MARS GLOBAL SURVEYOR: CRUISING TO MARS

by

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Abstract

The Mars Global Surveyor spacecraft was launched on November 7, 1996, an is now cruising to Mars. While the launch was excellent, and the spacecraft and its science payload are in perfect operating condition, a broken deployment damper on one of the two solar arrays has posed some concern relative to the use of that solar array as a drag surface during aerobraking operations at Mars. This paper discusses the in-flight events thus far in the cruise portion of the Mars Global Surveyor mission, including those special events executed to characterize the performance of the partial deployed solar array. In addition, those ground activities focused on re-evaluating the baseline aerobraking plan and re-qualifying the solar array for aerobraking in its partially deployed state will be highlighted.

Introduction

The Mars Global Surveyor mission was established by NASA to fulfill many of the objectives of the Mars Observer mission that failed just three days short of Mars in August 1993. The Surveyor Program for the robotic exploration of Mars was one of the fastest programs to be established for planetary exploration. Work began on the first of the program's first mission, Mars Global Surveyor, in February 1994, just five months after the failure of Mars Observer. Then, in a "faster-better-cheaper" mode of project management, the Mars Global Surveyor was ready for launch in November 1996. The Mars Surveyor Program was established to perform a comprehensive robotic exploration of Mars with launches of up to two missions in each Mars launch opportunity every two years for a period of ten years.

The Surveyor Program missions will trace the common thread of water in the evolution of Mars. Mars Global Surveyor's mission is to provide the initial global data base of the surface and atmosphere of the planet to be recorded over the period of a full Martian year or 687 earth days.

Mars Observer was to have completed this global mapping objective with a synergistic suite of eight instruments which included wide and narrow angle imaging, IR spectroscopy and radiometry, gamma ray spectroscopy, radio science, magnetic field measurements, and laser ranging for topography. The payload also carried a UHF radio relay system for relaying data from surface missions back to Earth. Because of the launch mass constraints of the Surveyor missions, Mars Global Surveyor could not carry to two heaviest instruments of this Mars Observer set, the Pressure Modulator Infrared Spectrometer and the Gamma Ray Spectrometer. Those two instruments will be carried on the 1998 and 2001 Surveyor orbit launches to complete the set of global measurements.

Mission

Mars Global Surveyor essentially fly the Mars Observer mission and will carry the Mars Orbiter Camera, the Thermal Emission Spectrometer, the Mars Orbiter Laser Altimeter, a Magnetometer/Electron Reflectometer, an Ultra Stable Oscillator, and the Mars Relay into a circular, polar, sun synchronous orbit of two hour period, crossing the Martian equator at 2 P.M. local solar time every orbit.

After a ten-month cruise to Mars, the spacecraft will use, on September 12, 1997, its chemical propulsion system to allow itself to be captured by Mars' gravity into a 48 hours, elliptical capture orbit. From there, four months of aerobraking will reduce the orbit to the 2 hour period required for the global mapping operations. Then, after a period of orbital and gravity field calibrations, Mars Global Surveyor will be ready to begin its two year mapping task on March 15, 1998. Near the end of the mapping period, the Mars Relay system will be used to relay data from the Mars Surveyor '98 lander and from two New Millennium microprobes carried to Mars on the '98 landers' cruise stage. Following the mapping mission, Mars Global Surveyor will remain as an element of communications infrastructure in Mars orbit.

The spacecraft was launched by a McDonnell-Douglas Delta II 7925 vehicle on November 7, 1996. This was the second day of the launch period. Rain and high upper level winds prevented launch on the first day of the period. Performance of the launch vehicle was very good. When the spacecraft's first telemetry data was received by the Canberra., Australia station, the spacecraft's electronic systems were performing as expected. However, it was observed that the -Y solar panel was not fully deployed.

