Mars Global Surveyor Mission: Overview and Status

A. L. Albee, F. D. Palluconi, R. E. Arvidson

The Mars Global Surveyor (MGS) spacecraft achieved a 45-hour elliptical orbit at Mars on 11 September 1997 after an 11-month cruise from Earth. The mission is acquiring high-quality global observations of the martian surface and atmosphere and of its magnetic and gravitational fields. These observations will continue for one martian year.

The MGS spacecraft was launched from Cape Canaveral on 7 November 1996 aboard a Delta II rocket. The three-axis stabilized spacecraft, built by Lockheed Martin, utilizes numerous spare components and science instruments from the Mars Observer (MO) spacecraft in a configuration about half of MO's size (1.2 × 1.2 × 0.8 m). The 45-hour elliptical MGS orbit is being changed to a circular mapping orbit by aerobraking, utilizing repeated dips into the upper atmosphere of Mars to slow the spacecraft and reduce the size and eccentricity of its orbit. Two solar arrays, each 3.5 × 1.9 m, provide 980 watts of power and provide the drag for the aerobraking process. No movable scan platform is provided as in most past missions. While mapping at Mars the spacecraft is continuously nadir-pointed, rotating at its orbital rate of 118 min, as the antenna tracks Earth and the solar arrays track the sun.

The MGS carries out many of the objectives of the ill-fated MO mission. The MGS instruments and experiments include line-scan wide angle and narrow angle cameras (MOC), a thermal emission spectrometer (TES), a laser altimeter (MOLA), radio science (RS) measurements that use the spacecraft's radio system with an ultrastable oscillator, two magnetometers (MAG) complemented with an electron reflectometer (ER), and a radio system to relay data from future landers on the surface of Mars. The spacecraft accelerometer and the horizon sensor are serving as additional atmospheric sensors during the aerobraking period. Detailed descriptions of the instruments and the experiments were published in 1992 in a MO special issue (*1*).

Status. After orbital insertion at Mars on 11 September 1997 MGS entered the aerobraking period and should have reached the circular mapping orbit early in 1998. However, fracture of a damper arm during deployment of the solar panels during the early cruise phase resulted in structural damage to one panel, the extent of which did not become clear until about a month into aerobraking. At that time the orbit had a 35-hour period and the orbit periapsis altitude was raised to about 175 km above the martian surface to lower the pressure on the panel. The science instruments were operated in their preferred nadir orientation near periapsis for a month while the problem was assessed and the science data acquired during this assessment period is reported in this issue (*2*). A new mission plan was adopted which delays the entry into the circular mapping orbit until March 1999 after a total of more than 900 aerobraking orbits. This plan reduces the pressure being exerted on the solar panels to one-third the level assumed in the original plan (Fig. 1).

To ensure the safety of the MGS spacecraft, aerobraking will continue at a low level of pressure (0.2 N m^{-2}) on the panels until a 12-hour orbit is attained, near the time of solar conjunction in late April 1998. Science observations in the nadir orientation during the low (periapsis) portion of the 12-hour orbit will be resumed before and after solar conjunction and will continue for a 4-month science-phasing period. Aerobraking will resume in September and continue until February 1999. Systematic observations in the 2-hour mapping orbit will then commence, but in the 2:00 a.m. (relative to the sun) position rather than in the originally planned 2:00 p.m. position and will continue through the arrival of the Mars Surveyor '98 (MS98) mission (*3*) in December 1999 (Fig. 1). As was originally planned the mapping orbit will be near circular (eccentricity of 0.01) with an index altitude of 378 km, near polar (inclination of 92.5°), and sun-synchronous (2 a.m./2 p.m.), but the spacecraft will now be moving from south to north on the sunlit side rather than from north to south. This science-mapping orbit has a 118-min period with a 7-day near repeat cycle so that Mars will be mapped in 26-day cycles with a high, constant sun angle. Continuous measurements will be made from this orbit over many such cycles, permitting repetitive observations and differentiation of daily and seasonal changes.

