# Mars Global Surveyor Mission Description

## Mission Overview

Mars Global Surveyor (MGS) was the successor to the failed Mars Observer (MO) spacecraft, which was lost as it approached orbit insertion in August 1993. MGS carried five of the original seven MO investigations; the Gamma Ray Spectrometer (GRS) was reflown on the 2001 Mars Odyssey, and the Pressure Modulated Infrared Radiometer (PMIRR) eventually reached Mars in 2006 aboard Mars Reconnaissance Orbiter (MRO) under the name Mars Climate Sounder MCS). When the reports on the first year of MGS operations were published in 2001, MGS had already returned more information about Mars than all previous missions to that planet combined (Albee, 2001). The mission to that point was described in an overview paper (Albee et al., 2001) and a series of papers submitted by members of the science teams which will be cited below.

The Mars Global Surveyor (MGS) spacecraft was launched from the Cape Canaveral Air Station in Florida on 7 November 1996 aboard a Delta-2/7925 rocket. The 1062-kilogram spacecraft, built by Lockheed Martin Astronautics, traveled nearly 750 million kilometers over the course of a 300-day cruise to reach Mars on 12 September 1997 (JPLD-12088).

Upon reaching Mars, MGS fired its main rocket engine for a 25-minute Mars orbit insertion (MOI) burn. This maneuver slowed the spacecraft and allowed the planet's gravity to capture it into orbit. The initial MGS orbit was highly elliptical and had a period of 45 hours.

After orbit insertion, MGS performed a series of orbit changes to drop the low point of its orbit into the upper fringes of the Martian atmosphere at an altitude of about 110 kilometers. During every atmospheric pass, the spacecraft slowed by a small amount because of air resistance. This slowing caused the spacecraft to lose altitude on its next pass through the orbit's high point. MGS was to use this aerobraking technique over a period of four months to lower the high point of its orbit from 56,000 km to near 400 km in altitude, resulting in a nearly circular orbit for mapping. Aerobraking was complicated by discovery of a broken damper arm on one of the solar panels about three weeks into the procedure. After study, spacecraft engineers concluded that aerobraking could resume, but with less stress on the panel. As a result, MGS reached its mapping orbit about a year later than planned; but science observations were interleaved with orbit adjustments.

The spacecraft began its primary mission (the Mapping Phase) on March 9, 1999; at the same time its orbit counter was reset to 1, meaning that the first 1683 orbit numbers were repeated. During mapping operations, the spacecraft orbited Mars with a period of 117.65 minutes at an 'index' altitude of 378 km. The orbit parameters resulted in an 88 revolution near-repeat cycle of approximately 7 martian days. With the true altitude ranging between 368 and 438 km and an inclination of 92.96 degrees, navigators could use interactions between the orbit and the gravity field to maintain equator crossings at approximately 2 AM and 2 PM local time without human intervention or expenditure of fuel. The mapping phase of the mission lasted for approximately one Mars year (687 days), ending January 31, 2001, on orbit 8505 (Albee et al., 2001).

A series of four extended mission phases began on February 1, 2001, (orbit 8506), and continued until communication with the spacecraft was lost on November 2, 2006 (orbit 34202). During that time operations continued in much the same way as during the primary mission, with ongoing data collection by the science instruments. Failure of an oscillator in the laser altimeter reduced its capabilities, but it continued to function in a radiometry mode. Performance of some other instruments was degraded over time; but the MGS camera system continued to provide high-quality imaging of potential landing sites, the radio science experiment was measuring atmospheric profiles, and the spacecraft was providing backup relay (communications) functions until the end.

MGS was built of lightweight composite materials and divided into four sub-assemblies: the equipment module, the propulsion module, the solar array support structure, and the high-gain antenna support structure. On board power was provided by the solar arrays; attitude was controlled by gyroscopes and small thrusters working in conjunction with celestial and sun sensors.

Mars Global Surveyor carried four on-board science instruments. The Mars Orbiter Camera (MOC) had both a wide-angle mode for global coverage and a narrow-angle mode with resolution of 1.4 meters (Malin et al., 1992). Results from the first Mars year of operation have been summarized by (Malin & Edgett, 2001). The Thermal Emission Spectrometer (TES) measured infrared radiation (Christensen et al., 1992). TES was used to determine the general mineral composition of patches of ground as small as 9.0 square kilometers; in addition, TES also scanned the Martian atmosphere to provide data for the study of the clouds and weather (Christensen et al., 2001). The Magnetometer and Electron Reflectometer (MAG/ER) were used to measure the global magnetic properties of Mars, which provided insight on internal structure (Acuna et al., 1992; Acuna et al., 2001; Mitchell et al., 2001). The Mars Orbiting Laser Altimeter (MOLA) gathered data that allowed calculation of surface feature heights to accuracies of 30 meters (Zuber et al., 1992; Smith et al., 2001B).