The cruise portion of the mission from Earth to Mars is devoted to navigational events, and science payload checkout and calibration. Two-way doppler and ranging data from NASA's Deep Space Network 34 meter tracking stations are used to model the spacecraft's trajectory and to provide the data that will enable trajectory correction maneuvers to target the proper arrival point at Mars. Four trajectory correction maneuvers are contained in the mission plan. The first one of 27 meters/second was executed on November 21, 1996, with a 58 second firing of the spacecraft's main rocket engine. This maneuver removed the planetary protection aim point bias and corrected for minor launch errors. The remaining three maneuvers further refine the trajectory as the spacecraft approaches Mars. They are scheduled for late March, late April and late August of 1997.

The science instrument suite was turned on for checkout and calibration shortly after first trajectory correction maneuver. With Earth still relatively nearby, the instruments were pointed toward it for calibration purposes. All instruments were found to be in good operating condition. A sign reversal in the alignment data for the spacecraft's celestial sensor prevented as accurate pointing as was desired, but the sequence of calibration events was none the less quite successful. A later event to checkout the laser altimeter's performance with a ground station at the Goddard Space Flight Center was foiled by stormy weather. This checkout will be re-attempted in late spring. The Mars Orbiter Camera's composite optical structure has been baked free of retained moisture and focus checks have been made. While the mapping oriented instruments are powered off during the cruise portion of the mission, the Magnetometer and the Ultra Stable Oscillator remain on. The Ultra Stable Oscillator is calibrated periodically for long term stability and provides an accurate frequency source for one-way tracking acquisitions and navigation.

Following Mars orbit insertion, the aerobraking portion of the mission posses the mission's highest risk events. Because the spacecraft could not carry enough fuel to use propulsion to achieve the mapping orbit, as was the design for Mars Observer, aerobraking was chosen to achieve the mapping orbit. Once the spacecraft is captured into a elliptical orbit, the spacecraft will be carefully dipped into the planet's upper atmosphere at the orbit's nearest point to the planet - its periapsis. The slight slowing of the spacecraft's velocity caused by the drag of the atmosphere lowers the high point of the orbit - its apoapsis. Successive drag passes over a four month period will reduce the initial elliptical orbit to a circular one. At each aerobraking pass, the spacecraft is oriented to place its "back end", that is, its rocket engine end - opposite from the science instruments, into the atmospheric flow. The spacecraft's solar arrays are positioned like a badminton shuttlecock to maintain the proper relation of center of mass and center of aerodynamic pressure for stability, and the back sides of the solar arrays are used as drag surfaces to create the force necessary to slow the spacecraft's velocity.

Spacecraft

The Mars Global Surveyor spacecraft was constructed, primarily, of spares from Mars Observer. New elements include the solar arrays, batteries, traveling wave tube amplifiers, composite structure, solid state recorders and the propulsion system. Over three hundred specific findings from the Mars Observer failure investigations were evaluated and included in the adaptation of this hardware for Mars Global Surveyor. The use of an existing electronic architecture was a significant expedient in the rapid development of the system. The electronic hardware was provided by NASA's Jet Propulsion Laboratory to Lockheed Martin Astronautics in Denver, Colorado, who provided the new elements, assembled and tested the system. An excellent partnering relationship was established between the Mars Global Surveyor project and Lockheed Martin.

The spacecraft is three axis stabilized with the remote sensing science instruments body fixed. The X-band power amplifiers are located in a compartment on the back side of the deployable, two axis articulated 1.5 meter high gain antenna. Two solar arrays composed of silicon and gallium arsenide solar cells generate electrical power and charge two nickel hydrogen batteries. Solid state records replaced the tape units from Mars Observer. Sun senses, a celestial sensor, gyroscopes and accelerometers provide the attitude control inputs. A dual mode propulsion system consists of a bi-propellant main engine and mono-propellant thrusters for thrust vector control and reaction wheel unloading. The spacecraft weighed slightly over 1062 kg at launch of which 389 kg was fuel for a total velocity change capability of 1,282 m/s. A particularly notable achievement in the integration of the science payload was the successful location of the magnetometer sensors at the ends of the solar arrays rather than at the ends of a long boom as on Mars Observer.

