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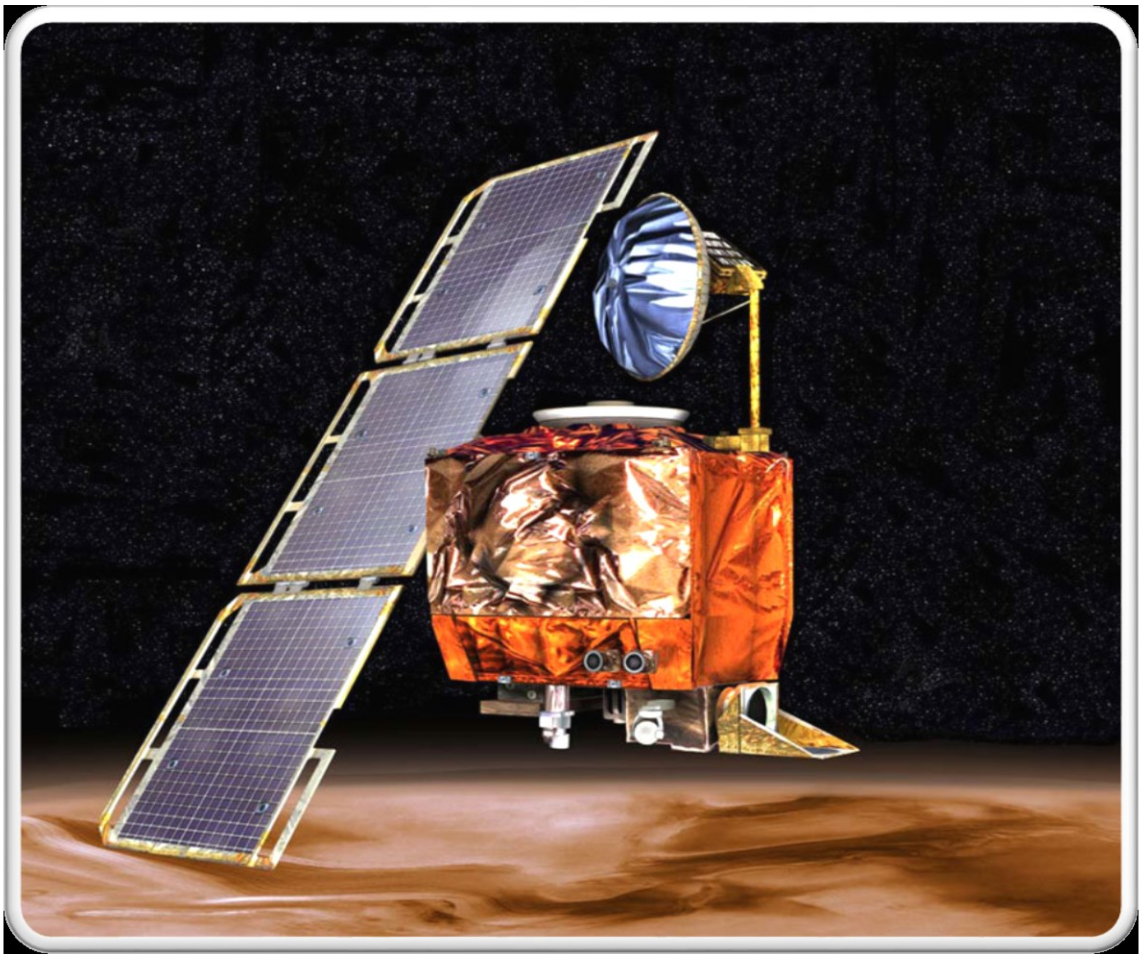
NASA Mars Climate Orbiter Project Failure (1999) REPORT



Requirement Engineering
Under the guidance of Mr. Upendra Athipola

Module Code : UFCFM6-15-3

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1. Introduction

The Mars Climate Orbiter (MCO) was a 338-kilogram robotic guided space probe launched by NASA on December 11, 1998 to review the Martian climate, Martian atmosphere and surface changes and to act because the communications relay within in the Mars Surveyor '98 program for Mars Polar Lander.

