Loss of Mars Polar Lander

December 3, 1999 in the vicinity of space Mars

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NASA (U.S. National Aeronautics and Space Administration) lost contact with its spacecraft "Mars Polar Lander (MPL)" just prior to its scheduled atmospheric entry and landing on the south polar region of Mars. Communication was never regained. It is assumed that the MPL's legs contact sensor tripped during descent, which signaled false indication that the spacecraft had landed, resulting in a premature shutdown of the engines 40 meters above the surface. MPL crashed on the Martian surface, and its two Deep Space 2 Microprobes (DS2) were presumably destroyed upon impact.

Figure 1. Artist's Concept of Mars Polar Lander [5]

1. Event

NASA lost contact with the spacecraft "Mars Polar Lander (MPL)" just prior to its scheduled atmospheric entry and landing in the south-polar region of Mars. The Polar Lander was carrying two Deep Space 2 (DS2) Microprobes designed to study the Martian weather, climate, and water and carbon dioxide levels. It is not known whether the lander reached the terminal descent propulsion phase. The microprobes were never located.

2. Course

NASA launched MPL on January 3, 1999.

After a 11-month travel (7.57 million km) to Mars, MPL was about to enter the Mars' atmosphere in the early morning of December 3. To land on the south polar region of Mars, a final trajectory-correction maneuver was executed 6.5 hours before entry.

After its initial high-speed entry into the Martian atmosphere, the MPL's descent plan was as follows.

(Figure 2 illustrates the entry, descent and landing phase of MPL.)
At about an altitude of 7.5 km to landing, while the Lander was still moving at 250 km/sec, it would deploy its 8.4-meter-wide parachute. Although the parachute would substantially slow the descent, it would be unable to slow it below 80 m/sec in Mars' thin atmosphere. 10 seconds after parachute deployment, the heat shield would be released to crash onto the surface so that the friction produced by the Martian atmosphere would quickly decelerate the vessel from its initial velocity. 16 seconds after the release of the heat shield, the MPL's three legs, folded up to fit inside the shield, would swing down and latch in position. When the Lander was about 1800 meters above the surface and descending at 80 m/sec, the parachute and backshell would separate from MPL, and in 0.5 seconds, the three clusters of landing thrusters would start firing. The engine thrust would be modulated during the remaining descent in accord with data from the probe's multi-beam landing radar to gradually slow the vessel to a gentle 2.4 m/sec final descent.