An ultra-stable oscillator (USO) in conjunction with the on-board telecommunications equipment and ground equipment at stations of the NASA Deep Space Network (DSN) made up the Radio Science Subsystem (RSS) (Tyler et al., 1992). RSS measurements included radio tracking of the spacecraft to improve the gravity field model of Mars, radio occultation observations to study the structure of the atmosphere and ionosphere, and surface scattering measurements to characterize potential landing sites (Tyler et al., 2001).

A sixth 'instrument' was the Mars Relay, a cylindrically shaped antenna that was used to collect data transmitted to MGS from landers on the Martian surface. These landers were carried to Mars by later spacecraft and operated after completion of the MGS primary mission.

A seventh instrument was the Accelerometer, which measured the deceleration of the spacecraft as it passed through periapsis during the aerobraking orbits. The deceleration could be used to infer atmospheric drag and, thereby, density. From the atmospheric density and altitude, it was then possible to infer pressures and temperatures above 100 km altitude, a region not accessible to other instruments (Bougher & Keating, 1999).

The MGS Horizon Sensor, originally included for attitude monitoring and control, was also used for study of the martian atmosphere (Martin & Murphy, 2001).

Mission Phases

Six mission phases were originally defined for significant spacecraft activity periods. These were the Pre-Launch, Launch, Cruise, Orbit Insertion, Mapping, and Relay Phases. The Cruise Phase included both Inner and Outer Cruise components. Once every seven Martian days during the Mapping Phase, the spacecraft approximately retraced its ground track; these 88-orbit intervals are known as 'repeat cycles.'

The final mission phase, Relay, was intended to support the 1998 Mars Polar Lander and possibly the Mars 2001 Lander. It was planned to run from February 1, 2001, through January 1, 2003. Since the Mars Polar Lander was lost and the 2001 mission was reconfigured without a lander, MGS no longer needed a Relay phase. Instead, a series of Extended Mission phases replaced Relay. Relay support, such as for the Mars Exploration Rovers starting in 2004, was woven into the Extended Mission planning.   
  
Prelaunch  
 The Prelaunch Phase extended from beginning of the MGS mission until the start of the launch countdown at the Kennedy Space Center.

Mission Phase Start Time : 1994-10-12

Mission Phase Stop Time : 1996-11-06

Launch

The Launch Phase extended from the start of launch countdown until completion of the injection into the Earth-Mars trajectory.

Mission Phase Start Time : 1996-11-06

Mission Phase Stop Time : 1996-11-07

Cruise

The Cruise Phase extended from injection into the Earth-Mars trajectory until Mars orbit insertion. During the Inner Cruise sub-phase, MGS aimed its solar panels toward the Sun and communicated through its low-gain antenna; during the Outer Cruise sub-phase, the high-gain antenna could be used while the solar panels generated acceptable levels of power. The transition occurred on 1997-01-09.

Mission Phase Start Time : 1996-11-07

Mission Phase Stop Time : 1997-09-12

Orbit Insertion

After orbit insertion, MGS performed a series of orbit changes to drop the low point of its orbit into the upper fringes of the Martian atmosphere at an altitude of about 110 kilometers. During every atmospheric pass, the spacecraft slowed by a small amount because of air resistance. This slowing caused the spacecraft to lose altitude on its next pass through the orbit's high point. MGS was to use this aerobraking technique over a period of four months to lower the high point of its orbit from 56,000 km to near 400 km in altitude, resulting in a nearly circular orbit for mapping.

At the low point of orbit 15, on October 8, 1997, MGS experienced difficulties, later diagnosed as due to excess vibrations of one of the solar panels. The problem was associated with the fracture of a panel damper arm (Albee et al., 1998). While an evaluation of the solar array problem was underway, periapsis was raised to about 172 km on October 13, 1997, and remained near that altitude until November 7, 1997 (orbits 19 through 36). During this 26-day period the spacecraft instrument panel was pointed toward Mars during close approaches (i.e., near periapsis) and the first extensive set of science observations was conducted. Orbits 19-36 are known as the Assessment Orbits or the Aerobraking Hiatus. The science observations were acquired during the descending leg of each orbit -- that is, as the spacecraft moved from north to south.

