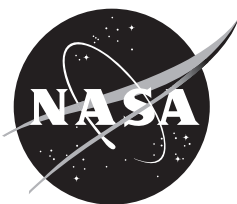
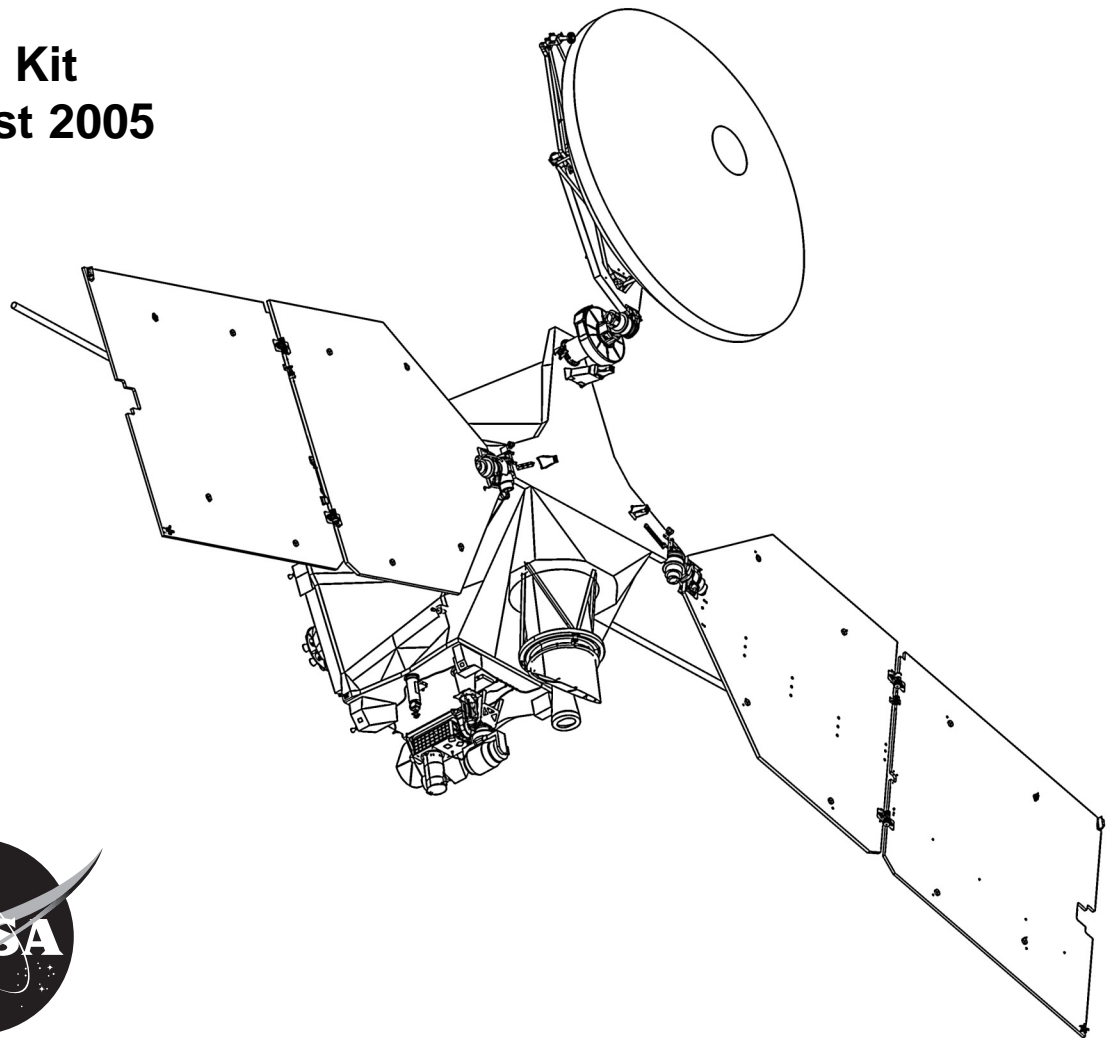


NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

# Mars Reconnaissance Orbiter Launch

Press Kit  
August 2005





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## **GENERAL RELEASE:**

### **NASA'S NEW MARS ORBITER WILL SHARPEN VISION OF EXPLORATION**

NASA's next mission to Mars will examine the red planet in unprecedented detail from low orbit and provide more data about the intriguing planet than all previous missions combined. The Mars Reconnaissance Orbiter and its launch vehicle are nearing final stages of preparation at NASA's Kennedy Space Center, Fla., for a launch opportunity that begins Aug. 10.

The spacecraft will examine Martian features ranging from the top of the atmosphere to underground layering. Researchers will use it to study the history and distribution of Martian water. It will also support future Mars missions by characterizing landing sites and providing a high-data-rate communications relay.

"Mars Reconnaissance Orbiter is the next step in our ambitious exploration of Mars," said Douglas McCuistion, director of the Mars Exploration Program in NASA's Science Mission Directorate. "We expect to use this spacecraft's eyes in the sky in coming years as our primary tools to identify and evaluate the best places for future missions to land."

The spacecraft carries six instruments for probing the atmosphere, surface and subsurface to characterize the planet and how it changed over time. One of the science payload's three cameras will be the largest-diameter telescopic camera ever sent to another planet. It will reveal rocks and layers as small as the width of an office desk. Another camera will expand the present area of high-resolution coverage by a factor of 10. A third will provide global maps of Martian weather.

The other three instruments are a spectrometer for identifying water-related minerals in patches as small as a baseball infield; a ground-penetrating radar, supplied by the Italian Space Agency, to peer beneath the surface for layers of rock, ice and, if present, water; and a radiometer to monitor atmospheric dust, water vapor and temperature.

Two additional scientific investigations will analyze the motion of the spacecraft in orbit to study the structure of the upper atmosphere and the Martian gravity field.

"We will keep pursuing a follow-the-water strategy with Mars Reconnaissance Orbiter," said Dr. Michael Meyer, Mars exploration chief scientist at NASA Headquarters. "Dramatic discoveries by Mars Global Surveyor, Mars Odyssey and the Mars Exploration Rovers about recent gullies, near-surface permafrost and ancient surface water have given us a new Mars in the past few years. Learning more about what has happened to the water will focus searches for possible Martian life, past or present." Dr. Richard Zurek of NASA's Jet Propulsion Laboratory, Pasadena, Calif., project sci-

entist for the orbiter, said, "Higher resolution is a major driver for this mission. Every time we look with increased resolution, Mars has said, 'Here's something you didn't expect. You don't understand me yet.' We're sure to find surprises."

The orbiter will reach Mars in March 2006. It will gradually adjust the shape of its orbit by aerobraking, a technique that uses the friction of careful dips into the planet's upper atmosphere. For the mission's 25-month primary science phase, beginning in November 2006, the planned orbit averages about 190 miles above the surface, more than 20 percent lower than the average for any of the three current Mars orbiters. The lower orbit adds to the ability to see Mars as it has never been seen before.

To get information from its instruments to Earth, the orbiter carries the biggest antenna ever sent to Mars and a transmitter powered by large solar panels. "It can send 10 times as much data per minute as any previous Mars spacecraft," said JPL's James Graf, project manager. "This increased return multiplies the value of the instruments by permitting increased coverage of the surface at higher resolution than ever before. The same telecommunications gear will be used to relay critical science data to Earth from landers."

To loft so big a spacecraft, weighing more than two tons fully fueled, NASA will use a powerful Atlas V launch vehicle for the first time on an interplanetary mission.

The mission is managed by JPL, a division of the California Institute of Technology, Pasadena, for the NASA Science Mission Directorate. Lockheed Martin Space Systems, Denver, is the prime contractor for the project and built the spacecraft.

For information about Mars Reconnaissance Orbiter on the Web, visit <http://www.nasa.gov/mro>

- End of General Release -

# Media Services Information

## NASA Television Transmission

NASA TV is carried on the Web and on an MPEG-2 digital signal accessed via satellite AMC-6, at 72 degrees west longitude, transponder 17C, 4040 MHz, vertical polarization. It's available in Alaska and Hawaii 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 NASA TV information and schedules on the Web, visit: [www.nasa.gov/ntv](http://www.nasa.gov/ntv)

## Launch 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 1 p.m. EDT July 21. Pre-launch briefings at Kennedy Space Center are scheduled at 1 p.m. and 2 p.m. EDT Aug. 8, 2005. Specific information about upcoming briefings, as they are scheduled, will be kept current on the Internet at [www.nasa.gov/mro](http://www.nasa.gov/mro)

## Internet Information

Extensive information on the Mars Reconnaissance Orbiter project including an electronic copy of this press kit, press releases, fact sheets, status reports, briefing schedule and images, is available at [www.nasa.gov/mro](http://www.nasa.gov/mro). More detailed information on the mission is available at the Mars Reconnaissance Orbiter project website at [mars.jpl.nasa.gov/mro](http://mars.jpl.nasa.gov/mro)

# Quick Facts

## Orbiter

Dimensions: Height 6.5 meters (21 feet) with 3-meter-diameter (10-foot) dish antenna; width 13.6 meters (45 feet) with pair of 5.35- by 2.53-meter (17.56- by 8.30-foot) solar panels

Mass: 2,180 kilograms (4,806 pounds) total at launch, consisting of 139 kilograms (306 pounds) science payload, 892 kilograms (1,967 pounds) other dry weight, plus 1,149 kilograms (2,533 pounds) of propellant and pressurant

Power: 20 square meters (220 square feet) of solar panels providing 2,000 watts at mission's farthest point from the Sun, plus nickel-hydrogen batteries for periods when the panels are not in sunshine

Science instruments: Hyper-spectral imaging spectrometer, very-high-resolution camera, context camera, color camera, climate sounder, shallow subsurface radar

## Launch Vehicle

Type: Atlas V-401 (two-stage Atlas booster with Centaur upper stage)

Height with payload: 57.4 meters (188 feet)

Mass fully fueled: 333,000 kilograms (730,000 pounds)

## Mission

Launch location: Pad LC-41, Cape Canaveral Air Force Station, Florida

Launch period: August 10 to September 5, 2005

Earth-Mars distance on August 10, 2005: 116 million kilometers (72 million miles)

Mars arrival: March 10 to March 16, 2006 (depending on launch date)

Earth-Mars distance on March 10, 2006: 215 million kilometers (134 million miles)

One-way speed-of-light time from Mars to Earth on March 10, 2006: 12 minutes

Total distance traveled, Earth to Mars: About 500 million kilometers (310 million miles)

Aerobraking phase: March to October 2006

Primary science phase: November 2006 to December 2008

Orbit during science phase: Near-polar orbit at altitudes ranging from 255 kilometers (158 miles) to 320 kilometers (199 miles); 112 minutes per orbit

Quantity of planned science data return: 26 terabits or more

Communications relay phase: January 2009 to December 2010 (mission extensions possible)

## Program

Cost: About \$720 million total, consisting approximately of \$450 million spacecraft development and science instruments; \$90 million launch; \$180 million mission operations, science processing and relay support for 5.5 years



# 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 million miles) to a maximum of 249.2 million kilometers (154.8 million miles); average distance from the Sun 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)
- ❑ 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

# Where We've Been and Where We're Going

Building on scientific discoveries and lessons learned from past and ongoing missions, NASA's Mars Exploration Program is working over many years to establish a sustained observational presence both around and on the surface of 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. With international cooperation, the long-term program is guided by compelling questions that scientists are interested in answering about Mars, developing technologies to make missions possible within available resources. The program's strategy is to seek to uncover profound new insights into Mars' past environments, the history of its rocks and interior, the roles and abundance of water and, quite possibly, evidence of past and present 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.

