Mars Observer: The Next Mars Mission

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The next mission to Mars, called Mars Observer, will be launched in September 1992. After the capture of the spacecraft by the planet and the adjustment into a low, Sun-synchronous, polar-mapping orbit in late 1993, observations will continue for a Mars year (687 days). The scientific mission centers around global geoscience and climatology observations of the Mars atmosphere, surface, and interior. The seven experiments carried by the spacecraft involve gamma-ray spectroscopy, magnetometry, surface and atmospheric imaging, atmospheric sounding, laser altimetry, gravity mapping, and thermal emission spectroscopy. All experiments contain microprocessors, which will be controlled remotely from the investigator's home institution. The long planned period of continuous 24 h/day observation promises a rich harvest of global and seasonal information. Mars Observer stands between the initial exploration of Mars and the more intensive explorations, possibly involving human beings, that are only now being planned.

Introduction

THE scientific activity of the Mars Observer mission is organized around the twin themes of geoscience and climatology. Full mapping operations will begin late in 1993 and will continue for a full Mars year (687 days) through the fall of 1995. This long period will provide sufficient time to examine the full range of seasonal behavior and to thoroughly map the planet.

Background

Mars is the most closely examined of any planet other than the Earth. Over 20 space vehicles have been sent to the vicinity of Mars in either a flyby, orbiter, or landed mode, the most recent being the Soviet Phobos II Orbiter in 1989. A key objective in this exploration involves understanding the origin and subsequent evolution of Mars in the context of its nearest neighbors, Earth and Venus. These three terrestrial planets formed in the same region of the solar system at the same time, but they have subsequently followed quite different evolutionary paths. For example, the surface atmospheric pressure at Venus is 90 times that of Earth's, but on Mars the surface pressure is less than one-hundredth that of Earth's. The atmospheres of both Venus and Mars are dominated by the greenhouse gas, carbon dioxide, and they are, thus, of considerable interest since this gas also figures prominently in concerns about climate change on Earth.

Although the Martian atmosphere is thin by terrestrial standards, it does contain measurable amounts of water vapor. At times, the Martian relative humidity reaches 100%, leading to formation of water clouds, fogs, and frost in addition to carbon dioxide clouds and frost. However, it cannot rain on Mars at present because the atmospheric pressure is too low for liquid water to be stable. Apart from water vapor in the atmosphere, water is also known to exist on Mars in the extensive northern permanent polar cap. Surprisingly, the smaller southern permanent polar cap is covered, even during southern summer, by carbon dioxide frost and is not a source of water for the atmosphere at present.

Ample evidence exists, in the form of very large flood-type channels and loosely integrated drainage networks, that water in large amounts was present on the Martian surface in the past. What happened to it? Current thinking places some of this water beneath the surface in a frozen state while some has escaped as vapor and has been carried off into interplanetary space by erosion of the Martian atmosphere in the solar wind. Unraveling the history of water on Mars is one of the underlying motivations for the Mars Observer mission. If we can understand the behavior of the atmosphere at present, we can more confidently extrapolate backward in time to understand conditions at earlier epochs.

The thinness of the Martian atmosphere is an advantage for a variety of remote sensing experiments because it permits a nearly unobstructed view of the surface from orbit. Its thinness even permits some measurements, like gamma-ray spectroscopy, which are not possible from Earth orbit because of absorption of the emitted gamma rays by our thicker atmosphere. It is fortunate that measurements of surface properties can be made from orbit because, although Mars is a smaller planet than Earth, its 144×10^6 km^2 surface area is equal to the entire continental area of the Earth. For a long time to come, remotely sensed data will be the only type we will have from many regions of Mars.

The surface of Mars is especially important in understanding the evolution of the terrestrial planets because parts of its surface preserve direct evidence of processes going back all the way to the period of late bombardment following planetary formation (about 4 billion years ago). The first U.S. mission to Mars, Mariner 4, returned images of this moonlike, heavily cratered region of Mars. On Earth, this early bombardment record has been either erased or heavily modified. Sea floor creation and subsequent subduction has erased most traces of the Earth's early oceanic crust, and on the continents erosion has been nearly as effective. Subduction of the crust appears to be absent on Mars, and erosion has been considerably less effective. In this sense, the early history of Mars is more open to inspection than is the early history of Earth.

