MARS GLOBAL SURVEYOR: ON THE WAY TO MARS

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ABSTRACT

The Mars Global Surveyor (MGS) spacecraft was launched toward Mars on 7 November 1996 and will arrive at Mars on 12 September 1997. This mission is the first in the extensive NASA Mars Surveyor Program and had a two year development period. In this report the status of the MGS mission, prior to entry into Mars orbit, will be described along with a description of the experiments to be conducted. The Mars Global Surveyor mission is intended to accomplish a portion of the scientific objectives of the Mars Observer mission which was lost in 1993, three days before entering Mars orbit. To meet the established objectives a low, sun-synchronous, near circular, polar-mapping orbit is required which drives the need for aerobraking before mapping begins in March of 1998. MGS will carry a lander to orbiter relay capability for use with several small probes to be dropped to the surface of Mars by the 1998 Surveyor mission and the Surveyor lander. The MGS mission is designed for one Mars year (687 days) of mapping operation at Mars and will overlap in time the 1998 Surveyor mission and the start of the Planet B mission providing the opportunity to conduct cooperative experiments with multiple landed and orbiting vehicles at Mars.

Introduction

The Mars Global Surveyor (MGS) spacecraft was launched toward Mars on 7 November 1996 from the Cape Canaveral Air Force Station using a Delta II 7925 launch vehicle. MGS is the first in a series of NASA vehicles to be launched to Mars about every two years over the next decade. The spacecraft will enter Mars orbit in the early morning hours (UTC) of 12 September 1997 and within a few days will begin aerobraking to substantially reduce the eccentricity of the initial orbit, Aerobraking will last four months and the orbit period will be reduce in this process from 45 to 2 hours. Following aerobraking the spacecraft will be used to provide a detailed survey of the Martian gravity field and the results of this mapping will be used to set the final elements for the orbit to be used during mapping of the planet. Mapping of Mars will begin in mid-March 1998 from a low, near-circular, polar, sun-synchronous orbit and continue for a full Mars year (687 days).

The MGS science payload was selected to begin recovering from the loss of the Mars Observer spacecraft in the fall of 1993 and consists of the following instruments: Magnetometer/Electron Reflectometer, Mars Orbiter Camera, Mars Orbiter Laser Altimeter, Thermal Emission Spectrometer and an Ultra-Stable Oscillator for Radio Science. A Mars Relay system is provided to assist in the return of data from surface vehicles. Both the lower launch mass and budget for MGS versus Mars Observer meant that two instruments carried by Mars Observer are not a part of the MGS payload. These instruments are: the Pressure Modulator Infrared Radiometer (to fly on the 1998 Surveyor orbiter and the Gamma Ray Spectrometer (which is to fly on the 2001 Surveyor orbiter).

Cruise Activities and Events

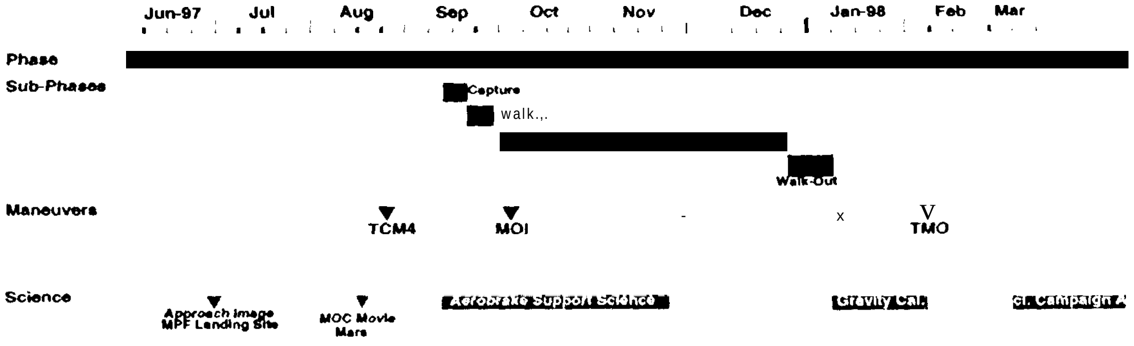
Cruise activities have been limited to those necessary to maintain the health of the spacecraft and instruments and adequately prepare for Mars orbit insertion, aerobraking and mapping. The one purely scientific activity during cruise involved a search for gravitational waves using the Radio Science equipment. Al I of the experiments have been turned on and operated successfully, cruise calibrations have been completed and observations have been made with some instruments of earth (Thermal Emission Spectrometer and Mars Relay) and Mars (Mars Orbiter Camera).