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, rapidly developed planetary missions with highly focused scientific goals, Mars Pathfinder far exceeded its expectations and outlived its primary design life. This lander, which released its Sojourner rover at the Martian surface, returned 2.3 billion bits of information, including more than 17,000 images and more than 15 chemical analyses of rocks and soil and extensive data on winds and other types of weather. Investigations carried out by instruments on both the lander and the rover suggest that Mars had liquid water on its surface and a thicker atmosphere. The lander and rover functioned far beyond their planned lifetimes (30 days for the lander and seven days for the rover), but eventually, after about three months on the Martian surface, depletion of the lander's battery and a drop in the lander's operating temperature are thought to have ended the mission.

□ **Mars Global Surveyor** (November 1996 - present): During its primary mapping mission from March 1999 through January 2001, NASA's Mars Global Surveyor collected more information than any other previous Mars mission. Today the orbiter continues to gather data in a second extended mission. As of May 1, 2003, it has completed more than 20,000 orbits of Mars and returned more than 137,000 images, 671 million laser-altimeter shots and 151 million spectrometer measurements. Some of the mission's most significant findings include: evidence of possibly recent liquid water at the Martian surface; evidence for layering of rocks that points to widespread ponds or lakes in the planet's early history; topographic evidence that most of the southern hemisphere is higher in elevation than most of the northern hemisphere, so that any downhill flow of water and sediments would have tended to be northward; identification of gray

hematite, a mineral suggesting a wet environment when it was formed; and extensive evidence for the role of dust in reshaping the recent Martian environment. Global Surveyor provided valuable details for evaluating the risks and attractions of potential landing sites for the Mars Exploration Rover missions, and served as a communications relay for the rovers during and after their landings.

❑ **Mars Climate Orbiter and Mars Polar Lander** (1998-99): These NASA spacecraft were both lost upon Mars arrival.

❑ **Mars Odyssey** (April 2001 - present): This NASA orbiter's prime mapping mission began in March 2002. Its suite of gamma-ray spectrometer instruments has 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. By one estimate -- likely an underestimate -- the amount of water ice near the surface, if melted, would be enough water to fill Lake Michigan twice. Odyssey's infrared camera system has also provided detailed maps of minerals in rocks and soils. A layer of olivine-rich rock in one canyon near Mars' equator suggests that site has been dry for a long time, since olivine is easily weathered by liquid water. Nighttime infrared imaging by Odyssey's camera system 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 relays via this orbiter have been the rovers' main way of sending information to Earth. About 90 percent of data from the rovers has been relayed via Odyssey, which passes over each rover twice a day.

❑ **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 2003 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 slight alteration by exposure to water. By June 2003, Spirit had driven to a range of hills about 2.6 kilometers (1.6 miles) from the landing site in a quest for exposed bedrock. Exploring in the hills since then, Spirit has found an assortment of rocks and soils bearing evidence of extensive exposure to water, including the iron-hydrogen-oxide mineral goethite and 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 a type of hematite that usually, but not always, forms in the presence of water. 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 2003, 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 heat shield and a nickel-iron meteorite near this crater, Opportunity drove more than 3 kilometers (2 miles) southward to reach a different type of terrain in search of rocks with different information to add about the region's wet history.

□ **Mars Express** (2003): This is a European Space Agency orbiter with NASA participation in two of its seven instruments. The spacecraft has been returning color images and other data since January 2004 after entering orbit in late December 2003. It has confirmed water ice in Mars' south polar cap and added information about how the solar wind has been removing water vapor from Mars' atmosphere for billions of years. Mars Express has found traces of methane in Mars' atmosphere. Scientists propose that this gas would break down rapidly enough to be undetectable if there is not an active source, either biological or non-biological, maintaining the amount. The orbiter has also mapped variations in the concentration of water vapor in the lower portion of the atmosphere. The spacecraft's June 2005 deployment of the antenna for a ground-penetrating radar instrument prepares for a search for layers bearing ice and possibly water beneath the surface of Mars.

□ **Phoenix Mars Scout** (2007): The first in a planned series of competitively selected NASA Mars Scout missions, Phoenix will land in icy soils near the north polar ice cap of Mars and explore the history of the water in these soils while checking for organic chemicals and monitoring polar climate. It is scheduled to launch in August 2007 and land in May 2008. The stationary lander will operate for up to three months. Its robotic arm is designed to dig a trench up to half a meter (20 inches) deep and deliver samples from it to an onboard laboratory to analyze the samples' chemistry and physical properties. The mission will serve as NASA's first exploration of this ice-rich region and renew the search for carbon-bearing compounds, last attempted by the Viking landers of the 1970s. The Phoenix mission plan, developed by a team led by a University of Arizona scientist, was one of 25 proposals submitted to become the first Mars Scout mission. NASA selected Phoenix from among four finalist proposals in 2003. A major role for Mars Reconnaissance Orbiter in 2008 will be to serve as the primary communications relay for Phoenix.

□ **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 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 favor-

able to microbial life, the rover will analyze dozens of samples scooped from the soil and cored from rocks. Instruments have been selected that could 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 for sending later missions to sites that are scientifically compelling but difficult to reach.

❑ **Additional Mars Scouts** (2011 and later): Mars Scouts are competitively proposed missions intended to supplement and complement, at relatively low cost, the core missions of NASA's Mars Exploration Program. Phoenix is the first. The next round of proposals and selection targets a launch no sooner than 2011.

❑ **Beyond 2011:** For the second decade of this century, NASA proposes additional missions to examine the geological record and current environment at selected sites on Mars, possibly including extended surface operations, deep-drilling or the first mission to return samples from Mars. The flexible program includes many options. Scientists and mission planners foresee technology development providing advanced capabilities, such as life-detection investigations, drilling to reach underground sites, a Mars ascent vehicle and a rendezvous in Mars orbit.

❑ In support of the **Vision for Space Exploration**, NASA has also begun preparations for sending human explorers to Mars and beyond. An early step in realizing the vision will be development of a crew exploration vehicle in the next few years; a crucial intermediate step will be return of astronauts to the Moon by 2020, this time for a sustained presence there. Meanwhile, plans envision precursor robotic missions to Mars between 2011 and 2020 that will pave the way for human exploration there by examining the challenges to human missions and demonstrating solutions. Some challenges that astronauts will face are environmental factors, such as dust and radiation. Others are technological requirements, such as reliable precision landing and an adequate energy supply.

# Science Investigations

Water is a key to at least four of the most critical questions about Mars: Has Mars had life? Could Mars support human outposts? Can Mars teach us helpful information about climate change? Do Mars and Earth share the same geological processes?

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" with spacecraft sent to Mars in recent years, resulting in discoveries such as fresh gullies carved by fluid, copious ice mixed into the top layer of surface material and ancient rock layers formed under flowing water.

The Mars Reconnaissance Orbiter mission will follow the water further. The string of water-related discoveries by spacecraft currently at Mars leave many questions that this orbiter is well equipped to investigate. We now know there was standing water on the planet. How extensively? How long? How often? Where did it well up from underground and where did it flow down from uphill drainage networks?

Deciphering the relationships among today's layers of material at and near the surface will help scientists answer these questions and raise new ones. For example, Mars Reconnaissance Orbiter may be able to resolve whether layers seen in the walls of canyons such as Valles Marineris are pasted on from the slumping of walls above them, as they might be if water emerged from the walls, or exposures of underlying layers emplaced before the deepening of the canyon cut through them, like in Arizona's Grand Canyon. How large an area and how long a period is evidenced in the water-related layers around Opportunity's landing site in Meridiani Planum? Observations by Mars Reconnaissance Orbiter may improve estimates of the answers by tracing the edges of layers and following where one extends beneath another.

Mars has shown surprises each time researchers have used increased resolution to examine it. The surface bears diversity in mineral composition and physical structure down to the smallest scales discernable from orbit so far. Researchers anticipate that the considerably higher resolution and coverage possible with Mars Reconnaissance Orbiter will reveal more. For example, the mission might find deposits of water-related minerals that don't cover enough ground to be detected by previous orbiters.

## Science Objectives

Since its early planning stages, the Mars Reconnaissance Orbiter mission has had three underlying science objectives:

1. Advance our understanding of Mars' current climate, the processes that have formed and modified the surface of the planet, and the extent to which water has played a role in surface processes.

2. Identify sites where possible effects of liquid water indicate environments that may have been conducive to biological activity or might even now harbor life.
3. Identify and characterize sites for future Mars landings.

In pursuit of these objectives, the mission will make observations and measurements to:

- Assess Mars' seasonal and time-of-day variations in water, dust and carbon dioxide in the atmosphere.
- Characterize Mars' global atmospheric structure and surface changes.
- Search for sites with evidence of water or hydrothermal activity.
- Examine the detailed stratigraphy (layers laid down over time), geologic structure and composition of Mars' surface features.
- Probe beneath the surface for evidence of subsurface layering, reservoirs of water or ice, and the internal structure of polar ice caps.
- Map and monitor the Martian gravity field to improve knowledge about Mars' crust and variations in atmospheric mass.
- Identify and characterize prospective landing sites with high potential for discoveries by future missions.

## **Research Strategy**

The orbiter will use a wide range of wavelengths for its investigations, from ultraviolet through visible and infrared to short-wave radio. It will see Mars' surface in greater detail than any previous Mars orbiter.

The tremendous amount of data generated by observations in many wavelengths and at high resolutions dictates the importance of the orbiter's large high-gain antenna and high-powered telecommunications system for sending the data to Earth. Nevertheless, limits on time and data capacity mean that only a small fraction of Mars can be examined at the highest resolution. The surface of Mars covers an area about the same as all the dry land on Earth. Surprises detectable with this orbiter's capable instruments could lie anywhere. Choosing where to look closely will affect what discoveries are made.