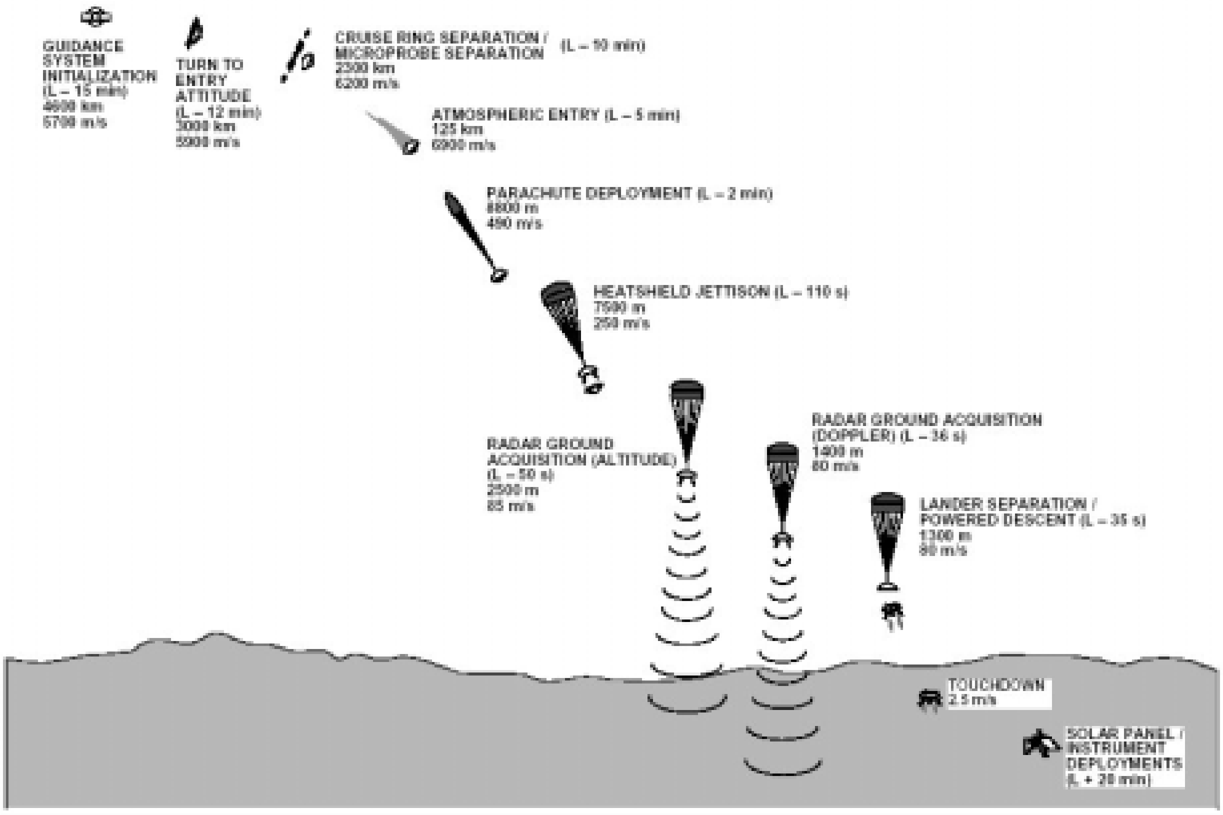

Figure 2. MPL's Entry, Descent and Landing Phase [1]

At 12:02 pm PST (U.S. Pacific Standard Time), MPL entered the atmosphere. The high temperature from the heat during MPL's descent in the atmosphere closed off the communication signal with the Earth. MPL touchdown was expected at 12:14 pm PST, with a data transmission to Earth scheduled to begin 24 minutes later. However, no communication from MPL was received.

After detaching from MPL, the two DS2 probes were to extend and drill deeper into the ground to search for water as shown in Figure 3. The first data from the DS2 probes was expected to reach the Earth at 7:25 pm PST on December 4, about 7 hours after MPL touchdown. However, no communication from the probes was received.