Following launch it was discovered that the solar array on the -Y side of the spacecraft did not latch at its inner hinge. investigation led to the conclusion that the solar array damper at this hinge line had failed and some portion of the damper was preventing the array from latching. The -Y array was determined to be about 20 degrees from latching. The two solar arrays are used to provide the primary drag surfaces during aerobraking with the arrays rotated so that the non-solar cell side of the array faces the flow. In this planned configuration the forces on the -Y solar array would tend to open the array at the inner hinge, resisted only by the deployment hinge springs which are far too weak to hold against the forces generated during aerobraking. As a consequence the -Y array will be rotated 180 degrees, placing the solar cell side into the flow so that the drag force will tend to move the panel in the latch direction. To insure this new configuration will meet the requirements of aerobraking the solar array has been requalified thermally and mechanically, the spacecraft dynamics in the new configuration have been checked and the solar array gimbal has been qualified for the. expected loads.

On 8 May 1997, following a routine gyroscope calibration maneuver, the spacecraft experienced an attitude error (i.e. a star was misidentified) and entered "Contingency Mode", the first level of fault protection. Several hours later the spacecraft processors encountered a flight software bug which caused both processors to enter an infinite loop and the watch dog timers timed out and sent the processors to "Safe Mode", the deepest level of onboard fault protection. A Sun sensor alignment bias which contributed to the entry into Contingency Mode was corrected and the flight software bug, which produced the infinite loop, was found and fixed. The spacecraft spend 16 days in the Safe Mode state. This event is worth noting because it illustrates how difficult it is to find software coding errors in a flight software rich environment. The software in question here was written for the Mars Observer Spacecraft, tested in a spacecraft software simulator, tested in a spacecraft simulator consisting of spare flight hardware components, tested during assembly of the Mars Observer spacecraft and flown for eleven months during which time the Mars Observer spacecraft made many excursions into Contingency Mode all without triggering this software **bug.** This same software was again tested in a software simulator, a spacecraft simulator, during assembly of the MGS spacecraft and flown for six months before the problem surfaced.

As of the date of the writing of this report (July 1997) only a few cruise activities remain before the spacecraft enters Mars orbit in early September 1997 as shown in the near term mission timeline illustrated in Figure 1. In August a short, eight frame Mars Orbiter Camera movie will be acquired and the final small Trajectory Correction Maneuver (TCM-4) will be performed to setup for the Mars Orbit Insertion (MOI) main engine burn.

Figure 1 ***Near Term MGS Mission Timeline: Cruise, Aerobraking And The Transition To The Mapping Orbit***



Mars Global Surveyor (MGS) Aerobraking

Following capture of the MGS spacecraft into Mars orbit on 12 September 1997 Universal Time (it will still be late afternoon on 11 September in the United States) the Mars Global Surveyor Mission will begin an aerobraking phase lasting four months in which the orbital period wi 11 be reduced from an initial value near 45 hours to near the mapping orbit period of 117.7 minutes. A low sun-synchronous, near-circular, near-polar mapping orbit was selected for MGS because it allows uniform coverage independent of latitude for almost all of the planet, permits high resolution observations of the surface and allows separation of diurnal and longitude variations. The use of such orbits is common for terrestrial remote sensing spacecraft but they have not been used for planetary missions, despite the observational advantages, because they are energetically expensive.

A good way of examining the energy and velocity change (AV) requirements for such orbits and the difference between using chemical propulsion and aerobraking is to compare MGS and Mars Observer. The mapping orbit at Mars is the same for these two missions. MGS will carry two fewer instruments and will use aerobraking to circularize the initial capture orbit about Mars rather than using a series of chemical propulsive maneuvers as was planned for Mars Observer. The payloads of these two missions differ by 81 kg but the launch mass of MGS was 2.4 times smaller than that of Mars Observer and the chemical propulsive AV required to get into the near-circular mapping orbit is 11 times lower for MGS (125 vs 1367 m/s). The majority of the difference in launch mass between MGS and Mars Observer spacecraft (1060 vs 2572 kg) is in the fuel and oxidizer required by Mars Observer for circularization of the orbit. By using aerobraking for circularization, MGS was able to use a much smaller and considerably less expensive launch vehicle. This saving is sufficiently dramatic that future Mars missions which require a low circular orbit will likely take this approach, as indeed, the 1998 Mars Surveyor Orbiter has done.