Flight Operations

Flight operations of the Mars Global Surveyor mission is accomplished by the Mars Surveyor Operations Project. This geographically distributed organization was formed to operate all the of the spacecraft of the Mars Surveyor Program in the flight phases. Currently the project is operating Mars Global Surveyor and is preparing the ground operations elements for the system test and flight operations of the Mars Surveyor '98 orbiter and lander. In addition, the project supplies infrastructure to the ground operations system of the Stardust project, a Discovery mission, very synergistic with the Mars Surveyor '98 spacecraft.

The Jet Propulsion Laboratory manages the Mars Surveyor Operations Project. Mission management, navigation, sequencing and ground data system development and management are accomplished at JPL in Pasadena, California. Spacecraft health and welfare operations and mission control are accomplished by the project's industrial partner, Lockheed Martin Astronautics, in Denver, Colorado. Science instrument operations are conducted from the home institutions of the missions various science investigators. Tracking is provided NASA's worldwide Deep Space Network. This shared and distributed operations system is a model for the flight operations activities of future planetary exploration missions in JPL's Flight Operations 2000 plan.

Flight operations of Mars Global Surveyor have been quite smooth and without significant incidents. Only one command error has been made and that was a inconsequential error in the readout our process of one of the solid state recorders. After the first 30 days of flight, tracking time has been on the order of one tracking pass per day. Coverage by the project's mission controllers is only 12 hours per week. These periods are used primarily for commanding purposes - loading sequences or providing other spacecraft maintenance functions. Most of the spacecraft monitoring is done by automatic alarming systems which notify spacecraft engineers through standard pagers when an on-board condition requires attention. These techniques have significantly reduced the cost of flight operations. The Mars Surveyor Program requires that all flight operations, including science data reduction, be accomplished for $20M per year.

Solar Array Deployment Issue

Within minutes of the acquisition of the first telemetry from the Mars Global Surveyor spacecraft, it was detected that the -Y solar array had not completed deployed to its latched position. Telemetry showed that the position of the sensor measuring the angle of deployment, with respect to its position yoke, of the inboard section of the -Y panel stopped at 43 degrees of motion, rather than showing the full 180 degrees required for full deployment. Other telemetry indicated that from the 43 degree point the panel moved to its final position in an undamped manner. Subsequent data from a sun sensor located on the -Y inboard panel showed that it was approximately 20 degrees from its full deployed position. The outboard section of the panel was fully deployed and latched. Thus, the observed configuration consisted of the two panel sections deployed and coplanar, but at an angle of approximately 160 degrees to the panel yoke rather than the expected 180 degrees. This condition is of no immediate consequence to the cruise or mapping missions because two axis electrical actuators between the spacecraft bus structure and the panel's yoke can position the panel as required for electrical power generation.

A series of eight in-flight tests have been performed to further characterize the panel deployment situation. Attitude control data of the natural frequency of the panel suggested that the deployment hinge was hard against a stop of some kind in one direction, but free to move, against the torque of the deployment springs in the other direction. Using the electrical actuators, the panel was "wiggled" at various rates. The failure model, generally confirmed by these tests, suggests that as the outboard segment of the panel moved to its latched position during the initial panel deployment just after separation from the launch vehicle, the outboard segment had reached 43 degree of travel, and the shaft of the mechanical rate damper sheared, disconnecting the damper from the panel and disconnecting the position potentiometer from the panel, allowing the panel to proceed in an undamped manner. The lever arm that connected the damper to the edge of the inner panel was then allowed to fall into the hinge joint between the inboard panel and the yoke and became trapped there, preventing the panel to travel the full 180 degrees require for latching. Dimensional analysis confirmed the postulated geometry, and