Data collection during the assessment period. During the periapsis portion of the 35-hour orbit the spacecraft was oriented in the nadir position so that the instruments pointed to Mars for about 22 min. During this period of nadir pointing the altitude varied from about 475 km to 175 km back to 475 km and the altimeter was able to receive its return echo. The 18 ground tracks are shown in figure 1 of Smith *et al.* (*4*). The spacecraft then rolled back to point the main antenna toward Earth while TES and MOC continued to collect data across the southern hemisphere. MAG/ER collected data throughout the entire 35-hour orbit, but radio tracking was not possible during the nadir pointing and roll portions of the orbit and radio science occultation measurements were only possible on the first orbit-insertion orbit. Scientific data were obtained from all instruments during the 18 nadir-oriented orbits in the assessment period and similar data will be gathered from almost 400 12-hour orbits during the science-phasing period from late

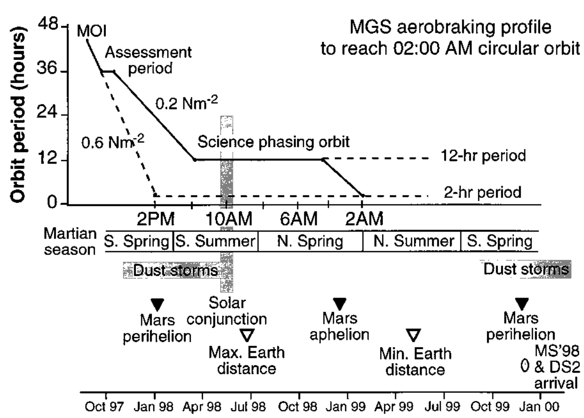

Fig. 1. Mission profile showing the phasing of aerobraking orbits, assessment orbits, science-phasing orbits, and circular orbits. Orbit period in hours is plotted against time and temporal events, including solar conjunction, nominal dust storm periods, Earth-Mars-sun distances, martian seasons, and arrival of Mars Surveyor '98 (MS98) (*3*) at Mars. The slope in the aerobraking periods corresponds to the average pressure exerted on the solar panels 0.6 N m^{-2} during the first aerobraking period and 0.2 N m^{-2} during the second and third periods. The orientation of the MGS orbit relative to the sun at noon is indicated by the times shown on the horizontal axis. MOI, Mars Orbit Insertion; S, southern; N, northern.

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March to mid-September of 1998.

Data collection during the aerobraking period. The atmospheric density of Mars at the aerobraking altitude showed significant variation over time as well as large orbit-to-orbit differences. On each orbit the density must be predicted to determine the appropriate and safe depth within the atmosphere for the aerobraking passage sufficiently in advance to command MGS to adjust its orbit. Although science data acquisition during the aerobraking phase was not in the original mission plan, MOC, TES, the accelerometer, the electron reflectometer, and the horizon sensor are all acquiring data to support density predictions. During the aerobraking passage through the atmosphere the spacecraft has the solar panels in a V-configuration with the instrument panel in the lee direction. The accelerometer data is used to provide density profiles of this atmospheric passage. At the end of the aerobraking as the spacecraft exits the atmosphere it rolls to point the main antenna toward Earth. During this roll MOC and TES can obtain visual and thermal coverage of Mars. In addition, images from the Hubble Space Telescope and ground-based whole disk microwave observations are being utilized to predict changes in the atmospheric density.

REFERENCES AND NOTES

1. Mars Observer Special Issue, *J. Geophys. Res*. **97**, 7663 (1992).
2. An archive of the data sets used in the papers in this issue is available as a CD-ROM and online through the Planetary Data System Geosciences Node HYPERLINK http://www.pds.geo.wustl.edu.
3. The Mars Surveyor '98 mission includes separate launches of the Mars climate Orbiter and the Mars Polar Lander. The New Millennium Mars Microprobe (DS2) is an experimental "hitchhiker" on the mission.
4. D. Smith *et al.*, *Science* **279**, 1686 (1998).