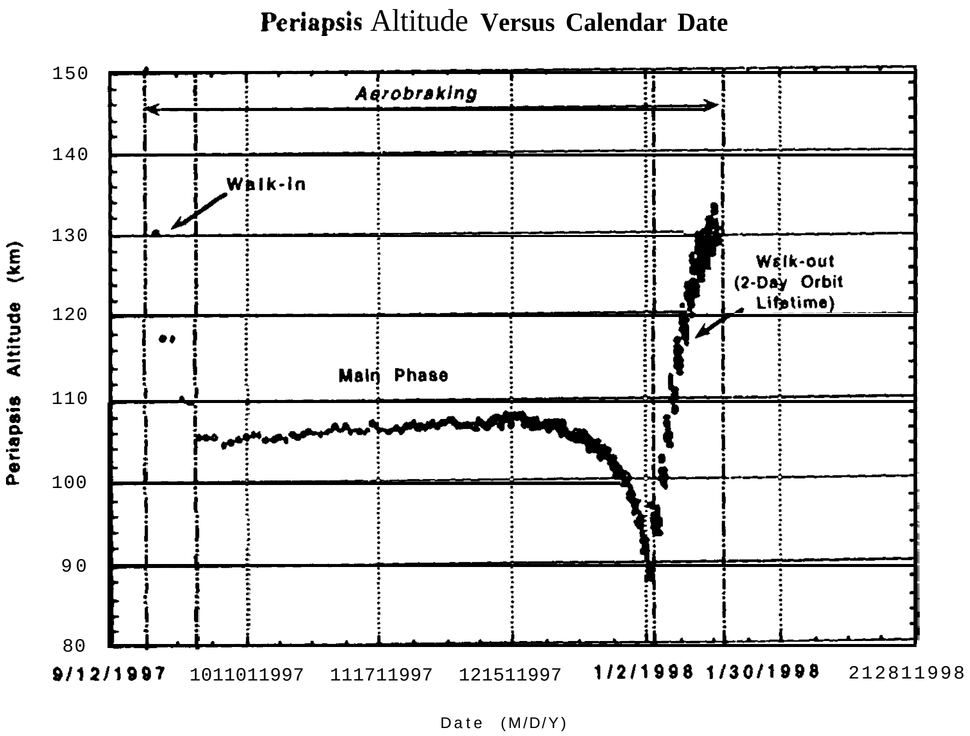
The Magellan spacecraft at Venus was the first planetary spacecraft to try aerobraking, as a demonstration, in the summer of 1993. The success of this demonstration was the predicate for the adoption of aerobraking by MGS. Aerobraking by MGS will differ from Magellan in two important respects. First, on MGS aerobraking will be done before the start of the main mapping activity. Thus, aerobraking success is required if the full set of mission objectives are to be accomplished. Second, to be successful, not only must the aerobraking procedure result in a circularization of the orbit at the proper altitude, but it must be accomplished such that at its conclusion the local time at the sunward equator crossing is within a few minutes of 2:00 PM with respect to the mean sun. This latter constraint, which is essential for the science objectives of the experiments, requires that aerobraking proceed in a deliberate manner without significant interruption. If a delay in aerobraking occurs in the early phases, the motion of Mars around the sun will cause the local time at the sunward equator crossing to be nearer to noon than 2:00 PM at the conclusion of aerobraking. These two factors make aerobraking the most challenging element of the MGS Mission.

The MGS spacecraft has been designed to meet these aerobraking requirements. For the drag portion of each periapsis passage the solar arrays are canted back from the direction of flow to create a dynamically stable configuration with the center of pressure behind the center of mass of the spacecraft. One of the panels of the solar arrays did not latch when deployed shortly after launch last October. As a result, for aerobraking, this panel will be rotated to place the solar cell side into the aerodynamic flow which will generate a torque tending to latch the panel and the associated gimbal will be powered to hold the array in place. Additional post-launch thermal testing of the qualification solar array and an equivalent gimbal drive motor have validated the suitability of this approach. The design has a margin of 90% with respect to unexpected changes in atmospheric mass density at periapsis. This means that the spacecraft can tolerate at least an unpredicted change of 90% in the periapsis density without exceeding a heating constraint of ().68 w/cm^2 (given the 17 m^2 projected area of the spacecraft this corresponds to a maximum dissipation of116 kilowatts). This level of margin substantially exceeds the level of density fluctuations experienced in the hundreds of periapsis passages during Magellan aerobraking. However, the region where aerobraking will occur on Mars (105 ±15 km) has not been well characterized on any planet and the additional margin is prudent.