Aerobraking resumed on November 8, 1997 (orbit 37), but with a periapsis approximately 10 km higher. Aerobraking was then conducted at about one-third the rate originally planned, placing the spacecraft in a 2 AM Sun-synchronous mapping orbit by March 1999 rather than the planned 2 PM mapping orbit in March 1998. The 2 PM orbit meant that the spacecraft would have crossed the equator in the descending leg of the orbit -- north to south -- at 2 PM, a desirable observing time for some instruments. This orbit could not be achieved given the new aerobraking constraints. However, a 2 AM orbit was possible because, although the descending leg of the orbit crossed the equator at 2 AM, the ascending leg (south to north) crossed the equator at the desired time of 2 PM.

Aerobraking was halted again on March 27, 1998, and resumed on September 24, 1998. The period from March 27 through April 28 was known as Science Phasing Orbit 1 (SPO-1, orbits 202 through 268). There was a break for solar conjunction (May 12) between April 29 and May 27. Then Science Phasing Orbit 2 (SPO-2, orbits 329-573) followed from May 28 through September 23. The two science phasing orbits were needed to synchronize the two-hour circular orbit period with the equatorial crossing time of 2 AM. A final period of aerobraking began September 24, 1998, and ended February 4, 1999. Another month was then used for the Gravity Calibration Orbit, other calibration activities, and final trajectory adjustments to put the spacecraft into its mapping orbit. The period between arrival at Mars and completion of the orbit adjustment activities is known collectively as the Orbit Insertion Phase. It ended on March 9, 1999, with orbit 1683.

Mission Phase Start Time : 1997-09-12

Mission Phase Stop Time : 1999-03-09

Subphases Dates Orbits

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Aerobraking Phase 1A 1997-09-12 to 1997-10-12 0001-0018

Aerobraking Hiatus 1997-10-13 to 1997-11-07 0019-0036

Aerobraking Phase 1B 1997-11-08 to 1998-03-27 0037-0201

Science Phasing Orbit 1 1998-03-27 to 1998-04-28 0202-0268

(SPO-1)

Solar conjunction 1998-04-29 to 1998-05-27 0269-0328

Science Phasing Orbit 2 1998-05-28 to 1998-09-23 0329-0573

(SPO-2)

Aerobraking Phase 2 1998-09-24 to 1999-02-04 0574-1284

Transition to Mapping 1999-02-04 to 1999-03-09 1285-1683

Mapping

The Mapping Phase was the period of concentrated science data acquisition. At the beginning of this phase, orbit numbering was restarted at 1. The Mapping Phase lasted for 687 days, approximately one Martian year. Mars was at opposition with the Sun on April 24, 1999, and in conjunction with the Sun on July 1, 2000.

As a risk reduction measure against possible problems with the deployment of the High-Gain Antenna, the first 20 days of the Mapping Phase were operated in so-called 'Fixed High-Gain Antenna' or FHGA mode. In this mode, the undeployed HGA was pointed at Earth for four to five orbits out of every twelve to transmit data. During data transmission, the science instruments were not pointed at Mars. The HGA was deployed on March 29, 1999, and the first day of full mapping was April 3, 1999.

Soon after the antenna was deployed (April 16, 1999) its azimuth gimbal jammed, causing an entry into contingency mode and interruption in the acquisition of science data. This interruption lasted until April 29, 1999, and then data were acquired in a modified FHGA mode (HGA deployed, but boresight fixed in the spacecraft +x direction) until May 6, 1999, when normal mapping resumed. It was determined that the restricted range of travel on the azimuth gimbal would allow normal mapping operations until early 2000.

So-called 'beta supplement mode' operations, in which the antenna was reoriented to allow Earth tracking during data acquisition, were begun on February 7, 2000. But beta supplement mode required that the antenna be 'rewound' while the spacecraft was being tracked and precluded collection of egress (exit) radio occultations.

Approximately three days of FHGA operation were inserted into the schedule (March 5, 2000, to March 7, 2000) to mitigate impact on radio science. Unexpected heating of MOLA resulted, and further FHGA operation was suspended pending resolution of the thermal problems. Radio science 'egress campaigns' were eventually resumed at a rate of approximately 24 hours every month.

Mission Phase Start Time : 1999-03-09 (orbit 0001)

Mission Phase Stop Time : 2001-01-31 (orbit 8505)

Extended Mission E1

The first Extended Mission phase (E1) began at the end of the Mapping Phase, 1 February 2001, and continued through 22 April 2002. Mars was at opposition with the Sun on June 13, 2001.