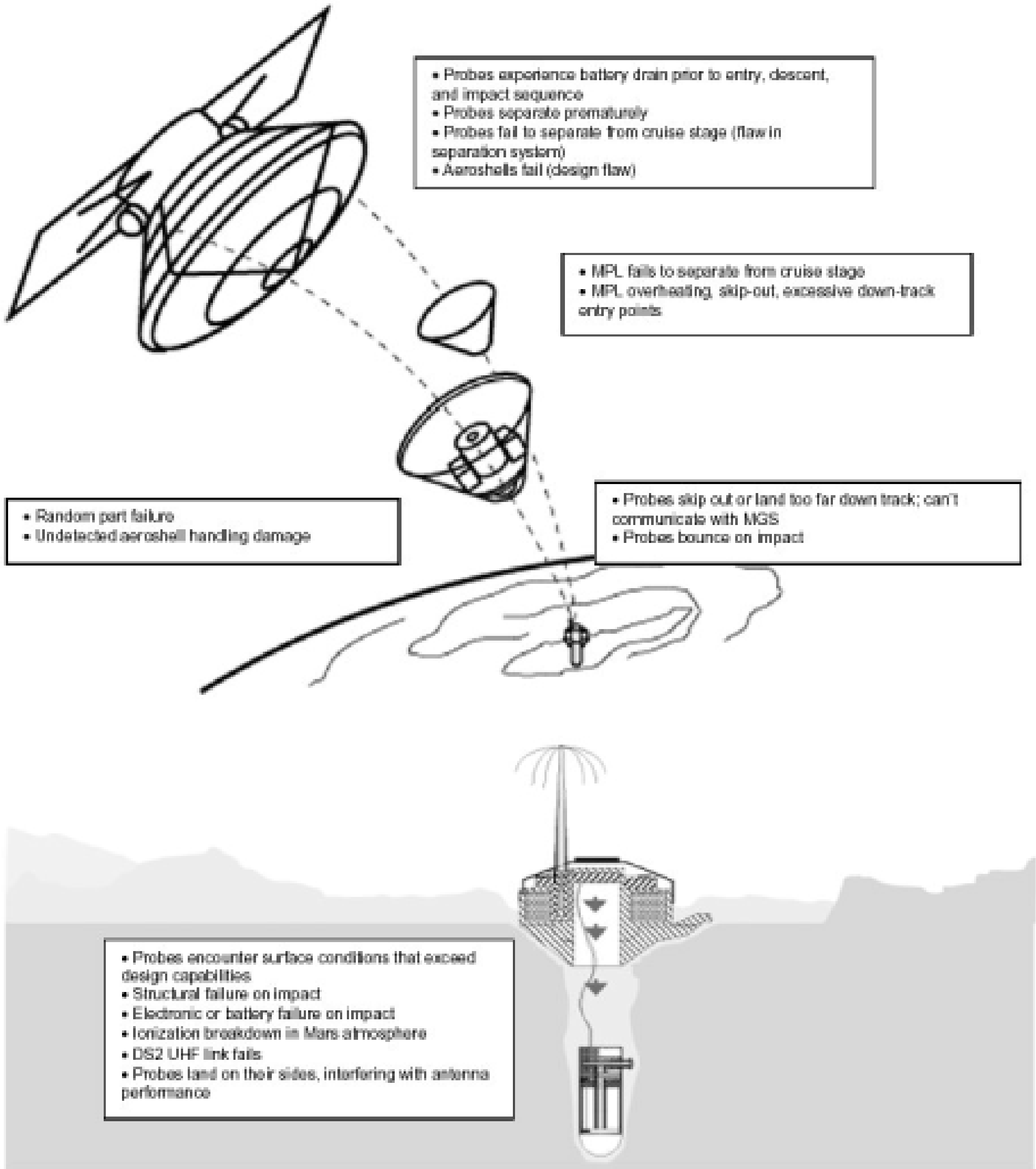

Figure 3. DS2 Entry, Descent, and Impact Sequence with Potential Failure Modes [2]

3. Cause

(1) Accidental tripping of the MPL's landing legs contact sensors during descent

NASA concluded that the MPL's onboard systems confused the jolt from the deployment of a landing leg with ground contact, and shutdown the engines prematurely at 40 meters altitude down to the actual landing. MPL was assumed to have crashed on the Martian surface at 22 m/sec (about 80 km/h).

(2) A design flaw in the ground-contact switch system

When the MPL's landing legs first swung down to lock into position after the release of the heat shield, sufficient force on flexible parts of the legs bounced the legs upwards again, and triggered the ground-contact switch to send false indicator signals to the computer system.

The Failure Review Board for the Mars Polar Lander discovered that this event repeated consistently in lab tests after the incident. Such behavior, however, was never detected during MPL's prelaunch tests, because different teams conducted MPL's tests before and after the legs' fold-down procedure.

(3) While the above cause was the most likely scenario, several other events were still possible. MPL might have burnt out in the Martian atmosphere, or it might have failed to land properly on the rugged Martian terrain.

4. Immediate Action

NASA first assumed that the communication antenna was not pointed towards the earth, or a minor trouble caused the computer to enter a temporary "sleep" mode and tried to send signals to change the antenna angles or wait for the computer to "wake."

NASA also used the Mars Global Surveyor satellite orbiting Mars in an attempt to communicate with MPL, however, all attempts failed. On January 17, 2000, NASA ended the intermittent search for MPL and the DS2 microprobes.

NASA appointed Thomas Young, a previous executive vice president of Lockheed Martin Corp., to chair the Mars Program Independent Assessment Team comprised of 18 aerospace scientists and review the failure.