MGS will begin aerobraking in Southern spring and the historical record of global dust storms indicates this is the most likely season for such storms to occur (the record also indicates such storms do not occur every Martian year). In such storms it is not the dust itself which is a concern, since there is no evidence that it reaches anywhere near the altitudes at which aerobraking will occur, but the increase in density at the aerobraking altitude associated with the expansion of the atmosphere due to the heating induced by the dust. Examination of the record of atmospheric temperature changes during the two global dust storms in 1977 observed from the Viking orbiters provides examples of rapid increases in atmospheric temperature associated with global storm development. Modelling of these temperature increases including the use of the Mars global circulation model at the NASA Ames Research Center indicates that the density at aerobraking altitudes could increase by as much as a factor of ten in a time as short several days following the start of a major storm. The circulation model results also indicate that for a storm that originates in the southern hemisphere on Mars, which has been the historical pattern, the temperature in the atmosphere of the northern hemisphere will start to increase before the dust itself crosses the equator and moves into that hemisphere. This is of importance for MGS as the periapsis latitude is in the northern hemisphere at the beginning of aerobraking and remains in that hemisphere for a major portion of the aerobraking time period.

Since the aerobraking altitude is selected based on the anticipated atmospheric density, the occurrence of a global dust storm necessitates moving periapsis to higher altitude as the storm builds but does not necessarily interrupt aerobraking. The period of time where global storm activity is most likely is shown by the horizontal bars marked "Dust Storms" in Figure 3. Anticipating this possible density change will be accomplished using the spacecraft itself, some of the MGS science instruments, terrestrial based measurements and measurements from the Pathfinder lander on the surface of Mars. Doppler tracking of the spacecraft will be nearly continuous during the aerobraking time period and the orbit determination process will provide an estimate of the periapsis atmospheric density each orbit. The spacecraft accelerometers will also be able to provide density scale height estimates based on the drag induced acceleration imparted to the spacecraft. Images from the Mars Orbiter Camera will be used to examine the planet for evidence of dust storm activity. Spectral measurements from the Thermal Emission Spectrometer will be used to monitor the atmospheric temperature. The spacecraft's infrared based horizon sensor will also be used to track the time history of atmospheric temperature and the Electron Reflectometer (part of the Magnetometer experiment) will

Figure 2 *Model Calculation Of Periapsis Altitude Versus Calendar Date For MGS Aerobraking Time period.*



provide electron density information including the altitude of the ionospheric peak electron density. From earth, passive microwave measurements of Mars will be conducted to derive the trend of atmospheric temperature with time and, for the early part of aerobraking, Hubble Wide Field Planetary Camera images will be available until Mars moves too close to the Sun. The Pathfinder lander will have been on the surface of Mars for three months at the start of MGS aerobraking and the history it can provide of atmospheric opacity and surface pressure will be very valuable in providing an indication of increased dust activity. These many sources of information on the Mars atmosphere will be used in a structured decision process to make judgments about the near term behavior of the atmosphere and the small propulsive maneuvers which are used to adjust the periapsis altitude.

The four months of the aerobraking time period have been divided into three sub-phases called walk-in, main and walk-out as illustrated in Figure 2. In the walk-in phase, the orbit periapsis is lowered from the capture orbit altitude of about *300* km to the altitude at which aerobraking will occur through a series of four propulsive maneuvers beginning at an altitude of 150 km. The spacecraft will remain at the aerobraking altitude during the main phase for three months as the apoapsis altitude is slowly lowered from 54,000 km to about 2000 km and the orbital period is reduced to under 3 hours. The final three weeks of aerobraking constitute walk-out which reduces the apoapsis altitude to 450 km while slowly increasing the periapsis altitude. During the aerobraking time period the descending orbit node location will have rotated from its initial position near 5:45 PM to nearly 2:00 PM. At this point aerobraking is terminated with a maneuver (ABX) which raises periapsis out of the region of significant drag. Following the completion of aerobraking, Mars gravity calibration measurements are conducted, final mapping orbit adjustments are made and the spacecraft and instruments are prepared for the start of mapping which will begin in March 1998. Mapping will continue for a full Mars year (687 days) and be followed by a six month Mars relay mission.

