

Mars Global Surveyor (MGS) Spacecraft Loss of Contact

This is a preliminary report by the Mars Global Surveyor Operations Review Board, an internal NASA board formed to look into why MGS went silent in November 2006 and to recommend processes or procedures that could increase safety for other spacecraft.

Summary

NASA's Mars Global Surveyor operated for ten years, longer than any other spacecraft sent to Mars. It pioneered the use of aerobraking, provided global mapping of the Martian surface, atmosphere, magnetic field and interior, and provided key imaging and communications support for subsequent missions. NASA extended its mission four times before its unfortunate loss. Key events pertaining to the loss of the spacecraft, whose last contact was on November 2, 2006, include:

- A modification to a spacecraft parameter, intended to update the High Gain Antenna's (HGA) pointing direction used for contingency operations, was mistakenly written to the incorrect spacecraft memory address in June 2006. The incorrect memory load resulted in the following unintended actions:
 - Disabled the solar array positioning limits.
 - Corrupted the HGA's pointing direction used during contingency operations.
- A command sent to MGS on November 2, 2006 caused the solar array to attempt to exceed its hardware constraint, which led the onboard fault protection system to place the spacecraft in a somewhat unusual contingency orientation.
- The spacecraft contingency orientation with respect to the sun caused one of the batteries to overheat.
- The spacecraft's power management software misinterpreted the battery over temperature as a battery overcharge and terminated its charge current.
- The spacecraft could not sufficiently recharge the remaining battery to support the electrical loads on a continuing basis.
- Spacecraft signals and all functions were determined to be lost within five to six orbits (ten-twelve hours) preventing further attempts to correct the situation.
- Due to loss of power, the spacecraft is assumed to be lost and all recovery operations ceased on January 28, 2007.

Incident Description

On November 2, 2006, NASA planned to communicate with MGS through the Deep Space Network (DSN) via a prescheduled 13-minute routine contact. Prior to this contact, commands had been transmitted to MGS. These commands were designed to move the position of the solar arrays away from the sun line in order to maintain thermal control. At the beginning of the contact on November 2, the spacecraft reported numerous alarms, indicating that one solar array drive had been stuck and that the spacecraft had automatically switched to the redundant drive controller. The spacecraft telemetry also gave indication that the solar array drive was rotating freely on the redundant hardware and gave no indication the mission was in immediate danger.

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The spacecraft operations team (Lockheed Martin (LM) in Denver, Colorado) appropriately and immediately contacted the necessary engineering personnel to help troubleshoot the problem(s).

At the next scheduled contact, approximately 2 hours later, the normal spacecraft signal was not detected by the main DSN receivers. The operations team subsequently attempted to command the spacecraft multiple times, without success. On November 4, 2006, the operations team declared a spacecraft emergency to ensure long-term DSN antenna coverage. All attempts to command the spacecraft and reestablish communication were unsuccessful. During the week following the anomaly, it was discovered that radio science equipment at the DSN, operating on a pre-programmed observation schedule, had recorded signals from MGS just hours after the initial anomaly. However that signal was below the detection limits of the main DSN receivers. Beginning on November 14th, 2006, NASA's Mars Reconnaissance Orbiter (MRO) and ESA's Mars Express tried unsuccessfully to image and locate MGS. Formal recovery efforts were terminated on January 28th, 2007.

Cause

The LM team performed a fault analysis to determine the cause of the spacecraft anomaly. An LM spacecraft engineer ultimately determined that the likely cause of the anomaly was an incorrect parameter upload that had occurred 5 months earlier (June 2006). A direct memory command to update the HGA's positioning for contingency operations was mistakenly written to the wrong memory address in the spacecraft's onboard computer. This resulted in the corruption of two independent parameters and had dire consequences for the spacecraft. The first parameter error caused one solar array to be driven against its hard stop, leading the MGS fault-protection system to incorrectly believe it had a stuck gimbal, causing MGS to enter contingency mode. Upon entry into contingency mode, the spacecraft's orientation was such that one of the batteries was directly exposed to the sun. This caused the battery to overheat which in turn gave a false indication of an overcharged battery and led to the premature termination of battery charging on each subsequent orbit. Even though the remaining battery continued to be charged, it was not being charged sufficiently to support the full electrical load, which was normally supported by both batteries. The end result was that both batteries were depleted, probably within 12 hours. The second parameter error caused the HGA to point away from the Earth when the spacecraft was, in fact, properly oriented to communicate to Earth. Communication from the spacecraft to the ground was therefore impossible, and the unsafe thermal and power situation could not be identified by the MGS's ground controllers.

To understand the cause of the memory load command being sent to the incorrect address, it is necessary to understand first a chain of events that began in September 2005. The MGS spacecraft was designed with a great deal of resiliency to failure. It had redundant control systems, whose control parameters were intended to be maintained identically. The parameter that controlled the positioning angle of the HGA in Contingency Mode required updating from time to time. The update in September 2005 is what started a chain of events that would ultimately result in the loss of the MGS spacecraft. The HGA parameter was actually updated on the two redundant control systems at two different times. The updates were commanded with slightly different (operator input) precision. This difference in precision, while numerically inconsequential, resulted in an inconsistency between the computer memories. A full memory readout taken at a later date revealed the difference between the two positioning angles, which warranted a correction by the operations team. During the effort to correct the inconsistency, the

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operations team specified incorrect memory addresses. The incorrect memory addresses caused the command upload to enter data into erroneous memory locations, resulting in the consequences described above.

Key Findings

Category 1: Operational Procedures and Processes

The anomaly was caused when the spacecraft entered Contingency Mode and referenced the key parameters that contained invalid data, uplinked months before. This caused the thermal and communication problems that led to the apparent demise of MGS. Despite the cause, the board found that the mission team followed existing procedures and processes. However, these procedures and processes were inadequate to catch the errors that occurred. Many of the factors contributing to this anomaly would not have occurred if these operating procedures and processes had been more thorough, or if the mission team had recognized the inadequacies and had addressed them.

Category 2: Spacecraft Design Weaknesses

The onboard fault protection was insufficient to handle the faults that were most likely encountered. The spacecraft mistakenly determined that a solar array was stuck and, based on this information, went to an attitude that was thermally unsafe for one of its batteries. In addition, telemetry did not provide the ground with sufficient data on the cause of the initial fault.

Category 3: Lifetime Management Considerations

The MGS mission had entered its fourth extended mission phase just prior to the anomaly. During MGS mission extensions, as is typical for long-lived missions, budgets and staff had been reduced in an effort to operate the mission as economically as possible. While the board found no direct evidence that these reductions caused this anomaly, it is the board's assessment that such reductions can inherently increase risk. The board found that periodic reviews should have been performed to assure that spacecraft control parameters were appropriate to the current state of the spacecraft and that risks associated with normal personnel turnover over time were not assessed. The board also noted that, while the training methodology for some operations positions was excellent, it was not uniformly applied.