To make the most effective use of the highest-resolution capabilities, the mission's science team will employ a strategy of mixing three distinct modes of observations: daily global-scale monitoring, regional surveys and targeted high-resolution observations. The broader views will aid interpretation of the higher-resolution data and will identify additional sites for targeted observations. Some instruments can observe in more than one mode. Targeted observations may combine nearly simultaneous data collection by more than one instrument, providing context for interpreting each other's data.

## Science Instruments

Mars Reconnaissance Orbiter will carry six science instruments. Two additional investigations will use the spacecraft itself as an instrument.

□ The **High Resolution Imaging Science Experiment** will photograph selected places on Mars with the most powerful telescopic camera ever built for use at a foreign planet. It will reveal features as small as a kitchen table in images covering swaths of Mars' surface 6 kilometers (3.7 miles) wide. Combining images taken through filters admitting three different portions of the spectrum will produce color images in the central portion of the field of view. Paired images of top-priority target areas taken from slightly different angles during different orbits will yield three-dimensional views revealing differences in height as small as 25 centimeters (10 inches).

Of the orbiter's three research modes (global monitoring, regional survey and targeted observations), this instrument's role will be in the targeted-observation mode. Researchers will use the high-resolution camera to examine shapes of deposits and other landforms produced by geologic and climatic processes. As one example, they will look for boulders in what appear to be flood channels, which would be evidence that the channels were cut by great flows of water, rather than glaciers or lava flows. And they will check the scale of layering in polar deposits. Those layers are believed to result from cyclical variations in Mars' climate; their thickness could be an indication of the time scale of climate cycles. Some layers are at least as thin as the current limit of resolution in orbital images, so higher-resolution imaging will add more information for deciphering climate history. Other anticipated targets include gullies, dunes and patterned ground.

This camera has a primary mirror diameter of 50 centimeters (20 inches) and a field of view of 1.15 degrees. At its focal plane, the instrument holds an array of 14 electronic detectors, each covered by a filter in one of three wavelength bands: 400 to 600 nanometers (blue-green), 550 to 850 nanometers (red), or 800 to 1000 nanometers (near infrared). Ten red detectors are positioned in a line totaling 20,028 pixels across to cover the whole width of the field of view. Two each of the blue-green and near-infrared detectors lie across the central 20 percent of the field. Pixel size in images taken from an altitude of 300 kilometers (186 miles) will be 30 centimeters (12 inches) across, about a factor of two better than the highest-resolution down-track imaging possible from any earlier Mars orbiter and a factor of five better than any extended imaging to date. As a rule of thumb, at least three pixels are needed to show the shape of a feature, so the smallest resolvable features in the images will be about a meter (3 feet) across for an object with reasonable contrast to its surroundings. The instrument uses a technology called time delay integration to accomplish a high signal-to-noise ratio for unprecedented image quality.

Dr. Alfred McEwen of the University of Arizona, Tucson, is the principal investigator for the High Resolution Imaging Science Experiment. Ball Aerospace, Boulder, Colo., built



the instrument for the university to provide to the mission. Additional information about the instrument is available at [hirise.lpl.arizona.edu](http://hirise.lpl.arizona.edu) .

□ The **Compact Reconnaissance Imaging Spectrometer for Mars** will extend the search for water-related minerals on Mars by providing spectra that can be used to identify the mineral composition of the surface. Each spectrum will indicate measurements of the amount of light that Mars surface materials reflect or emit in many different wavelengths, or colors, of visible and infrared light. Most minerals expected in the Martian crust, and especially those formed by water-related processes, have characteristic fingerprints in spectra of these wavelengths. The spectrometer will collect information that could find key minerals in patches as small as a house, using resolution about 10 times sharper than in any previous look at Mars in infrared wavelengths and sharp enough to discover a deposit left by an individual hot spring or evaporated pond, if such deposits exist.

The imaging spectrometer will work both in targeted and survey modes. It will target a few thousand selected areas for inspection at highest spatial resolution -- 18 meters (60 feet) per pixel -- and spectral resolution -- 544 different wavelengths. It will spend more of its time surveying the entire planet at resolutions of 100 to 200 meters (330 to 660 feet) per pixel in and about 70 different spectral channels ("colors"). The survey will find candidate sites for targeted inspection. The search for water-related minerals such as carbonates, clays and salts gets top priority for use of this instrument. Researchers are planning observations of sites such as smooth interiors of ancient craters that may have held lakes and volcanic regions that may have produced hot springs. They will also use the spectrometer to monitor seasonal changes in dust and ice particles suspended in the atmosphere.

The spectrometer has a telescope with a 10-centimeter (4-inch) aperture and a 2-degree field of view. That field of view produces images of swaths of Mars' surface about 10 kilometers (6 miles) wide. The instrument records the intensities of light in a range of wavelengths from 370 nanometers (violet) to 3,940 nanometers (near infrared) and divides that range into bands as small as 6.55 nanometers wide. It is mounted on a gimbal, which allows it to follow a target on the surface as the orbiter passes overhead.

The principal investigator for the Compact Reconnaissance Imaging Spectrometer for Mars is Dr. Scott Murchie of the Johns Hopkins University Applied Physics Laboratory, Laurel, Md., which provided the instrument. Additional information about the spectrometer is available at [crism.jhuapl.edu](http://crism.jhuapl.edu) .

□ The orbiter's **Context Camera** will return images of swaths 30 kilometers (18.6 miles) wide. Many of its images will be centered on the narrower swaths being imaged simultaneously by the high-resolution camera or the imaging spectrometer, or both. It has a resolution capable of showing the shapes of features smaller than a tennis court.

This instrument will perform roles in both the regional-survey and the targeted-observation modes. For the targeted mode, it will provide broad yet detailed visual context for interpreting observations by co-targeted instruments. Over the course of the primary science mission, it will produce regional surveys of about 15 percent of the planet's surface in relatively high resolution, which is expected to identify many targets for more detailed inspection. However, its ability to provide extended area imaging at moderately high resolution will enable it to examine the stratigraphy and morphology of many regional features and thus directly address key questions about changes in the Martian surface over geologic time and the roles that water and wind have played in these changes.

The camera is monochromatic and will produce black-and-white images. It has a single passband for visible light at 500 to 700 nanometers). It has a 5.8-degree field of view recorded onto a linear array 5,000 pixels wide, providing a resolution of 6 meters (20 feet) per pixel.

Malin Space Science Systems, San Diego, Calif., provided the Context Camera for this mission. Dr. Michael Malin is team leader for use of the instrument.

□ **Mars Color Imager** will produce daily global views to monitor changes in the atmosphere and on the surface. It can produce color images and see in ultraviolet wavelengths. Each image through the extremely wide-angle lens will catch the planet from horizon to horizon with spatial resolution selectable from one kilometer (0.6 mile) per pixel to 10 kilometers (6 miles) per pixel.

As a key instrument for the mission's global-monitoring mode, Mars Color Imager will provide daily weather maps of the entire planet and will track surface changes, such as the seasonal growing and shrinking of polar frosts and the movement of dust at other latitudes. Use of color filters will also enable researchers to identify the composition of clouds, which may be water ice, carbon-dioxide ice, or dust. Researchers will make use of the camera's ultraviolet filters to examine variations in the amount of ozone in the atmosphere. Ozone serves as a reverse indicator about water in Mars' atmosphere. Where there's more water, there's less ozone, and vice versa.

Mars Color Imager is essentially a copy of a camera that flew on the lost Mars Climate Orbiter mission. However the instrument on Mars Reconnaissance Orbiter has a wider fisheye lens to compensate for planned spacecraft rolls needed to target specific sites on Mars with other instruments. The camera has a field of view of 180 degrees. Its seven filters include five centered in visible-light wavelengths (425, 550, 600, 650 and 725 nanometers) and two in ultraviolet wavelengths (250 and 320 nanometers).

Malin Space Science Systems, San Diego, Calif., provided this instrument, and Dr. Michael Malin of that company is the principal investigator for it.

□ **Mars Climate Sounder** will study water vapor, dust, ices and temperatures in Mars' atmosphere. It will assess how they vary with altitude, map how they are distributed around the planet, and monitor their changes from day to night and from season to season. The results will aid understanding of the atmosphere's structure and circulation, thus the planet's weather and climate. The instrument looks both toward the horizon and straight down, in a broadband visible and in several thermal infrared channels. Looking toward the horizon, it can observe the atmosphere in vertical slices, assessing each 5-kilometer-thick (3-mile-thick) section from the surface to an altitude of 80 kilometers (50 miles). The resulting atmospheric profiles from different areas around the planet can be combined into daily, three-dimensional global weather maps for both daytime and nighttime.

Mars Climate Sounder is one of the instruments serving the mission's global-monitoring research mode. One goal for researchers using it is to examine how solar energy interacts with the atmosphere and the surface. The measurements will also serve understanding of how the atmosphere moves water around the planet seasonally and the give and take between the surface and the atmosphere in quantities of water and dust. One area of regional focus is the polar regions, where measurements of the amount of solar energy absorbed by the surface ice can be used to estimate the amount of carbon dioxide that is exchanged between the atmosphere and the surface during the Martian year.

The Mars Climate Sounder instrument will address the scientific goals of an earlier, much heavier instrument that flew on the ill-fated Mars Observer and Mars Climate Orbiter spacecraft. It uses a pair of telescopes with apertures of 4 centimeters (1.6 inches). They are mounted in a cylinder in a yoke frame articulated so that, without repositioning the spacecraft, the telescopes can point sideways to the horizon and to space, down onto the planet, or at calibration targets attached to the yoke. Detectors record the intensity of radiation in nine channels or bands of the electromagnetic spectrum. One channel covers visible and near-infrared frequencies from 300 to 3,000 nanometers (0.3 to 3 microns). The other eight channels are in the thermal infrared part of the spectrum, from 12 to 50 microns.

Principal investigator for the Mars Climate Sounder is Dr. Daniel McCleese of NASA's Jet Propulsion Laboratory, Pasadena, Calif., and JPL provided the instrument to the mission.

□ The orbiter's **Shallow Subsurface Radar** will probe beneath Mars' surface to find and map underground layers of ice, rock and, if present, liquid water. The information will come from the patterns of reflected radio waves transmitted by the instrument. The instrument will search to a depth of up to one kilometer (0.6 mile), with the actual depth of penetration depending on the composition of the upper crust of Mars. It will be able to distinguish between layers of different composition or physical state (e.g., liquid water) as thin as 10 meters (33 feet).