Mars Global Surveyor Mission And Science Experiments

The nature of the Mars Global Surveyor mapping mission and the scientific investigations to be conducted are strongly controlled by the design choices made during the development of the mission for the mapping orbit, the spacecraft and the operations environment. These choices allow complete global mapping of the entire Martian surface and atmosphere over the complete Martian seasonal cycle. The timeline for the mapping portion of the MGS mission is shown in Figure 3.

The mapping orbit selected is equivalent to that long used by terrestrial remote sensing satellites such at Landsat, SPOT and ADEOS. The orbit is to be near circular at about an orbital altitude of 400 km which permits high spatial resolution observation of the surface with instruments of modest size but is still high enough to keep the number of atmospheric drag makeup maneuvers required small. A high inclination (92.9 degrees) polar orbit was selected to allow observation of nearly the entire planet even with instruments such as the Mars Orbiter Laser Altimeter (MOLA) with small fields of view (-160 m). A near sun-synchronous orbit allows measurement comparison across lines of constant latitude and across season without it being necessary to account for diurnal variation which can be very large for Mars. The orbit will be "Frozen" with periapsis near the South pole and a small eccentricity (current estimate is an eccentricity of 0.0079) to reduce the effect of perturbations on the orbit from the non-spherical Martian gravitational field. A semi-major axis for the orbit will be selected such that the ground track of the spacecraft nearly returns to its starting point after seven days allowing complete global coverage in this time but with a non-repeating ground track which permits instruments such as the MOLA and the Mars Observer Camera (MOC), with small fields of view, access to nearly any point of the planet over time.

Using its horizon sensors, the spacecraft will maintain a continuous nadir orientation (to within ± 10 milliradians) allowing the instruments an uninterrupted view of the planet. Each days data collection will be returned within 24 hours through at least one NASA Deep Space Network station pass per day. There are no resource conflicts (e.g. power, view direction, data rate) between any of the instruments which will transfer data to the onboard solid state recorders continuously for the 687 days of the MGS mapping mission. Commanding of the instruments will be carried out from the home institutions of the Principal Investigators or Team Leader, where data will be returned. Uplink access to the spacecraft will be available nearly every day and investigators may change the operating parameters of their instrument from their home institution on short time scales (hours) if necessary.

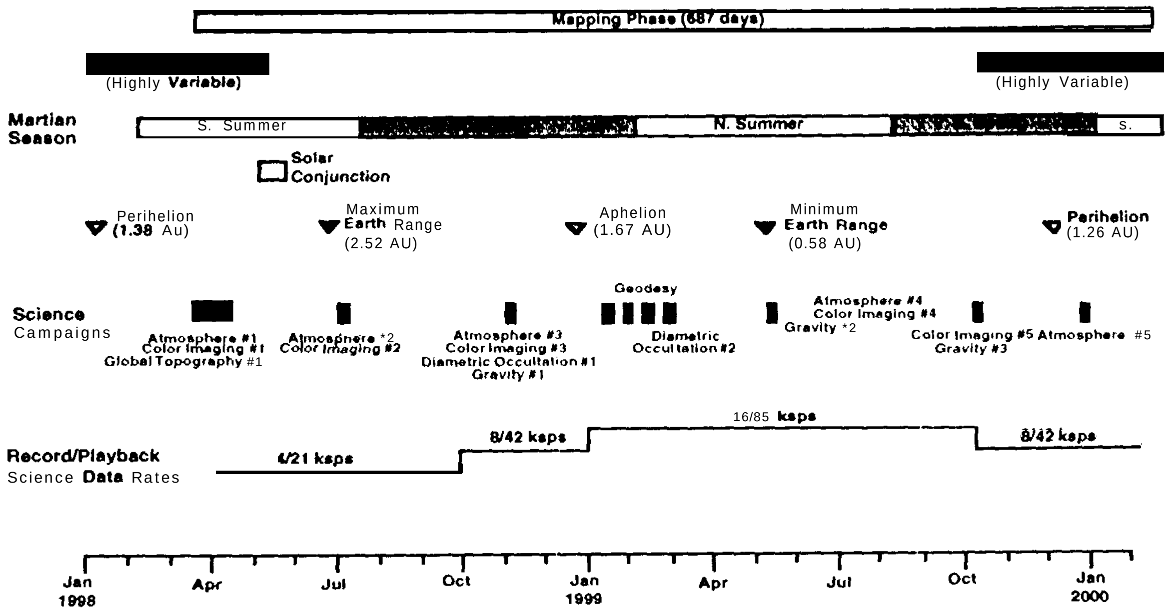
Following the completion of the mapping phase an addition 6 months of relay operations is planned to service the surface probes and lander to be carried to Mars by the 1998 Surveyor mission. The mapping timeline of Figure 3 indicates the location, duration and purpose of a number of "science campaigns" which will be used to enhance the scientific return of the mission. These campaigns provide periods of 24 hours/day Deep Space Network station coverage allowing the realtime data return of imaging data and as complete as possible tracking of the spacecraft for precision orbit determination and occultation coverage. Figure 3 also displays the rate at which data may be recorded and played back from MGS. These rates change depending on the earth-Mars distance and are at a minimum at the start of mapping.