Key Mission Elements

The scientific plans for the Mars Observer mission are organized around a set of spacecraft and mission choices that are

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being applied for the first time to a planetary mission. A low-altitude, near-circular, near-polar, and near-Sun-synchronous orbit has been selected for mapping the planet. Each aspect of this orbit contributes to the measurement opportunities. The low altitude (400 ± 25 km) produces higher spatial resolution and improved signal-to-noise ratios for some experiments. The near-circular orbit (eccentricity < 0.01) allows nearly uniform spatial resolution at all latitudes and longitudes, facilitating intercomparison of measurements from different locations. The near-polar orbit (inclination of 93 deg) permits observations to be made at all latitudes and longitudes and is the key to a global-mapping mission. The near-Sun-synchronous orbit (2 p.m. sunward equator crossing time) makes possible repeated observations at the same time of day, thereby making it possible to separate diurnal and seasonal behavior. This orbit also readily accommodates continuous observation from experiments that must use radiators to cool detectors. Mars Observer's Sun-synchronous orbit is similar to that used by the LANDSAT, Spot, and NOAA terrestrial polar orbiters. The orbit period is 118 min. This permits sampling at two times of day for 13 longitudes each Martian day.

The Mars Observer spacecraft will maintain a nadir-pointing orientation for the entire mapping mission, so that each experiment will be able to view Mars continuously for an entire Martian year. The spacecraft will support this continuous data collection with onboard tape recorders. A daily playback to Earth is planned for Mars' recorded data, along with supplemental real-time data transmissions for high-data-rate experiments. Several experiments that need to look in more than one direction, e.g., atmospheric sensors that need to look from the nadir point to the limb, will use internally driven electronic or mechanical articulation.

The science instruments will weigh approximately 150 kg. The average total science instrument power consumption will be about 121 W. This level of power will be continuously available to the science complement for the duration of the mapping mission. The number of bits of recorded data returned each day depends on the Earth to Mars distance and will range from a low of 3.5×10^8 bits/day when Mars is farthest from the Earth to a high of 1.4×10^9 bits/day near opposition.

Every experiment will be controlled by a microprocessor contained within the instrument. Throughout the long mapping mission, the investigators will remain at their home institutions and will command their instruments remotely from these locations through an operations center at the Jet Propulsion Laboratory (JPL) and the NASA Deep Space Network. In the same way, data returned from each experiment to JPL will be electronically sent to investigators at their home institutions. Taken together, these various factors—orbit, spacecraft, instruments, and operations arrangements—maximize the experimental opportunities within the context of a mission of modest cost.

Science Objectives

There are five scientific objectives for the Mars Observer mission. The first three encompass the geoscience objectives and involve measurements of the surface and interior (gravity and magnetics). The remaining two contain the climatology objectives and involve measurement of the atmosphere and surface. These objectives are 1) to determine the global elemental and mineralogical character of the surface material; 2) to define globally the topography and gravitational field; 3) to establish the nature of the magnetic field; 4) to determine the time and space distribution, abundance, sources, and sinks of volatile material and dust over a seasonal cycle; and 5) to explore the structure and aspects of the circulation of the atmosphere.

Experiments and Instrumentation

Each of the seven experiments selected for the mission contributes to meeting one or more of the scientific objectives. These experiments are described in the following.

The gamma-ray spectrometer (GRS) detects gamma rays emerging from within and near the Martian surface. These high-energy photons are created by the natural decay of radioactive elements or are induced by cosmic rays that interact with atoms in the atmosphere and surface. The GRS measures the energy distribution of these photons, and the experiment team will use this information to establish the amounts of each element present in the atmosphere and surface material. Elements such as potassium, uranium, thorium, calcium, magnesium, aluminum, iron, and others can be measured in the top meter of the surface. Although the spatial resolution of this experiment is low (generally >300 km for most elements), it is the only remote means of directly establishing elemental surface composition. The instrument also incorporates a neutron spectrometer for the measurement of the intensity of thermal and epithermal neutron flux. This measurement in conjunction with gamma-ray spectroscopy allows exploration of the stratigraphy of carbon and hydrogen in the upper 1–2 m of the surface. Cosmic gamma-ray spectra will also be recorded when the gamma-ray flux reaches a threshold level. Triangulation, using gamma-ray detectors in other parts of the solar system, will permit location of these cosmic gamma-ray bursts.