Operations were much the same as during Mapping. MGS supported orbit insertion and aerobraking for the 2001 Mars Odyssey spacecraft with rapid release of MOC and TES data in late 2001 and early 2002.

A new type of spacecraft maneuver was designed for MGS targeted science observations during the extended mission: the Roll Only Targeted Observation (ROTO). The maneuver was constrained to occur primarily in the roll axis and could not exceed +/- 30 degrees off nadir. The spacecraft was rolled during selected orbits to acquire off-nadir contiguous MOC, MOLA, and TES data, which could be used to support landing site certification for future missions.

Starting on August 16, 2001, the spacecraft was put into the 'Relay 16' or R16 attitude, in which it was pitched back along the velocity vector by 16 degrees. This reduced gravity-gradient torques, slowing momentum buildup in the spacecraft reaction wheels and reducing fuel consumption.

Mission Phase Start Time : 2001-02-01 (orbit 8506)

Mission Phase Stop Time : 2002-04-22 (orbit 13960)

Extended-Extended (E2) Mission

The E2 Mission phase began at the end of the E1 Extended Mission Phase, April 22, 2002, and continued until September 26, 2004. Mars was in conjunction with the Sun on August 10, 2002, and on September 15, 2004, and was in opposition with the Sun on August 28, 2003. There was a major maneuver in May 2004 to ensure aphelion power within local sun angle constraints.

Operations were similar to those in the E1 phase. ROTOs, the R16 attitude, and radio science 'egress campaigns' were continued. MGS life expectancy was increased to 10 years based on the rate of fuel consumption. Support of the Mars Exploration Rover (MER) missions was increased with both imaging of potential landing sites and testing of the UHF communication relay system. The MGS orbit was synchronized to support descent and landing of both MER rovers; over 6 terabits of surface science data were returned via the MGS Relay.

Mission Phase Start Time : 2002-04-22 (orbit 13961)

Mission Phase Stop Time : 2004-09-26 (orbit 24836)

Extended Mission (E3)

The E3 Mission phase began at the end of the E2 phase, September 27, 2004, and continued until September 26, 2006. Mars was at opposition with the Sun on November 7, 2005.

Operations were similar to those in the E2 phase except that a safe mode event in August 2006 showed that the high-gain antenna azimuth gimbal obstruction was no longer present and that Beta Supplement operation was no longer required. This saved gimbal life, eased sequencing, reduced fuel consumption, and allowed collection of more radio occultation data. A new estimate of attitude control fuel added 10 kg to the inventory, effectively removing fuel as a limiting factor in extending the mission lifetime. MGS supported MRO orbit insertion and aerobraking after its arrival in March 2006.

Mission Phase Start Time : 2004-09-27 (orbit 24837)

Mission Phase Stop Time : 2006-09-26 (orbit 33815)

Extended Mission (E4)

The E4 Mission phase began at the end of the E3 Extended Mission phase, September 27,2006, and continued until contact with the spacecraft was unexpectedly lost in early November 2006. Normal operations were suspended between October 17 and November 2, 2006, while Mars was in conjunction with the Sun (October 23).

Operations were similar to those in the previous Extended Mission phases. During this phase the 250000-th image was transmitted to Earth, of which 1750 were collected using ROTOs and 250 were collected using motion compensated ROTOs (CPROTOs) with surface resolution as small as 50 cm. Spacecraft loss may have resulted from a solar panel hitting a hard stop during an eclipse rewind, leading to a cascade of other events which culminated in catastrophic battery failure within 10 hours.

Mission Phase Start Time : 2006-09-27 (orbit 33816)

Mission Phase Stop Time : 2006-11-02 (orbit 34202)"

Mission Objectives

One of the most intriguing, unanswered scientific questions is why do Earth and Mars appear different today? At the time of their formation several billion years ago, Mars and Earth shared similar conditions. Both planets harbored vast quantities of surface water, thick atmospheres, and climates warmer than at present. Today, Earth is a lush world filled with a countless number of animal and plant species. In contrast, data gathered from Mars prior to MGS showed that the planet was trapped in conditions reminiscent of a global ice age. The dry and seemingly lifeless Martian surface makes the Sahara look like an ocean in comparison, and average daily temperatures make Antarctica seen balmy. Comparing the history and evolution of the two planets yields clues into Earth's past and possibly its future.

Science objectives for the failed Mars Observer Mission (Albee et al., 1992) were essentially identical to those for Mars Global Surveyor (Albee et al., 2001).