All the Mars Global Surveyor experiments have global mapping or sampling objectives.

The Magnetometer/Electron Reflectometer (MAG/ER) equipment consists of two fluxgate magnetometers mounted at the outer end of each solar array and a body mounted Electron Reflectometer. Cruise operation of the Magnetometer has established that spacecraft fields and field fluctuations are low which will be helpful in the search for an intrinsic magnetic field at Mars. The Electron Reflectometer measures the electron pitch angle distribution over a wide range of electron energies and, when combined with the local magnetic field , allows determination the magnetic field strength at altitudes well below the spacecraft orbital altitude. During aerobraking the ER will be used to determine the altitude of the peak in ionospheric electron density as an aid in estimating the atmospheric density at periapsis.

The Mars Orbiter Camera (MOC) equipment consists of a line array high resolution panchromatic camera (35 cm aperture) and two line array wide angle cameras with blue and red passbands. The high resolution system provides images with 1.5 m/pixel resolution at an altitude of 400 km and the wide angle systems provide limb-to-limb coverage. The high resolution images will be used to provide samples of all important Martian terrain types and the wide angle systems will be used to return a daily low resolution (7.5 km/pixel) images of the entire planet and to return moderate resolution (2-300 m/pixel) images of the planet. Bakeout of the telescope structure to remove moisture and focus testing has been successfully completed during cruise. An image of the Pathfinder landing area was acquired in July 1997 and further cruise imaging of Mars will occur in August of 1997.

Figure 3 *Mars Global Surveyor Mapping Phase Timeline*



The Mars Orbiter Laser Altimeter (MOLA) equipment consists of Q-switched Nd:YAG laser transmitter, a 50 cm Cassegrain telescope receiver and associated electronics. The altimeter will sample the surface at a rate of 10 Hz with a footprint size of about 160 m. As the spacecraft ground track speed is 3 km/s, the altimeter's samples will have a spacing of 300 m. The precision of the range determination is high (a few meters) with the absolute accuracy of the altitude profiles determined by the accuracy with which the spacecraft's orbit can be determined. It is estimated that for regions of the size 10X 10 km the absolute vertical accuracy will be better than 30 m. Like the other instruments the MOLA has been operated satisfactorily during the cruise to Mars.

The Thermal Emission Spectrometer (TES) equipment consists of a Michelson interferometer covering the spectral range 6.25 to 50 μm with 5 wavenumber spectral resolution and separate solar reflectance (0.35 to 2.8 μm) and broad-band thermal radiance (4.5 to 100 μm) channels. TES will be used to provide information on atmospheric structure, dust and cloud content, maps of the composition of surface mineral , rocks and ices, the thermophysical properties of the surface and the growth, retreat and total energy balance of the polar cap deposits. During cruise checkout TES acquired spectra of the earth and used the earth as a target to examine the off-axis response of the instrument.

The Radio Science (RS) investigation uses an onboard ultrastable oscillator, the spacecraft's receiving and transmitting equipment and the receivers and transmitters of the NASA Deep Space Network. The investigation will determine properties of the atmosphere at high vertical resolution during occultations of the spacecraft by Mars and provide a high-resolution model of the Mars gravity field. Extensive checkout of all the components of the RS investigation have been conducted during the cruise to Mars.

In late 1999 the Mars Global Surveyor Spacecraft will be joined by the 1998 NASA Surveyor orbiter and lander and the Japanese Planet B orbiter. The Mars Relay (MR) will support the surface probes and lander of the 1998 Surveyor mission and for the first time three spacecraft will be in orbit about Mars permitting a new range of experiments to be conducted.

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