The magnetometer/electron reflectometer (MAG/ER) is designed to detect the presence of both global and local magnetic fields. Mars is now the only planet from Mercury to Neptune whose magnetic field has not been measured. The magnetometer can detect the presence of a magnetic field directly, and the electron reflectometer, in conjunction with the magnetometer, can deduce the strength of the magnetic field in the region closer to the planet than the spacecraft by measuring the properties of electrons incident on the instrument. Previous measurements at Mars indicate that a global magnetic field, if present, is weak. Recent magnetic and particle measurements, made by the Soviet Phobos II mission in 1989, also supported the view that if a magnetic field is present it is very weak. The task of the magnetometer team will be to sort out the many processes that can produce a magnetic field and to successfully identify the actual field generated by processes inside Mars.

The Mars Observer camera (MOC) consists of two wide-angle assemblies, which can photograph the planet from limb to limb, and one narrow-angle (1.4 m/pixel) system. The wide-angle cameras will return low-resolution images of the entire planet every day to provide a record of the weather on Mars. These cameras will also return moderate-resolution images (of order 300 m/pixel) of the surface by returning only the central portion of the wide-angle images through editing done onboard the spacecraft. The high-resolution system will selectively return images from areas where key questions can be better understood through detailed knowledge of surface morphology and albedo. Because of the volume of returned data involved in the high-resolution imaging, even with data compression, only a few tenths of 1% of the Martian surface will be examined with this mode. A daily global image of Mars in the visible will provide for the first time an unbiased assessment of atmospheric phenomena. As an example, it will be possible to develop statistical information as a function of latitude, longitude, and season for local dust storms. This will permit an assessment of the role of local storms in the formation of global dust storms, should a global storm occur during the period of Mars Observer measurements. The very high-resolution measurements will provide a critical test of ideas involving climate change. Suggestions that ponded water or continental scale glaciers have shaped large areas of the surface can be tested by looking for the associated small-scale features, i.e., beaches and eskers, that accompany such processes.

The pressure modulator infrared radiometer (PMIRR) will obtain data about atmospheric structure and dynamics by making measurements primarily in the thermal infrared wavelength region. This instrument will concentrate its measurements at the limb of Mars, where the path through the atmosphere from the location of the spacecraft is greatest. PMIRR will scan upward from the limb, sounding the atmosphere to produce altitude profiles of temperature, pressure, water vapor, dust opacity, and cloud composition. These measurements will be used by the PMIRR experiment team to examine the structure and circulation of the atmosphere as a function of latitude, longitude, season, and altitude. PMIRR can also do atmospheric sounding in a nadir-looking mode and make surface measurements in this mode as well. The band selection permits full radiation budget measurements including the solar reflected and Mars emitted components.

The Mars Observer laser altimeter (MOLA) fires pulses of infrared light (1.06 μm) at the surface. From a laser, by measuring the travel time of the reflected pulse, it is possible to measure the distance from the spacecraft to the surface with a precision of several meters. By combining this measured distance with the distance from the center of the planet to the spacecraft, obtained from orbit reconstruction, the experiment team can gradually reconstruct the entire global topography of Mars. Although topography is basic to understanding the geophysics and geology of Mars, our absolute knowledge of this quantity is no better than a kilometer for much of the surface. The high precision of the Mars Observer altimeter, coupled with accurate orbits based on improved knowledge of the gravity field, will provide a many-fold improvement in understanding topographic relationships. As a byproduct of this altimetry, the surface reflectivity at 1.06 μm will be known for each of the 6×10^8 measurement locations.

In the radio science (RS) investigation, the experiment team will use the spacecraft telecommunications system and ground station receiving equipment to probe the atmosphere and gravity field of Mars. By carefully monitoring changes in the frequency of the radio signal from the spacecraft as it moves around Mars, the effect of the gravity field on the spacecraft velocity can be determined. Changes in the radio signal as the spacecraft passes in and out of occultation by Mars, as viewed from Earth, are used to construct high-resolution temperature profiles of the atmosphere. The pole-to-pole coverage and low altitude of the Mars Observer orbit will permit a significant improvement in understanding the gravity field of Mars. The radius of Mars will be accurately established at each of the occultation points, providing an independent means of checking the accuracy of the laser altimetry.