NASA canceled its 2001 Mars Surveyor Program to launch a lander with landing gears similar to the one on the lost MPL.

5. Countermeasure

Unknown.

6. Summary

The cost of space development is enormous and efforts to cut the cost are necessary. NASA, however, should have clarified where it can cut the cost or not (at the technology level at the time), otherwise, cost reduction can directly link to a failure and all the expenses can go down the drain.

The special antenna for communication during descent was taken off to cut the cost and MPL's communication with earth was never reestablished after it was cut off 12 minutes prior to landing. Accordingly, there were no data to tell if the planned sequence of processes were carried out and where in the course a malfunction happened.

The MPIAT report findings included the following:

- The 1998 Mars Surveyor Program, which comprised launches of the Mars Climate Orbiter and the Mars Polar Lander, was challenged by inadequate budget cost-caps and was significantly underfunded by 30%.
- The DS2 development had competent, but inexperienced, project managers.
- Senior management with years of experience at NASA Headquarters, JPL, and Lockheed Martin Astronautics failed to have the follower managers acquire proper management skills.
- The lack of device for communication during the entry, descent, and landing data for MPL was a major design mistake.
- The DS2 microprobes had unprofessional designs and were put through an inadequate test program; they were not at all ready for the mission.
- The program was significantly understaffed. The development team of government and civil workers overworked, sometimes 60 to 80 hours a week.

7. Knowledge

(1) Modifications to cut cost have the danger of turning into a cause of failure

To achieve a soft landing, Lunar Surveyors and Viking were equipped with a radar altimeter to control the final approach to the landing site. Terminal descent engines were designed to shutdown at 3 meters on the radar altimeter readings. The MPL landing system was simplified so the terminal descent engines would shutdown as soon as the onboard systems received a ground-contact signal from a landing leg.

(2) Multiple team operations have pitfalls in the boundary area among teams.

(3) Adequate funding, staffing and scheduling are critical to successful program implementation.

Such cost-cutting sometimes succeed, however, blindly believing in them should be avoided. A successful experience in cost-cutting can encourage skipping necessary processes and lead to failure.

(4) Giving low priority in transfer of technologies and management skills lead to failures.

8. Background

NASA Administrator Daniel Goldin implemented the Faster, Better, Cheaper (FBC) philosophy in 1992 in response to budget reductions. He stopped repeating 10s of years projects with huge budgets and started to encourage subletting tasks to contractors and civil-service workforce so that the agency could shorten development time, reduce cost, and increase the scientific return by flying more missions in less time.

Developed in accord with this FBC approach, the Mars Pathfinder lander and rover successfully reached the rocky terrain of the Martian equator on July 1997. Two months later, the camera-equipped Mars Global

Surveyor orbiter successfully reached Mars and continues to send images of unprecedented detail to the Earth.

However, the FBC effort was undermined by inadequate funding. The 1998 Mars Surveyor Program only had about half of the successful Mars Pathfinder lander and Mars Global Surveyor orbiter missions, significantly underfunded by at least 30%. The number of resident JPL (Jet Propulsion Laboratory in Pasadena, California) staff was reduced to 15. One third of previous staff was allocated to the flight control team of three Mars Surveyor Programs (Mars Global Surveyor, Mars Climate Orbiter and Mars Polar Lander). Preflight testing was inadequate. The loss of Mars Polar Lander followed the mission failure of Mars Climate Orbiter, which was launched on December 11, 1998 and lost in deep space due to suspected navigational errors on September 23, 1999.

References

[1] Mars Climate Orbiter Mishap Investigation Board (2000) *Report on Project Management in NASA*, *March 13*, *2000*, NASA.

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[3] AstroArts Inc., http://www.astroarts.co.jp

[4] Mars Program Independent Assessment Team (2000) *Mars Program Independent Assessment Team Summary Report*, *March 14*, *2000*, NASA.

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[6] Report of the Failure Review Board for the Mars Polar Lander, March 28, 2000.