The Shallow Subsurface Radar is a regional-survey instrument. Researchers will use it to follow up on the discovery by Mars Odyssey that the top layer of ground in many parts of Mars holds substantial quantities of hydrogen, believed to be in the form of water ice. The Odyssey instruments provided information about the top meter (3 feet) of ground. This radar will allow scientists to determine whether the ice-bearing material extends much deeper, helping scientists discern whether the ice content results from an equilibrium with the Martian atmosphere of today or persists as a remnant of a much thicker ice layer formed long ago. The instrument can distinguish icy layers from water-bearing layers. If the instrument does find any underground water, those sites could become landing-site candidates for future Mars rovers or human exploration. Researchers also plan to use the Shallow Radar for mapping the distribution of buried channels, studying the internal structure of Mars' ice caps, checking for liquid water underneath the ice caps, and examining the extent and relative depths of rock layers in selected regions. The structure of the upper crust may be very complex and so the use of surface observations may be critical to the proper interpretation of the radar data. Thus, areas like the Meridiani Planum region surrounding the rover Opportunity's research area are high-priority targets for radar mapping to see how far the surface layers with their water-related minerals extend laterally beneath the surface.

The instrument will transmit "chirps" lasting 85 milliseconds each at radio frequencies from 15 megahertz to 25 megahertz (wavelengths of about 15 meters or 50 feet in free space) with 10 watts of power. In most cases, it will operate on the night side of the planet. Compared with the only other ground-penetrating radar instrument ever to orbit Mars, the Mars Advanced Radar for Subsurface and Ionospheric Sounding on the European Space Agency's Mars Express, the instrument on Mars Reconnaissance Orbiter will focus on shallower layers and have higher resolution. The Shallow Subsurface Radar's antenna will extend five meters (16 feet) to each side of the spacecraft. It is stowed in a folded-up configuration for launch and will not be deployed until after aerobraking has been completed. During the mission's two-year primary science phase, investigations with the Shallow Subsurface Radar are expected to return more data than the entire NASA Magellan mission, which mapped 99 percent of the surface of Venus with an orbiting radar instrument in the early 1990s.

The Italian Space Agency (ASI) selected Alenia Spazio, Rome, as the prime contractor for the Shallow Subsurface Radar and selected Dr. Roberto Seu of the University of Rome La Sapienza as the principal investigator for the instrument's science team. The Italian Space Agency provided the Shallow Subsurface Radar to NASA as a facility science instrument, with Dr. Seu as team leader. As part of this international collaboration, NASA selected a team of U.S. co-investigators, led by Dr. Roger Phillips of Washington University, St. Louis, to support Dr. Seu's team.

Two additional facility science investigations will use spacecraft subsystems to conduct scientific investigations of Mars.

□ The **Gravity Investigation** will track variations in the orbiter's movement during the primary science phase of the mission in order to map the effects of variations in Mars' gravity on the spacecraft. Gravity provides information on the distribution of mass on and below the surface. Previous orbiters have identified variations in the planet's gravity that result from regional differences in crustal thickness, seasonal changes in polar caps and other factors. This spacecraft will yield higher-resolution data because it will be orbiting at a lower altitude, about 30 percent closer to the planet than Mars Global Surveyor or Mars Odyssey. This will allow smaller features on the surface to be resolved in gravity maps.

Researchers will use the gravity measurements to study the processes that led to formation of surface features. They expect to study the thinning of the crust beneath the Valles Marineris rift zone, to map how volcanic material accumulated beneath the largest volcanoes and to see how impact structures modified the early Martian crust. They also anticipate that the data will reveal tiny changes in mass distribution as carbon dioxide moves from the surface to the atmosphere and back again. (In its frozen form, carbon dioxide is known as dry ice.) From changes in mass revealed by the gravitational effect on the spacecraft, scientists expect to measure how much dry-ice snow falls at high latitudes in the winter. These measurements will contribute to understanding the weather and climate on Mars.

Team leader for this investigation is Dr. Maria Zuber of the Massachusetts Institute of Technology, Cambridge, and NASA's Goddard Space Flight Center, Greenbelt, Md.

□ The **Atmospheric Structure Investigation** will measure the vertical structure of Mars' upper atmosphere using sensitive accelerometers throughout the aerobraking phase of the mission. The rate at which the spacecraft is slowed by atmospheric friction (or drag) is proportional to the density of the air encountered. Thus, the upper atmosphere's effect on the spacecraft's velocity will be analyzed for information about changes in the density of the atmosphere on each of more than 500 orbits, at altitudes sometimes as low as 95 kilometers (59 miles) and possibly as high as 200 kilometers (124 miles). The information will guide safe aerobraking because knowledge of the changing upper atmosphere is critical for avoiding excessive friction that would overheat the spacecraft. This investigation will also contribute directly to the mission's science results, particularly regarding the major question of where Mars' ancient water has gone.

From the vertical structure of atmospheric density, scientists can determine atmospheric temperature and pressure. These may be clues to the fate of the water that was clearly on the Mars surface billions of years ago. One possibility is that water molecules are broken up by solar radiation into atomic hydrogen and oxygen, with the hydrogen escaping into outer space; another possibility is that some of the water is underground. The Atmospheric Structure Investigation will address the first possibility, loss of water via the escape of hydrogen to outer space. If the upper atmosphere is warm enough, some of the hydrogen atoms would have enough energy to escape the

planet. Determining the density and temperature of the atmosphere will improve estimates of this loss process.

Other information about Mars atmosphere could also come from this investigation, just as discoveries resulted from the team's similar accelerometer measurements during aerobraking phases of the earlier Mars Global Surveyor and Mars Odyssey missions. The Global Surveyor investigation determined that even intermediate-size dust storms in the southern hemisphere immediately produced threefold increases of density in the northern hemisphere at aerobraking altitudes. These increases could have put the mission at risk if the spacecraft had not been raised to a higher altitude. The team also discovered enormous planetary-scale waves in density, which could also put the spacecraft at risk. Investigators developed techniques to predict when the spacecraft would fly through the peaks and valleys of these waves to establish safe aerobraking altitudes. During Odyssey's aerobraking, the team discovered "winter polar warming" near the north pole of Mars at high altitudes. North polar Martian winter atmospheric temperatures were warmer than expected by about 100 degrees Kelvin (180 degrees Fahrenheit). Mars Reconnaissance Orbiter's Atmospheric Structure investigators will search for similar winter warming near the south pole.

A new electronics design by Honeywell is expected to improve the signal-to-noise ratio of the Mars Reconnaissance Orbiter's accelerometers by more than a factor of 100 over the accelerometers on Mars Odyssey. This should allow measurements to be made at much higher altitudes than in the past, substantially improving estimates of the environment where hydrogen may escape. The investigation should also establish the nature of atmospheric changes due to variations in altitude, latitude, season, time-of-day, Mars-Sun distance, meteorological activity, dust storm activity, and solar activity.

Dr. Gerald Keating of George Washington University, Washington, is the team leader for this investigation.

# Technology Objectives

The mission objectives for Mars Reconnaissance Orbiter do not end with the spacecraft's scientific discoveries. It also has important work to do in relaying communications from robots on Mars' surface and in demonstrating communication and navigation technologies for use by future missions. Three instruments in the payload serve these purposes:

□ **Electra** is a technology package enabling Mars Reconnaissance Orbiter to act as a navigational and communications aid for other spacecraft as they approach Mars and operate on the surface of Mars. It will use ultra-high frequency radio for relaying commands from Earth to stationary and mobile robots on the surface and for receiving science and engineering data to be relayed back to Earth via the orbiter's main antenna. As spacecraft with compatible systems approach Mars, signals from the Reconnaissance Orbiter's Electra will provide information about the arriving spacecraft's speed and distance relative to Mars, allowing improved precision in landing. Similarly, Doppler data from Electra communications, coupled with information about the orbiter's position, can accurately indicate the position of a stationary lander or a rover on the surface.

If either or both of the Mars Exploration Rovers Spirit and Opportunity are still operating in the late 2006, they could be the first surface robots to use Mars Reconnaissance Orbiter as a communications relay. The navigation and communications strategies for the Phoenix Mars Scout mission, scheduled for launch in 2007, are being developed to take advantages of the capabilities of Electra. Phoenix is slated to arrive at Mars in May 2008 and land at a site in the arctic plains.

□ The **Optical Navigation Camera** is part of a technology demonstration of a navigation technique. The demonstration will compare the predicted positions of Mars' two moons, Phobos and Deimos, with this camera's observations of the moons as the spacecraft approaches Mars. While this technique is not necessary for Mars Reconnaissance Orbiter's own navigation, the demonstration will prepare the way for relying on it for navigating precise arrivals for future missions that land on Mars. The camera has an aperture of 6 centimeters (2.3 inches) and a narrow field of view of 1.4 degrees.

□ The **Ka Band Telecommunications Demonstration** will allow comparison of the shorter-wavelength Ka radio band with the X band that is the standard for interplanetary spacecraft communication with Earth and the primary band for this mission. The Ka band equipment uses less power than its X-band counterpart to send the same amount of data. However, Ka band transmissions are more susceptible to being disrupted by water in Earth's atmosphere. Mars Reconnaissance Orbiter will use both bands for sending data to Earth, providing a comparison that will aid planning of communication systems for future interplanetary missions.

# Mission Overview

NASA's Mars Reconnaissance Orbiter will put a large, capable spacecraft into a low-altitude orbit around Mars for two years dedicated to examining the planet in unprecedented detail and, at least, an additional two years of providing communications-relay support for other missions. Before the primary science phase and the relay phase, the mission must execute four challenging phases to get where it needs to be to do its job: the launch phase of a few hours, the cruise phase of about five months, the approach and orbit insertion phase of about two months, and the aerobraking phase of four to six months.

## Launch Vehicle

A two-stage Atlas V-401 launch vehicle will lift Mars Reconnaissance Orbiter from Space Launch Complex 41 at Cape Canaveral Air Force Station, Fla., and put the spacecraft on a course toward Mars. The spacecraft's large payload of science instruments and, even more, the high-capacity telecommunications system needed to handle the huge flow of data from high-resolution instruments, add up to a heavy spacecraft and the need for a powerful launch vehicle. The Atlas V-401, provided by Lockheed Martin Space Systems, Denver, was selected through a competitive procurement process.

The first stage, or booster, of the Atlas V-401 will combust 284,089 kilograms (313 tons) of fuel and oxidizer in just over four minutes within a single, throttlable engine -- model RD-180, supplied by Russia -- with two thrust chambers. The kerosene-like fuel (type RP-1) and liquid oxygen will be loaded shortly before launch into cylindrical tanks that make up most of the vehicle's height. The booster engine will provide thrust totaling about 4 million newtons (900,000 pounds).

The second stage, connected with two interstage adaptors, is a Centaur upper stage. Its single, restartable engine -- model RL-10, from Pratt & Whitney Space Propulsion, West Palm Beach, Fla. -- uses liquid hydrogen and liquid oxygen and can provide up to 99,200 newtons (22,300 pounds) of thrust. The Centaur can control its orientation precisely. This ability is important both to control the direction of thrust during the engine burns and also to prevent sunlight from shining directly into the spacecraft cameras and sensors that would be damaged by such intense light.