5. The authors are the Project Scientist (A.L.A.), Deputy Project Scientist (F.D.P.), and the Interdisciplinary Scientist responsible for Data Archiving (R.E.A.) for the Mars Global Surveyor Mission. We are indebted to engineers at the Jet Propulsion Laboratory and LMA who have devoted themselves to this mission over the years and who operate the spacecraft today. Our special acknowledgement goes to Glen Cunningham, Project Manager. Portions of the work described in this paper were performed by the Jet Propulsion Laboratory under contract to the National Aeronautics and Space Administration.

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The Structure of the Upper Atmosphere of Mars: In Situ Accelerometer Measurements from Mars Global Surveyor

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The Mars Global Surveyor (MGS) *z*-axis accelerometer has obtained over 200 vertical structures of thermospheric density, temperature, and pressure, ranging from 110 to 170 kilometers, compared to only three previous such vertical structures. In November 1997, a regional dust storm in the Southern Hemisphere triggered an unexpectedly large thermospheric response at mid-northern latitudes, increasing the altitude of thermospheric pressure surfaces there by as much as 8 kilometers and indicating a strong global thermospheric response to a regional dust storm. Throughout the MGS mission, thermospheric density bulges have been detected on opposite sides of the planet near 90°E and 90°W, in the vicinity of maximum terrain heights. This wave 2 pattern may be caused by topographically-forced planetary waves propagating up from the lower atmosphere.

The Mars thermosphere is that portion of the upper atmosphere where the global mean temperatures increase with height above a minimum (~120 K) at altitudes of 100 to 120 km to maximum values of 200 to 350 K above 150 km. At the greater heights, the thermosphere is dominated by the absorption of extreme ultraviolet (EUV) solar radiation and by the diffusive separation of individual gases such as CO_2, O, N_2, and CO (*1*). Variability in the thermosphere reflects diurnal, seasonal, and solar cycle variations in the solar flux at Mars (*2*) and in the ability of energy to propagate upward from the lower atmosphere (that is, from below 100 km). This coupling of Mars' atmospheric regions is particularly affected by atmospheric heating (*3*) and dynamic forcing in response to changes in the amount of dust in the atmosphere (*4*). Overall, the expansion and contraction of the Mars lower atmosphere is controlled by several processes that are difficult to separate: (i) dust heating, (ii) solar infrared (IR) heating that varies with the Mars heliocentric distance, and (iii) various dynamic influences such as gravity waves, planetary waves, and tides.

Previous in situ measurements from Viking Landers 1 and 2 and Mars Pathfinder (*5*), and remote sensing measurements of air glow, plasma and neutral density scale heights, and monitoring of the altitude of the F1-peak in electron density (*1, 6*) have only partially characterized these thermospheric variations because of the limited coverage in space and time. Now, measurements from the *z*-axis accelerometer aboard MGS (*7*) have yielded to date more than 200 vertical structures of thermospheric density and derived temperature and pressure. These data have been obtained at successive MGS periapses over a 5-month period spanning northern fall on Mars (Ls = 180° to 270°) (*8*), from September 1997 to February 1998, as MGS continues aerobraking into its mapping orbit (*9*). During the mission the spacecraft periapsis has moved from 32°N to 50°N and from a local solar time (LST) of 6 p.m. to noon, with data acquired from 170 km to as low as 110 km.

The MGS *z*-axis accelerometer, aligned closely to the spacecraft velocity vector (v), measures the drag force acceleration (a), related to atmospheric density (ρ) by the classical relation:

$$\rho = [2m/v^2 C_D s]a \qquad (1)$$

with spacecraft mass (m), cross-sectional area (s) relative to v, and drag coefficient

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