*Basic Measurements and Data Collection*

Although several spacecraft preceded MGS to Mars, fundamental measurements remained to be made. No topographic model of the planet existed at the 100 meter level (and many areas were uncertain by kilometers); MOLA provided one with typical accuracies of 30 m. Preliminary measurements on the magnetic field were carried out by early spacecraft; but MGS MAG/ER was the first instrument to carry out a systematic mapping effort. Gravity models had been compiled from Mariner 9 and Viking data, but MGS RSS provided an order of magnitude improvement in these -- leading to improved understanding of the planet's interior.

*Atmospheric Processes*

Despite its forbidding climate, surface temperatures on Mars resemble the Earth's more than any other planet. These similarities in temperature result in part from the fact that Mars orbits the Sun only slightly farther out than the Earth as compared to other planets. For example, the ground at some locations near Mars' equator may warm up to as high as 25C at noontime. However, daytime temperatures still average well below freezing, and night temperatures dip much lower.

Martian temperatures may seem almost inviting to the seasoned outdoors explorer, but the composition of the atmosphere leaves much to be desired from a human perspective. Most of the martian air consists of carbon dioxide (CO2), similar to conditions on Venus. If breathing carbon dioxide seems uninviting, the density of the air will appear worse. Average barometric pressures on Mars are lower than those found at Earth's sea level by a factor of more than 125. In other words, the air at the surface of Mars is thinner than that found on Earth at an altitude 19 times higher than Denver, Colorado.

The extremely thin Martian air directly impacts the mystery of potential life on Mars, either in the past or present. The reason is that almost all of the water lies trapped in the Martian polar ice caps or frozen beneath the surface. Liquid water cannot exist on the surface because the thin atmosphere will cause melting ice to evaporate directly into water vapor.

Despite the hostile composition, density, and temperature by today's standards on Earth, the atmosphere of Mars is both interesting and dynamic. MGS objectives in this area included recording global daily images of the planet so that cloud patterns could be followed and the growth of dust storms could be monitored over a full martian year. TES and RSS were both able to measure vertical structure within the atmosphere, another key to understanding transport of material within the atmosphere -- including precipitation of CO2 itself on the winter polar cap.

*Surface Processes*

Geologically, Mars is one of the most interesting planets in the Solar System. Although only half the diameter of Earth, Mars maintains large water and CO2 ice caps at the poles, a canyon much deeper than the Grand Canyon and longer than the contiguous 48 United States are wide, crater valleys as large as the western United States, and a handful of monstrous volcanoes that make Mount Everest appear tiny in comparison.

A study of Martian geology is crucial to deciphering clues about the history of the Earth. Mars is the only planet in the solar system that both has an atmosphere and contains surface features that cover almost the entire range of history. On Earth, pristine rocks and other surface features from the first billion years of our planet's existence do not exist because geological events, weather, and life have caused drastic alterations. Because Earth and Mars shared similar conditions near the time of their formation, the MGS exploration of Mars allows us to take a peek into Earth's past in a way not possible by studying the Earth by itself.

Although liquid water on Mars will quickly evaporate, photographs transmitted back to Earth by NASA missions prior to MGS revealed giant flood channels, dry river beds, and flood plains on the surface. This evidence of past water on Mars led some scientists to consider Mars as the prime location in the Solar System to search for extraterrestrial life. The speculation was that because Mars once possessed a thicker atmosphere and vast quantities of surface water billions of years ago, then the planet may have harbored conditions favorable to the formation of life despite its present forbidding climate.

Viking and Mars Pathfinder returned information on elemental composition of some Mars surface materials at specific landing sites. But regional and global information was needed to understand both the current state and history of rocky surfaces. MOC provided high-resolution image data; and TES acquired spectral signatures of rock units so that thermal inertia, surface rock distributions, and composition could be inferred.

MOC also revealed contemporary activity on the surface during the instrument's own lifetime including 20 new impact craters, numerous boulder trails, secular enlargement of south polar pits, and fresh channel outflows likely to be water-related.

*Search for Life*

Sensors aboard various NASA spacecraft launched to Mars over the 30 years prior to MGS showed that advanced life forms almost certainly do not exist on the planet today. However, many felt that the planet might hide bacterial forms of life or their fossil remains. Although Mars Global Surveyor did not conduct a search for life on Mars, it gathered detailed data that will help in understanding the mystery of the missing water. This type of study provides important background data to help scientists in their search for Martian life on future missions.

*Other Studies*

In addition to studying Mars, the spacecraft was also used for experiments of opportunity, such as searching for gravitational waves during cruise (Estabrook et al., 1995) and probing the Sun's corona during solar conjunction (Woo, 1993).

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