A payload adaptor connects the orbiter to the Centaur. This structure is about 1.2 meters (47 inches) in diameter. It provides an electrical interface through which the orbiter communicates with the launch vehicle, and thus to ground crews, before and during the launch. A releasable clamp band attaches the orbiter to the Centaur. When it is released, push-off springs separate the two.

The spacecraft will ride aloft inside a protective fairing atop the Centaur stage. The fair-



ing, or nose cone, is 4 meters (13 feet) in diameter. With the fairing on top, the vehicle ready for launch will stand 57.4 meters (188 feet) tall.

The first Atlas V was launched in August 2002. Mars Reconnaissance Orbiter will be the first interplanetary spacecraft launched on an Atlas V, and the first on any of the Atlas series since Pioneer Venus in May 1978. However, the Atlas series, with more than 580 launches since the first in 1957, served frequently in the lunar and interplanetary missions of the 1960s and '70s. An Atlas launched the very first successful mission to Mars, NASA's Mariner 4, on Nov. 28, 1964.

## **Launch Timing**

As Earth and Mars race in circles around the Sun, with Earth on the inside track, Earth laps Mars about 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 and plans to use future ones indefinitely. The next Mars opposition will be Nov. 7, 2005. Not all Mars oppositions are the same, because the two planets' orbits are elliptical, not circular.

During the 2005 opposition period, the closest approach of the two planets will be on Oct. 30, when they will be 69.42 million kilometers (43.1 million miles), about 24 percent farther than during the 2003 opposition. That distance, the launch vehicle's power, the spacecraft's weight, and the desired geometry of approach to Mars are all factors in determining the range of possible launch dates. The period begins on Aug. 10, 2005, and lasts 21 days, through Aug. 30, 2005.

The window of possible launch times on the first day of the launch period will begin at 7:54 a.m. Eastern Daylight Time and last for two hours. The length of the window on the other 20 days ranges from 30 minutes to two hours.

## **Launch Sequences**

Between ignition and liftoff, the booster engine will ramp quickly to an initial throttle setting of 75 percent. Before the vehicle clears its own height, the engine will throttle up to 92 percent. The throttle settings vary by launch date for most of the remaining burn until the booster engine shuts off four minutes after liftoff. Ten seconds before cutoff, engine will throttle back to about 50 percent. By the time of booster-engine cutoff, the launch vehicle will be about 300 kilometers (186 miles) downrange at an altitude of 101 kilometers (63 miles).

Ten seconds after booster-engine cutoff, the Centaur upper stage, with payload attached, will separate from the depleted first stage. The first stage will fall into the Atlantic Ocean. Nine seconds after separation, the Centaur's engine will ignite, and a

few seconds after that, the vehicle will shed the fairing that has shielded the payload to this point. The Centaur engine's first burn will last 9 minutes and 35 seconds, delivering the spacecraft and upper stage into a parking orbit around Earth and cutting off at about 13 minutes after liftoff. At this point the spacecraft will be about 3,200 kilometers (approximately 1,990 miles) downrange at an altitude of 185 kilometers (115 miles).

The shape of the planned parking orbit is an ellipse varying in altitude from 148 kilometers (92 miles) to 185 kilometers (115 miles). However, the spacecraft will not complete even one orbit. The Centaur engine will start its second burn anywhere from 33 to 55 minutes after its first cutoff, depending on launch date. This burn will last about 5 minutes and 29 seconds, lofting the spacecraft out of Earth orbit and on its way toward Mars. Six minutes after the Centaur engine's second cutoff, the second stage releases the clamp that attaches the Mars Reconnaissance Orbiter. By that point, not quite an hour after liftoff, the two-stage Atlas V will have accelerated the spacecraft to about 11,000 meters per second (25,000 miles per hour). Shortly after that, the separated Centaur performs its last maneuver, taking itself out of the orbiter's flight path to avoid colliding with the orbiter or flying to Mars.

Once the orbiter has separated from the upper stage of the launch vehicle, it will unfold its two solar-array panels from their stowed configuration. The spacecraft will be on the night side of Earth when this happens, so it will still be running on batteries until it gets back into sunlight, 20 to 30 minutes after separation. Deployment and pointing of the high-gain antenna, a dish 3 meters (10 feet) in diameter, will follow deployment of the solar arrays.

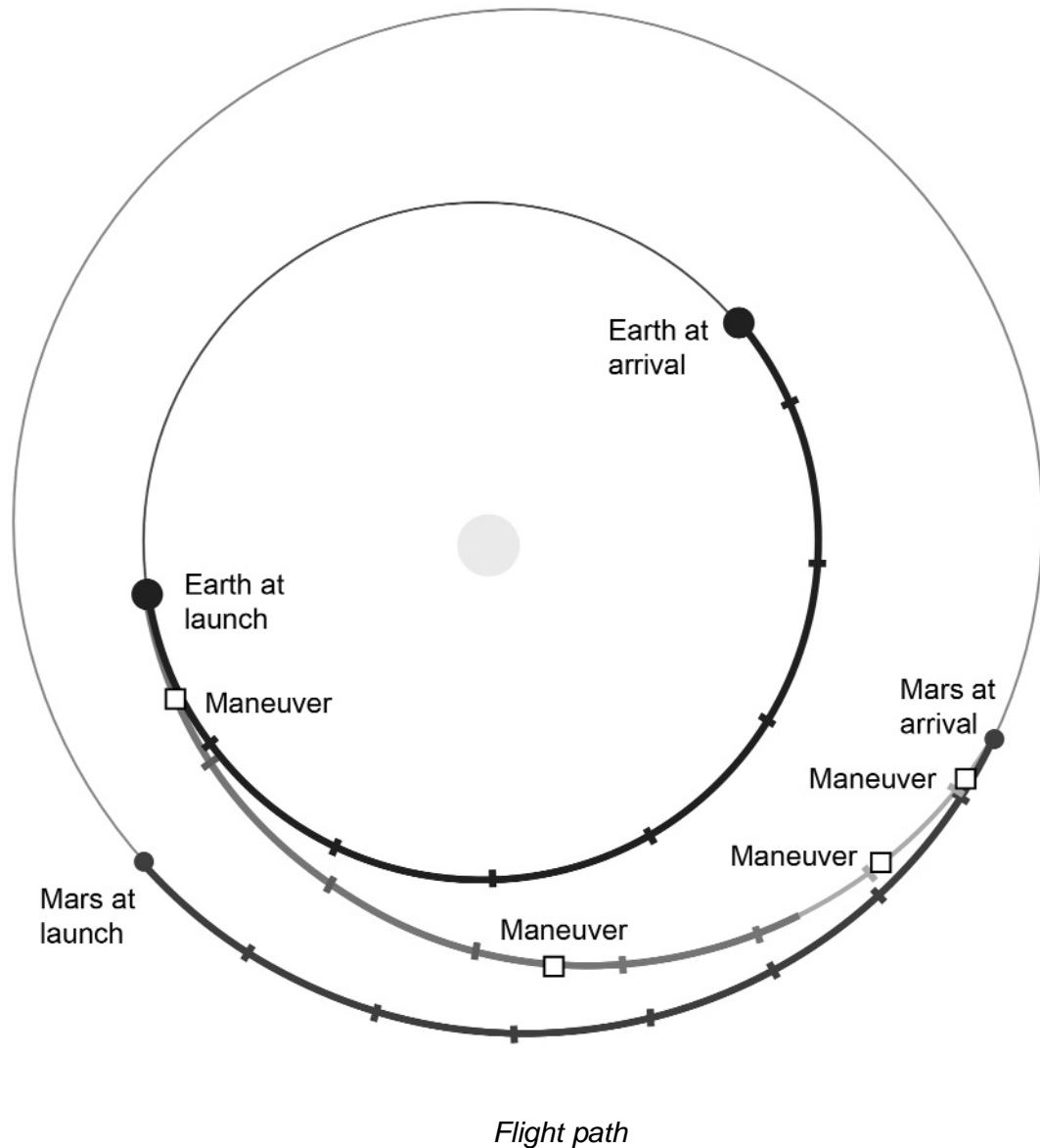
### **Interplanetary Cruise**

The trip from Earth to Mars will take about seven months, with arrival on March 10, 2006. For planning purposes, project managers consider the cruise phase as beginning about three days after launch and ending two months before Mars arrival. Main activities during cruise include daily monitoring of orbiter subsystems, navigation activities to determine and correct the vehicle's flight path, as well as checkout and calibration of spacecraft subsystems and science instruments.

During cruise, the spacecraft will keep its solar arrays facing the Sun and will periodically adjust its high-gain antenna to maintain communications with Earth.

Five trajectory correction maneuvers are planned during the trip. The first and largest is scheduled 15 days after launch, and will use the orbiter's most powerful 170-newton thrusters. Up until that point, the spacecraft's flight path will have been intentionally biased slightly off-course to prevent the Centaur upper stage from following the spacecraft and hitting Mars. This is an extra precaution in addition to the Centaur's final collision-avoidance maneuver after separation from the orbiter.

The rest of the trajectory correction maneuvers will use the spacecraft's intermediate-



power, 22-newton thrusters instead of the more powerful set. All the maneuvers, including the first, will also use smaller, 0.9-newton thrusters to provide attitude control during the change in velocity.

The second trajectory maneuver is scheduled Nov. 17, or 99 days after the opening of the launch period. The third and fourth maneuvers are 40 days and 10 days before arrival at Mars. The last scheduled maneuver is a contingency activity to be performed only if needed. It can be conducted as early as 24 hours before orbit insertion and as late as six hours before orbit insertion.

The calculations for trajectory corrections are based on very accurate determinations

of the spacecraft's position, direction of movement and velocity. The Mars Reconnaissance Orbiter mission will combine two traditional tracking techniques with a newer triangulation method to improve navigational precision. One of the traditional methods 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. The other 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.

The 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 at Deep Space Network sites on two different continents simultaneously receive signals from the spacecraft, then the same antennas are used to observe natural radio waves from a known celestial reference point, such as a quasar.

Other important events during the cruise stage will put various systems and instruments into final working order. Among these tasks are calibrations and alignments of antennas, cameras and reaction-control thrusters. Camera checks will include imaging of Earth's Moon and the star Omega Centauri. The Electra ultra-high-frequency communications system will be tested in a link with a ground station at Stanford, Calif. Other tests will assess electromagnetic interference among spacecraft systems and instruments in the space environment, and for jitter disturbance in high-resolution camera images.

### **Approaching Mars and Entering Orbit**

The mission's approach phase begins two months before arrival at Mars and extends until the spacecraft gets a health check after it begins orbiting Mars. The most critical event is the "Mars orbit insertion" thruster burn calculated to slow the spacecraft enough for Mars' gravity to capture it into orbit.