The thermal emission spectrometer (TES) operates primarily in the thermal infrared portion of the electromagnetic spectrum. The nature of radiation from the Martian surface at these wavelengths depends on temperature, surface mineralogy, and other factors. The investigation team will use spectrometer measurements to determine the thermal and mineralogical properties of the surface. The instrument will also provide data about Martian atmospheric properties, including cloud type (carbon dioxide or water ice) and dust opacity. TES is the third experiment (along with PMIRR and RS) to make atmospheric measurements. The differing atmospheric data sets obtained by these three instruments will permit intercomparison of the results of different measuring techniques, thus greatly strengthening confidence in the accuracy of the results obtained. TES uses a 3×2 (three detectors crosstrack) detector array in each of its operating wave bands. The spatial resolution of each detector is 3 km. It will be possible to map the entire surface over the course of the mission. Like PMIRR, TES carries wave bands permitting full radiation budget measurements.

Mars Balloon Relay

In addition to these seven experiments, the spacecraft will carry an eighth device, supplied by the French Centre Nationale d'Etude Spatiales, which will support the penetrators and landers of the Soviet Mars 1994 mission, when that spacecraft reaches Mars in the fall of 1995. The equipment carried by the Mars Observer spacecraft consists of a receiver/transmitter combination operating continuously at frequencies near 400 MHz. A receiver attached to the Mars 1994 landers will continuously monitor the transmitter frequency. When the signal strength reaches a threshold value indicating that the Mars Observer receiver is close enough to receive data, a transmitter on the lander will relay scientific and engineering information up from the surface to the receiver on the spacecraft. The transmission will terminate when the receiver on the surface detects that the signal from the Mars Observer transmitter has dropped below the required threshold. The data relayed up from the Mars 1994 landers will be stored in the large solid-state memory of the MOC, where it will then be encoded and processed for return to Earth. Mars Observer will augment the return of data from the landers. The primary data return path is through the Soviet Orbiter.

Organization and Scientific Personnel

The Mars Observer project is managed for NASA by the Jet Propulsion Laboratory. NASA Lewis Research Center will supply the Titan III launch vehicle through a commercial launch services contract with Martin-Marietta Commercial Titan, Inc. NASA Marshall Space Flight Center will supply the upper stage, which is being developed by the Orbital Sciences Corporation and built by the Martin-Marietta Astronautics Group. The spacecraft is being developed through a system contract with the General Electric Astro Space Division. Integration of scientific instruments with the spacecraft began in July 1991.

The seven Mars Observer experiment teams were selected through a NASA announcement of opportunity in 1985, as were five interdisciplinary scientists. Ten Soviet participating scientists will join the scientific effort, and the Soviet Mars 1994 balloon experiment team will include several American participating scientists. In the year before launch, Mars Observer will select a number of additional participating scientists through an open NASA research announcement to be released in 1991. The participating scientist program provides an opportunity to enlarge the scientific teams during the data collection and analysis period.

Tracking and data acquisition for the mission will be provided by the NASA Deep Space Network. Launch will occur from launch Complex 40 at the NASA Kennedy Space Center with the first day of a 28-day launch window opening on Sept. 16, 1992.

Summary

Mars is the only planet in the solar system, other than the Earth and its Moon, that can be visited and personally explored by humans in the near future. The presidential Moon-Mars initiative, announced in the summer of 1989, increases the need to better understand the Martian environment. Thus, Mars Observer stands between the initial exploration of Mars, already carried out by both U.S. and Soviet spacecraft, and the more intensive examination of the planet with robotic surface rovers, sample returns, and human beings, which are possible in the future.

Although our knowledge of Mars is substantial, it is trivial when compared to our knowledge of Earth. By providing global measurements of the Mars atmosphere, surface, and interior over a full Martian year, thus recording the full range of seasonal behavior, the Mars Observer mission will consolidate the knowledge gained from both ground-based studies and previous spacecraft missions, add extensive new measurements, and provide a strong foundation for more intensive investigations of Mars in the future.

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