilometers (4 miles) southward to reach an even larger and deeper crater. Here, geological evidence of environmental conditions from a greater span of time lies exposed for investigation.

❑ **Mars Express** (2003 - present): This is a European Space Agency orbiter with NASA participation in two of its seven instruments: a ground-penetrating radar, and a tool for studying how the solar wind removes water vapor from Mars' outer atmosphere. The spacecraft has been returning color images and other data since January 2004 after entering orbit in late December 2003. Its infrared spectrometer found deposits of clay minerals indicating a long-ago wet environment that was less acidic than the one that produced the minerals studied by Opportunity. Mars Express has found traces of methane in Mars' atmosphere. Scientists propose that this gas would break down rapidly enough to be undetectable unless there is an active source, either biological or non-biological, maintaining its concentration in the atmosphere. Since deployment of the radar antenna in June 2005, the spacecraft has examined ice-rich layered deposits covering the polar regions. Its mapping of layered deposits at Mars' south pole indicates that the quantity of water ice there is equivalent to a liquid layer 36 feet deep covering the entire planet.

❑ **Mars Reconnaissance Orbiter** (2005 - present): This multipurpose spacecraft is examining the surface, subsurface and atmosphere of Mars with advanced instruments, returning the copious information to Earth with a communications system capable of much greater data rates than any earlier interplanetary mission. It began its primary science investigations in November 2006, following 426 carefully planned dips into the top of Mars' atmosphere to adjust the size and shape of its orbit after arriving at Mars in March 2006. By February 2007 it had already collected more data about Mars than any previous mission. Its observations have provided mineral and structural clues about ancient underground water and more recent polar layers. Its scrutiny of rock abundances in candidate landing areas for Phoenix prompted a switch in which area was most favored. The orbiter's telescopic camera, capable of resolving features as small as a desk, and its infrared spectrometer, capable of identifying mineral deposits as small as a baseball infield, are also examining potential landing sites for NASA's Mars Science Laboratory. The telecommunications capability of Mars Reconnaissance Orbiter will serve as a relay asset for Phoenix and later surface missions.

❑ **Mars Science Laboratory** (2009): This NASA mission will use precision landing technologies to put a roving science laboratory at a selected site on Mars with a payload of science instruments more than 10 times as massive as those of any earlier Mars rovers. The laboratory is designed to operate for more than a Martian year (687 Earth days) and travel across a much greater range than previous rovers. To help scientists assess whether the landing area ever had or still has environmental conditions favorable to microbial life, the rover will analyze dozens of samples scooped from the soil and drilled from rocks, with instruments typically found in Earth-based science laboratories but miniaturized to be carried inside the rover. Instruments have been selected that could reveal the geologic history and present environment of the site, identify and inventory the chemical building blocks of life in the samples, and identify features that may show effects of biological processes. The mission will mark major advances in measurement capabilities and surface access. It will demonstrate technologies for accurate landing that will be necessary to send later missions to sites that are scientifically compelling but difficult to reach, and it will prove techniques that will contribute to human landing systems.

❑ **Additional Mars Scouts**: Mars Scouts are competitively proposed, moderate-cost missions that supplement the sequence of larger, "facility-class" strategic missions of NASA's Mars Exploration Program. Phoenix is the first. NASA requested proposals in 2006 for the second Mars Scout mission, to be launched in 2011. Two of the proposals have been funded for feasibility studies this year with the intent to select one as the 2011 mission. These finalists are the Mars Atmosphere and Volatile Evolution mission and the Great Escape mission, either of which would fly an orbiter for examining the chemistry and dynamics of Mars' upper atmosphere.

❑ **ExoMars** (2013): The European Space Agency is planning this mission to put a rover on the surface and a data-relay satellite into orbit. NASA is funding development work on two organic-chemistry instruments that could be part of the rover's scientific payload. ExoMars is being designed to look for signs of past or present life.

❑ In support of the **Vision for Space Exploration**, NASA has also begun development of the infrastructure, capabilities and technologies to enable future human exploration missions to the moon, Mars and beyond. As the first step on this journey, NASA is engaged in developing a new human transportation system to replace the space shuttle after its retirement in 2010. This system will include the Orion crew exploration vehicle and the Ares 1 crew launch vehicle, which will be used to safely transport astronauts to and from Earth orbit. Building on this capability, the additional development of an Ares 5 cargo launch vehicle and a lunar landing vehicle will prepare the United States for a return of astronauts to the lunar surface by 2020. Planning is underway to define the role of this sustained presence of astronauts at a future lunar outpost in supporting NASA's long-term exploration goals -- including preparing humans and their systems for someday venturing to Mars. Meanwhile, the Mars scientific robotic program will continue to take measurements and apply technologies in its planned missions to help pave the way for astronauts. Upcoming examples of this preparatory work include an atmospheric entry and landing instrumentation package and a surface radiation monitor on Mars Science Laboratory scheduled for launch in 2009.

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 kilometers (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 burned up due to steep entry

Mars 3: USSR, 5/28/71, Mars orbiter/lander, arrived 12/3/71, lander operated on surface for 20 seconds before failing

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 flyby module and lander, arrived 3/12/74, lander failed due to fast impact

Mars 7: USSR, 8/9/73, Mars flyby module and lander, arrived 3/9/74, lander missed the planet

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 more than 50,000 photos

Phobos 1: USSR, 7/7/88, Mars/Phobos orbiter/lander, lost 8/88 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, high-detail mapping through 1/00, third extended mission completed 9/06, last communication 11//2/06

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: Japan, 7/4/98, Mars orbiter, failed to enter orbit 12/03

Mars Climate Orbiter: U.S., 12/11/98, lost upon arrival 9/23/99

Mars Polar Lander/Deep Space 2: U.S., 1/3/99, lander and two probes, lost on arrival 12/3/99

Mars Odyssey: U.S., 3/7/01, Mars orbiter, arrived 10/24/01, currently conducting extended science mission and providing relay for Mars Exploration Rovers

Mars Express/Beagle 2: European Space Agency, 6/2/03, Mars orbiter/lander, orbiter completed prime mission 11/05, currently in extended mission; lander lost on arrival 12/25/03

Mars Exploration Rover Spirit: U.S., 6/10/03, Mars rover, landed 1/4/04 for three-month prime mission inside Gusev Crater, currently conducting extended mission

Mars Exploration Rover Opportunity: U.S., 7/7/03, Mars rover, landed 1/25/04 for three-month prime mission in Meridiani Planum region, currently conducting extended mission

Mars Reconnaissance Orbiter: U.S., 8/12/05, Mars orbiter, began orbiting 3/12/06, currently conducting primary science phase

Program/Project Management

Phoenix Mars Lander is a project led by principal investigator Peter Smith of the University of Arizona, Tucson, and managed by NASA's Jet Propulsion Laboratory, Pasadena, Calif.

At NASA Headquarters, Washington, the Mars Program is managed by the Science Mission Directorate. Alan Stern is science associate administrator, James Green is director of the Planetary Science Division, Douglas McCuistion is Mars program director, Michael Meyer is lead scientist for the Mars Exploration Program, Karen McBride is program executive for Mars Scouts, Ramon DePaula is program executive for Phoenix and Robert Fogel is program scientist for Phoenix.

At the Jet Propulsion Laboratory, Fuk Li is Mars program manager, Richard Zurek and David Beaty are Mars chief scientists, Barry Goldstein is Phoenix project manager and Leslie Tamppari is Phoenix project scientist.

Lockheed Martin Space Systems, Denver, Colo., built the spacecraft and shares operational roles with JPL. Edward Sedivy is the company's Phoenix program manager.

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