One month before reaching Mars, the spacecraft will begin its optical navigation experiment, which lasts until two days before Mars arrival. It will point the Optical Navigation Camera at Mars' moons, Phobos and Deimos. By comparing the observed positions of the moons to their predicted positions relative to background stars, navigators will calculate the precise position of the orbiter. This optical navigation is a demonstration to prepare for future missions that might use this technology. Mars Reconnaissance Orbiter's own orbit insertion will not require use of position calculations from this experiment.

Navigators' aim point for Mars Reconnaissance Orbiter is 360 kilometers (223 miles) above the planet's surface, with the spacecraft approaching from the south. The spacecraft will need to slow itself by about 1,000 meters per second (about 2,200 miles per hour) in order to be captured into orbit. The six main engines will fire for about 25 minutes. About 15 minutes into the burn, the spacecraft will pass as close to the planet's surface as it will get on this day, and at about that same time it will both enter into

Mars' shadow and slip behind Mars from Earth's perspective. Until it goes behind Mars, the spacecraft will be in communication with Earth during the orbit-insertion burn. The burn will end while the spacecraft is out of communication, and the orbiter will reappear and re-establish communications after about 30 suspenseful minutes without a signal.

If orbit insertion goes exactly as planned, the first orbit will take 35 hours to complete, as the spacecraft swings out as far as 44,500 kilometers (27,700 miles) from the planet before completing the circuit with an approach to about 300 kilometers (186 miles) above Mars' surface. The ground crew will assess the orbiter's health and run a final rehearsal of aerobraking procedures before beginning aerobraking activities.

## **Aerobraking**

Aerobraking uses friction with the planet's upper atmosphere to slow the orbiting spacecraft and change the shape of its orbit. The shape of the orbit Mars Reconnaissance Orbiter should fly for making best use of its science instruments has been carefully designed. The desired orbit is a near-polar, low-altitude orbit whose most distant altitude at 320 kilometers (199 miles) is about 25 percent farther from the planet than its closest point at 255 kilometers (158 miles). Initially, the orbit-insertion engine burn will put the spacecraft into an orbit with a very different shape, with the most distant point about 15,000 percent farther from the planet than the closest point. The mission will use hundreds of carefully calculated aerobraking dips into the upper atmosphere over the course of about six months to achieve that dramatic change in shape.

The process uses brief burns from the thrusters while the spacecraft is at the far end of the ellipse --called the "apoapsis." The burns are used only to adjust how deeply the spacecraft dips into the atmosphere at the "periapsis" end of the ellipse, where the orbit comes closest to the planet. It is the atmospheric drag on the spacecraft during the periapsis part of the orbit that does most of the work to decrease the apoapsis altitude. Compared to relying only on rocket engines to shape orbits, aerobraking reduces the amount of fuel that must be launched from Earth by nearly one-half. This is the motive for aerobraking, a technique NASA has previously used with success for the Mars Global Surveyor and Mars Odyssey orbiters.

Generally, the density of a planetary atmosphere decreases with increasing altitude. However, Mars' upper atmosphere is quite changeable in how dense it is at any given altitude. Experience gained from earlier orbiters plus monitoring by this mission's own Atmospheric Structure Investigation will aid calculations of how low to bring the periapsis from day to day. This constant monitoring is necessary because efficient aerobraking requires a balance between getting enough friction to slow the spacecraft but not too much heating. Too much friction could overheat the spacecraft. Too little could prevent getting the orbit to the right shape in time to lock it into the desired time-of-day pattern for the mission's science phase.

In its configuration for aerobraking, the orbiter presents a frontal area of 37.5 square meters (404 square feet) including the back surfaces of the solar panels and high-gain antenna. The more compact and massive main structure of the spacecraft is out in front of these larger surfaces in the direction of travel. This configuration gives the spacecraft a self-righting stability comparable to a badminton shuttlecock.

Mars Reconnaissance Orbiter will begin aerobraking about a week after arriving at Mars. The process will start with a "walk-in" phase for about 12 days, then switch to a main phase of aerobraking lasting up to five-and-a-half months, concluding with a "walk-out" phase of about five days.

During walk-in, thruster burns when the spacecraft is farthest from the planet will incrementally lower the other end of the orbit enough for the spacecraft to begin encountering atmospheric drag. Once the periapsis lowers to the altitude where the optimal amount of atmospheric drag is found, the main phase of aerobraking will begin to use the drag to lower the apoapsis. As the orbit shrinks in size, it will also lessen in duration. At the start of the main phase of aerobraking, each orbit will take more than 30 hours to complete. By the end of the main phase, the spacecraft will be completing an orbit every two hours. The walk-out phase will raise the periapsis back out of the atmosphere. This will slow the final process and prevent overheating during long drag passes as the orbit becomes more circular and the speed at periapsis is significantly reduced.

After aerobraking has been completed, a few transition activities in September and October 2006 will get the orbiter ready to begin its primary science phase. These include three or four thruster-firing maneuvers for fine-tuning the shape of the orbit, deployment of the antenna for the radar, opening the cover on the imaging spectrometer, and final testing and calibration of scientific instruments.

The orbit and the spacecraft will be ready for the start of the mission's main event, the primary science phase. But just before that phase begins, the geometry of the Sun, Earth and Mars will affect communications while Mars passes behind the Sun, from Earth's perspective. This event, called a "solar conjunction," occurs about every 26 months. Radio signals between Mars and Earth during a conjunction pass too close to the Sun to be received reliably. For mission-planning purposes, the conjunction is considered to last as long as Mars and the Sun are less than five degrees apart in Earth's sky, from Oct. 7, 2006, to Nov. 8, 2006.

## **Science Phase**

During its primary science phase, from November 2006 to December 2008, Mars Reconnaissance Orbiter will examine parts of the planet in unprecedented detail and monitor the entire planet daily throughout a full cycle of Martian seasons. Beginning right after solar conjunction allows slightly more than one Martian year of observations without interruption by another conjunction. Mars will be about one-third of the way

through a northern hemisphere summer in November 2006. Throughout the science phase, the orbiter will generally keep its instruments pointed at Mars to collect data and its high-gain antenna pointed at Earth to send the data home. With daily support by NASA's Deep Space Network for receiving the data on Earth, Mars Reconnaissance Orbiter will return more than five times as much data as all previous missions to Mars combined.

The primary science orbit is designed to serve the mission's research goals. The spacecraft will pass almost directly over the poles on each orbit. The orbit will remain at a fixed angle to the Sun; every time the spacecraft passes northbound over the equator, it will see mid-afternoon lighting on the ground. A complete orbit will take about 1 hour and 52 minutes. By the next time the orbiter comes around and crosses the equator again, the planet underneath will have rotated just enough that the orbiter sees the same time-of-day on the ground beneath it.

In altitude, the slightly elliptical orbit will range from 255 kilometers (158 miles) at the low point, or periapsis, to 320 kilometers (199 miles) at the highest point, or apoapsis. The periapsis will be over the south pole, the apoapsis over the north pole. This shape reflects the slightly asymmetrical shape of Mars and so it deviates from a circular orbit. For comparison with the orbiters currently at Mars, Mars Global Surveyor flies a nearly circular orbit at about 378 kilometers (235 miles), Mars Odyssey flies one at 400 kilometers (250 miles), and Mars Express flies an elliptical, 7.5-hour orbit ranging from 259 to 11,560 kilometers (161 to 7,183 miles).

The primary science orbit for Mars Reconnaissance Orbiter will have two cycles of repeating its ground track to allow researchers to go back for a closer look at features seen in regional surveys. That is, 359 days after any given orbit, the spacecraft will repeat essentially the same path as the earlier orbit. However, there is a much shorter cycle of 17 days in which any place on the planet can be viewed by rolling the spacecraft up to 20 degrees to the left or right of straight-downward (nadir) pointing of the instrument deck. Thus, a given target can be viewed in any 17-day cycle or can be viewed from different direction (e.g., as need for stereo images) in two successive cycles.

## **Relay Phase**

A two-year phase when the top priority for Mars Reconnaissance Orbiter will be communications support for other missions is scheduled to begin when the primary science phase ends in December 2008 and run for two years. Important relay support will begin before that, however.

The Electra communications package on Mars Reconnaissance Orbiter will enable the orbiter to assist with navigation and communication for spacecraft arriving at Mars. It will be able to communicate with spacecraft on the surface of Mars at data rates from 1 kilobit per second to 2 megabits per second. The relay can work only when the orbiter

is about 20 degrees or more above the horizon from the perspective of a lander or rover on the surface. Due to the orbiter's relatively low altitude, that will limit each relay session to about five minutes or less. Communications between the orbiter and a lander or rover will take advantage of the development of an international standard, called the Proximity-1 protocol, for the data transfer. The Consultative Committee for Space Data Systems, an international partnership for standardizing techniques used for handling space data, developed Proximity-1.

NASA's Phoenix Mars Scout mission is in development for launch in August 2007 and landing in May 2008. Phoenix would land in icy soils near the north polar ice cap of Mars and spend up to three months examining the history of the water in these soils, checking for organic chemicals and monitoring polar climate. Plans for the Phoenix mission envision support from Mars Reconnaissance Orbiter for navigation and communication during the approach to Mars, then two to three relay contacts daily at rates of up to 128 kilobits per second during Phoenix' surface operations.

The surprisingly long lives of NASA's Mars Exploration Rovers have raised the possibility that either Spirit or Opportunity will be the first user of Mars Reconnaissance Orbiter's relay capabilities. Those rovers have relied on NASA's Mars Odyssey for relaying more than 90 percent of the data they have returned, and have also used NASA's Mars Global Surveyor and the European Space Agency's Mars Express to relay data.

NASA's Jet Propulsion Laboratory is developing the next-generation Mars rover, with a science payload about 10 times as massive as the current rovers'. This rover, called Mars Science Laboratory, is slated for launch in October 2009 and landing on Mars in October 2010. Mars Reconnaissance Orbiter will have an important role as communications relay for Mars Science laboratory.

## **End of Mission**

The Mars Reconnaissance Orbiter's prime mission will end Dec. 31, 2010, after the two-year-long relay phase. If left at the low-altitude orbit used during the prime mission, the spacecraft could be expected to gradually lose altitude due to friction with the upper reaches of the atmosphere, and might fall to the planet's surface within a few years. Instead, at the end of the prime mission, the orbiter's thrusters will take the spacecraft to a higher orbit so that it will remain in orbit for decades. The end-of-mission orbit will be an ellipse ranging in altitude from about 350 to 410 kilometers (217 to 255 miles).

The initial launch mass of the orbiter will include more than enough propellant for the prime mission. Even after the end-of-mission maneuver, the orbiter is expected to have enough extra propellant for about five additional years of operation. Unless that propellant is needed for contingencies during the prime mission, NASA would have the option of assigning the orbiter an extended mission to continue support for future Mars missions. From the end-of-mission orbit, Mars Reconnaissance Orbiter could supplement



the relay support and would still be NASA's most capable asset for evaluating potential landing sites for future missions even though imaging resolution would be reduced by 30 percent at the higher altitude. Assuming its atmospheric instruments were still operating, the Mars Reconnaissance Orbiter could also provide near-real-time support for future landers, just as Mars Global Surveyor did for the Mars Exploration Rovers.

## **Communications**

From launch day until the end of its operations, Mars Reconnaissance Orbiter will rely on NASA's Deep Space Network of antenna stations on Earth. The radio links between the spacecraft and the Deep Space Network antennas will provide tracking capability during the trip to Mars; uplinked commands to the spacecraft; and downlink of all the engineering, science-instrument and relayed data from the orbiter.

The Deep Space Network transmits and receives radio signals through large dish antennas at three sites spaced approximately one-third of the way around the world from each other. This configuration ensures that spacecraft remain in view of one antenna complex or another as Earth rotates. The antenna complexes are at Goldstone in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. 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. The network provided routine communications for 30 flying spacecraft during the second quarter of 2005.

The orbiter is expected to return 34 terabits of data during its primary science phase, more than five times all previous Mars missions combined. Most of that data will come through two sessions per day, each about eight hours long, using 34-meter antennas. Plans call for using 70-meter antennas for supplemental coverage during the portions of the primary science when Mars is farthest from Earth.

Mars and Earth will be about 384 million kilometers (2.39 million miles) apart -- nearly their maximum distance from each other -- right at the beginning of the orbiter's primary science phase in November 2006. At that distance, radio signals traveling at the speed of light take about 21 minutes to make the one-way trip, and the orbiter is expected to send data to a 34-meter antenna on Earth at a rate of about 600 kilobits per second (about three CD-ROMs worth of data per hour). The minimum Earth-Mars distance during the orbiter's prime mission will be in December 2007, when the two planets will come within 88 million kilometers (55 million miles) of each other. Radio signals travel that distance in about four minutes, and Mars Reconnaissance Orbiter is expected to transmit to a 34-meter antenna that far away at a rate of about 2.6 megabits per second (about 14 CD-ROMs worth of data per hour). The spacecraft's maximum data-transmission rate, with a 70-meter antenna on the receiving end, is expected to be about 3.5 megabits per second, fast enough to fill a CD-ROM in about three minutes.

The mission will use X-band radio frequencies as its principal communication channel with Earth. Counting the capacity from supplemental use of 70-meter antennas as well as two daily sessions with 34-meter ones, the quantity of data received per day via X band is expected to vary from about 40 to 90 gigabits (about 60 to 140 CD-ROMs worth). The mission will also demonstrate the use of Ka band radio frequencies. After that demonstration's goals are met, Ka band transmissions might add significantly to the total amount of science data sent to Earth by the orbiter. The Ka band equipment uses less power than its X band counterpart to send the same amount of data. However, Ka band transmissions are more susceptible to being disrupted by water in Earth's atmosphere

## **Planetary Protection Requirements**

In the study of whether Mars has had environments conducive to life, precautions are taken against introducing microbes from Earth. The United States is a signatory to an international treaty that stipulates that exploration must be conducted in a manner that avoids harmful contamination of celestial bodies. In compliance with that treaty, the flight hardware of the Mars Reconnaissance Orbiter has been designed to meet NASA's Planetary Protection Policy.

For a planetary orbiter mission such as this, the current policy offers two alternative strategies: by assuring a long-term orbital lifetime (more than 50 years) or by flying a very clean spacecraft (measured by a microbiological burden of no more than 50,000 microbial spores). The low-altitude orbit needed for the mission to achieve its science goals makes it unfeasible to depend on impact avoidance, since a low-altitude spacecraft failure could result in an impact of Mars considerably before 50 years passes. Consequently, the project has demonstrated compliance with the total microbiological burden requirement.

In the event of a premature entry into the martian atmosphere, portions of the spacecraft that will be heated to 500 degrees Celsius (932 degrees Fahrenheit) or hotter for at least half a second during friction with Mars' atmosphere will be sterilized by that process. For other parts of the spacecraft, a combination of dry-heat microbial reduction, manufacturing controls and cleaning are keeping the number of spores within permissible levels.

Another type of precaution is to be sure any hardware that doesn't meet these standards does not go to Mars accidentally. When the Atlas V's Centaur upper stage separates from the spacecraft, the two objects are traveling on nearly identical trajectories. To prevent the possibility of the Centaur hitting Mars, that shared course is deliberately set so that the spacecraft would miss Mars if not for its first trajectory correction maneuver, about 15 days later.

The NASA planetary protection officer is responsible for the establishment and enforcement of the agency's planetary protection regulations.

# Spacecraft

The Mars Reconnaissance Orbiter spacecraft consists of the payload and the systems that enable the payload to do its job and send home the results.

The spacecraft has been assembled around a main structure made of strong, light-weight materials including titanium, carbon composites and aluminum honeycomb.

## **Propulsion Subsystem**

The spacecraft's propulsion system will perform maneuvers such as trajectory corrections during the cruise to Mars, braking to insert the spacecraft into orbit the day it arrives, and orbit adjustments during aerobraking.

The orbiter carries a total of 20 small rocket engines, or thrusters, of three sizes. The six largest ones each produce about 170 newtons (38 pounds) of thrust when they are in use. The main function for these six is to slow the spacecraft's velocity as it first flies close to Mars so that it will be captured into orbit by Mars' gravity. All six will fire at the same time for this mission-critical event, called Mars orbit insertion. By using relatively small engines rather than a single larger one, the mission is less susceptible to an orbit-insertion failure due to an engine malfunction. The six 170-newton thrusters will also be used for the spacecraft's first trajectory correction maneuver, scheduled for 15 days after launch.

Six intermediate thrusters can each produce 22 newtons (5 pounds) of thrust. They will be used for other trajectory correction maneuvers during the trip to Mars and for the maneuvers to adjust the altitude of aerobraking dips into the upper atmosphere. The smallest eight thrusters each produce 0.9 newtons (0.2 pounds) of thrust. They can control the orientation of the spacecraft as an alternate system to attitude-control reaction wheels or when the momentum built up in the wheels needs to be reduced. They will also be used to control rolling of the spacecraft during orbit insertion and trajectory correction maneuvers.

All of the thrusters consume 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. The spacecraft's propellant tank can hold the 1,220 kilograms (2,690 pounds) of hydrazine fuel, about 70 percent of which will be used for orbit insertion. To push the hydrazine to the thrusters, the spacecraft uses pressurized helium stored in a separate tank.

## **Power Subsystem**

The spacecraft's electrical power comes from two solar arrays, with a pair of nickel-hydrogen batteries to fill in when the spacecraft is in the shadow of a planet or the arrays are not facing the Sun.

Each array is 5.35 meters (17.56 feet) long by 2.53 meters (8.30 feet) wide. On the front side, 9.5 square meters (102 square feet) of the surface is covered with 3,744 individual photovoltaic cells. The cells can convert about 26 percent of the solar energy that hits them into electricity. At Earth, the two panels combined can generate about 6,000 watts. But at Mars, sunshine is weaker and the output will be 2,000 watts. The arrays are mounted on opposite sides of the orbiter, with a gimbaled connection that allows them to be turned at any angle to face the Sun.

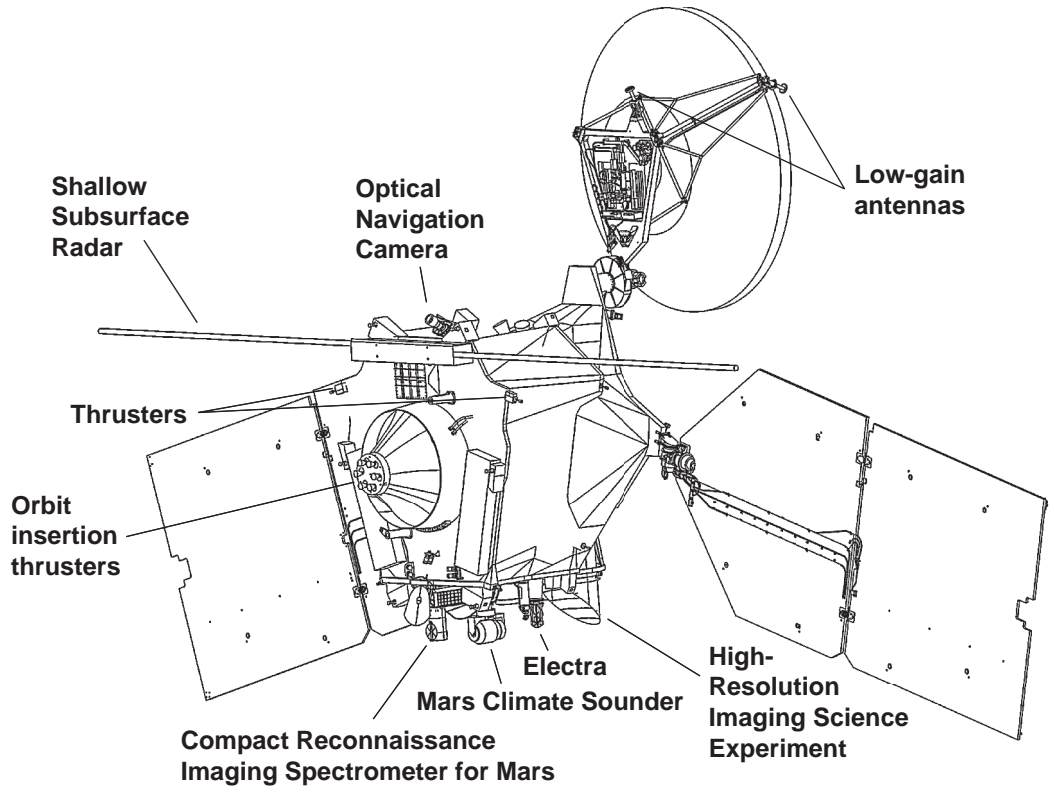
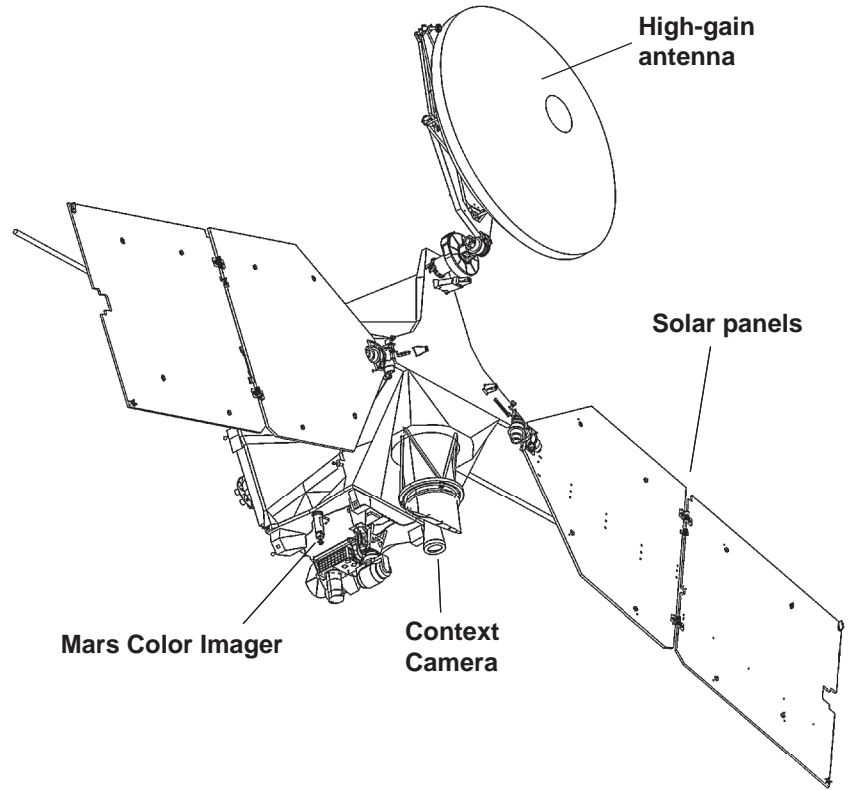
## **Communications Subsystem**

To communicate with Earth, the spacecraft has three antennas, three amplifiers and two transponders. It has the capacity to transmit data at up to 6 megabits per second, but in practical use transmitting from Mars to Earth it's peak rate is expected to be about 3.5 megabits per second, about 10 times higher than any previous Mars mission has used.

The main antenna is the biggest thing on the spacecraft other than the solar panels. It is a parabolic dish antenna 3 meters (10 feet) in diameter, mounted with a gimbal that allows it to be pointed without needing to change the orientation of the whole spacecraft. This is the high-gain antenna, meaning it is highly effective in pulling in or sending out a signal. It must be pointed at Earth to be effective. The spacecraft's other two antennas are smaller, low-gain antennas, which cannot communicate at such high data rates, but do not need to be pointed at Earth to work. They serve as backups for emergencies and special events, such as launch and orbit insertion. The low-gain antennas are mounted on the high-gain antenna, one facing forward and the other backward so that communication with Earth will be possible regardless of the spacecraft's orientation.

Two of the three amplifiers boost signals in the X-band of radio frequencies, planned as the primary channel for the mission. One of these is a backup in case the first fails. Each can send signals at 100 watts of power. The third amplifier supports the mission's demonstration of using the shorter-wavelength Ka band as an alternate channel. It can send signals at 35 watts.

The orbiter's transponders translate between digital data (the ones and zeros used by computers) and radio signals, modulating the outgoing signals to put data into them and demodulating signals received from the ground. They also have two specialized



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functions: transmitting in ways that provide spacecraft-position information to navigators and automatically responding when they detect incoming signals. One of the two transponders is a backup to the other.

In addition to its subsystem for communication with Earth, Mars Reconnaissance Orbiter carries a communication package called Electra for communicating with other spacecraft near Mars or on Mars. Electra will use the ultra-high-frequency radio band.

### **Command and Data Handling Subsystem**

The spacecraft will manage its data with a space flight computer and a solid-state recorder.

The computer features an X2000 Rad 750 microprocessor, a computer chip based on a 133 megahertz PowerPC processor but enhanced to reliably endure the natural radiation and other rigors of an outer-space environment. The Rad 750 provides processing power of up to 48 million instructions per second for use by payload instruments as well as the spacecraft subsystems.

The computer will run flight software, which includes many applications for operating the spacecraft, for protecting its health if problems arise and for recovering from problems.

The solid-state recorder provides storage space for up to 160 gigabits of information. It will be the primary location for holding data from the science instruments until it can be transmitted to Earth. The computer also has available 128 megabytes of high-speed, random-access memory.

### **Guidance, Navigation and Control Subsystem**

To control which way it is pointing, the spacecraft will use several instruments to sense its orientation and movement, and dual systems for changing its orientation, such as for pointing of instruments.

Each of two star trackers (one of which is a backup) is 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. This gives precise information about the spacecraft's orientation, and the trackers can update the information several times per second. Sixteen Sun sensors (eight of which are backups) are mounted at various points around the spacecraft and report whether or not sunlight is hitting them. If the spacecraft loses its bearings, these sensors enable it to locate the Sun so that it can turn the solar arrays toward the Sun.

An instrument called an inertial measurement unit, which also has a back-up duplicate, includes accelerometers to measure changes in the spacecraft's velocity in any direc-

tion and ring-laser gyroscopes to measure how fast the spacecraft's orientation is changing.

To change its orientation, the orbiter's primary tool is a set of three 10-kilogram (22-pound) reaction wheels spinning at right angles to each other (plus a spare). Speeding up the rotation of a wheel turns the spacecraft in the opposite direction from that wheel's spin. It's the basic physics of every action having an opposite reaction. Orientation can also be changed with the spacecraft's smallest thrusters. That method can accomplish a turn faster, but it uses some of the limited supply of propellant and the motion is not as smooth as a turn using reaction wheels. With repeated use, the reaction wheels spin faster and faster. Occasionally they need to be slowed down. While the wheels are being slowed, the thrusters are used to maintain the spacecraft's orientation.

# Mars: The Water Trail

Forty years ago, as the world 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 lifeforms 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 completely 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, not unlike those on 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.

But along the way since then, 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 Viking orbiters have detected potential signs of an ancient coastline that may have marked the edges of a long-lost sea. The three orbiters and two rovers active at Mars in 2005 have each advanced the story. The 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; and that, still today, significant amounts of water as ice or hydrated minerals make up a fraction of the top surface layer of Mars from high latitudes to some mid-latitude regions.

Although it appears unlikely that complex organisms similar to Earth's 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 may have been 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, 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 Mars Global Surveyor identified the hematite deposit that made Meridiani Planum one of the top-priority targets selected as landing sites for the 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 been covered with 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 mission of the Mars Reconnaissance Orbiter is another manifestation of combining targeted inspection with wider surveys. This spacecraft will examine selected sites in greater detail than any previous Mars orbiter -- with high enough resolution to see individual rocks as small as some that Opportunity has drilled into, to identify minerals in deposits no larger than the crater (dubbed "Eagle") where Opportunity landed and to distinguish between buried layers as thin as about 7.5 meters (25 feet) thick. It will also observe the entire planet every day and make regional surveys as context for the high-resolution observations. The mission's goals include both providing information from orbit about the history of water on Mars and also identifying the best sites for future landings.

## **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 the Red Planet 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 included 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 the Red Planet 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 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 far wetter Mars.

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 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 concluded that life may have begun on Earth in 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 entombed 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, Mars Pathfinder observed rounded pebbles and sockets in larger rocks, suggesting conglomerates that formed in running water. Mars Global Surveyor's camera has detected possible evidence for recent liquid water in many settings, including hundreds of hillside gullies. Mars Odyssey's spectrometers have found large amounts of ice mixed in with Mars surface materials. 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 underneath flowing surface water. Halfway around the planet, its twin rover, Spirit, also found rocks extensively altered by water. The European Space Agency's Mars Express has identified exposures of water-related minerals. That spacecraft and telescopic studies from Earth have found traces of atmospheric methane at Mars that might come from volcanic or biological sources.

### **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 power volcanoes or 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.

Mars appears to stand between those sets of worlds, on the basis of current yet evolving knowledge. Like Earth and Venus, it possesses a myriad of 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. New theories are emerging thanks to the discoveries of Mars Odyssey, and some scientists believe a giant ice sheet may be buried under much of the relatively smooth northern plains. Many scientists suspect 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 perhaps 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 can exist only as a solid or a gas, but only temporarily as a liquid. Scientists are now learning that over millions of years, the planet can vary its tilt, severely altering climate and perhaps stability of water on the surface.

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 incredible 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 today -- 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.

# Historical Mars Missions

*Mission, Country, Launch Date, Purpose, Results*

[Unnamed], USSR, 10/10/60, Mars flyby, did not reach Earth orbit  
[Unnamed], USSR, 10/14/60, Mars flyby, did not reach Earth orbit  
[Unnamed], USSR, 10/24/62, Mars flyby, achieved Earth orbit only  
Mars 1, USSR, 11/1/62, Mars flyby, radio failed at 106 million km (65.9 million miles)  
[Unnamed], USSR, 11/4/62, Mars flyby, achieved Earth orbit only  
Mariner 3, U.S., 11/5/64, Mars flyby, shroud failed to jettison  
Mariner 4, U.S. 11/28/64, first successful Mars flyby 7/14/65, returned 21 photos  
Zond 2, USSR, 11/30/64, Mars flyby, passed Mars but radio failed, returned no planetary data  
Mariner 6, U.S., 2/24/69, Mars flyby 7/31/69, returned 75 photos  
Mariner 7, U.S., 3/27/69, Mars flyby 8/5/69, returned 126 photos  
Mariner 8, U.S., 5/8/71, Mars orbiter, failed during launch  
Kosmos 419, USSR, 5/10/71, Mars lander, achieved Earth orbit only  
Mars 2, USSR, 5/19/71, Mars orbiter/lander arrived 11/27/71, no useful data, lander 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 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, now conducting third extended mission  
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 conducting prime mission through November 2005, 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

# Program/Project Management

The Mars Reconnaissance Orbiter project is managed by the Jet Propulsion Laboratory, Pasadena, Calif., for NASA's Science Mission Directorate, Washington.

At NASA Headquarters, Alphonso Diaz is science associate administrator, Douglas McCuistion is Mars program director, Dr. Michael Meyer is the lead scientist for the Mars Exploration Program, Dr. Ramon DePaula is program executive for Mars Reconnaissance Orbiter and Dr. R. Stephen Saunders is program scientist for the Mars Reconnaissance Orbiter.

At the Jet Propulsion Laboratory, Dr. Fuk Li is the Mars program manager, Dr. Daniel McCleese is Mars chief scientist, Jim Graf is Mars Reconnaissance Orbiter project manager and Dr. Richard Zurek is Mars Reconnaissance Orbiter project scientist.

Lockheed Martin Space Systems, Denver, Colo., built the spacecraft and shares operational roles with JPL. Kevin McNeill is program manager at Lockheed Martin for the Mars Reconnaissance Orbiter.

8-02-05