The MCO Mission objective was to orbit Mars as the first interplanetary weather satellite and provide a communications relay for the MPL which is due to reach Mars in December 1999. The MCO was launched on December 11, 1998, and was lost sometime following the spacecraft's entry into Mars occultation during the Mars Orbit Insertion (MOI) maneuver. The spacecraft's carrier signal was last seen at approximately 09:04:52 UTC on Thursday, September 23, 1999.

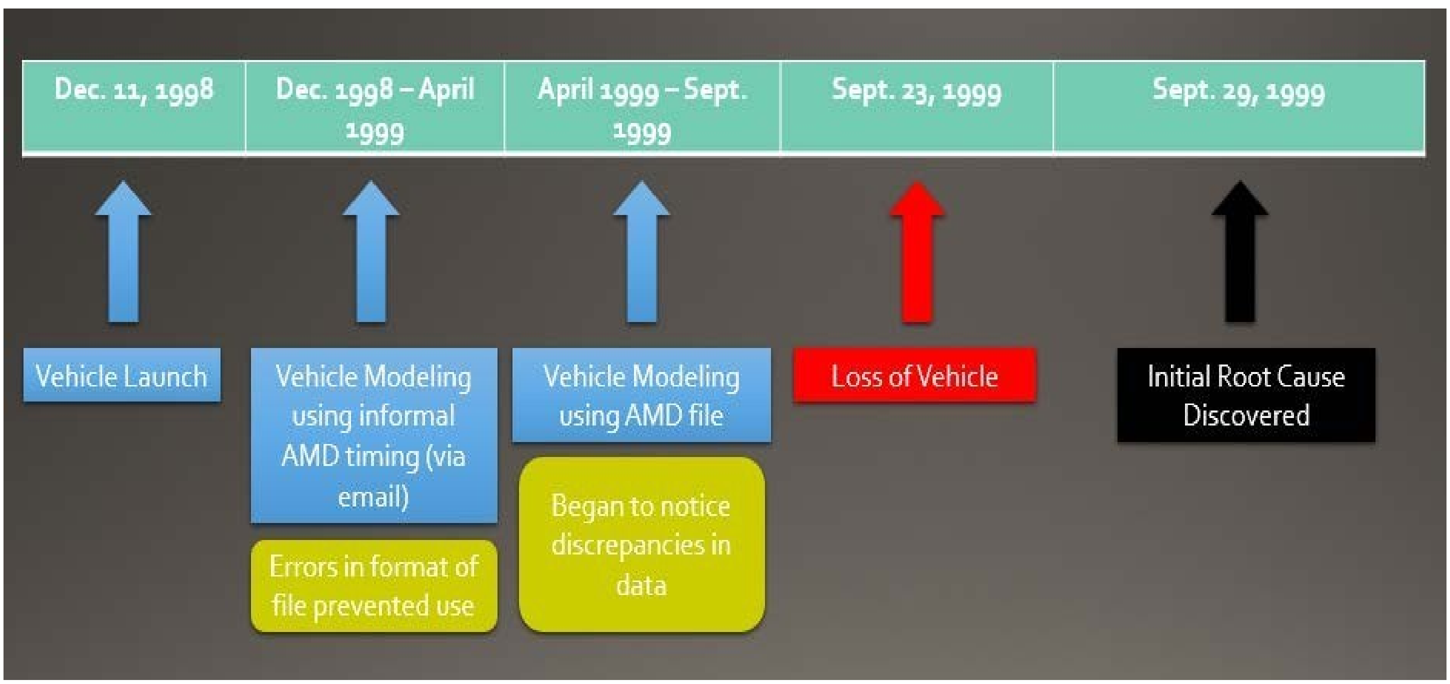

Figure 1: MCO Project Timeline

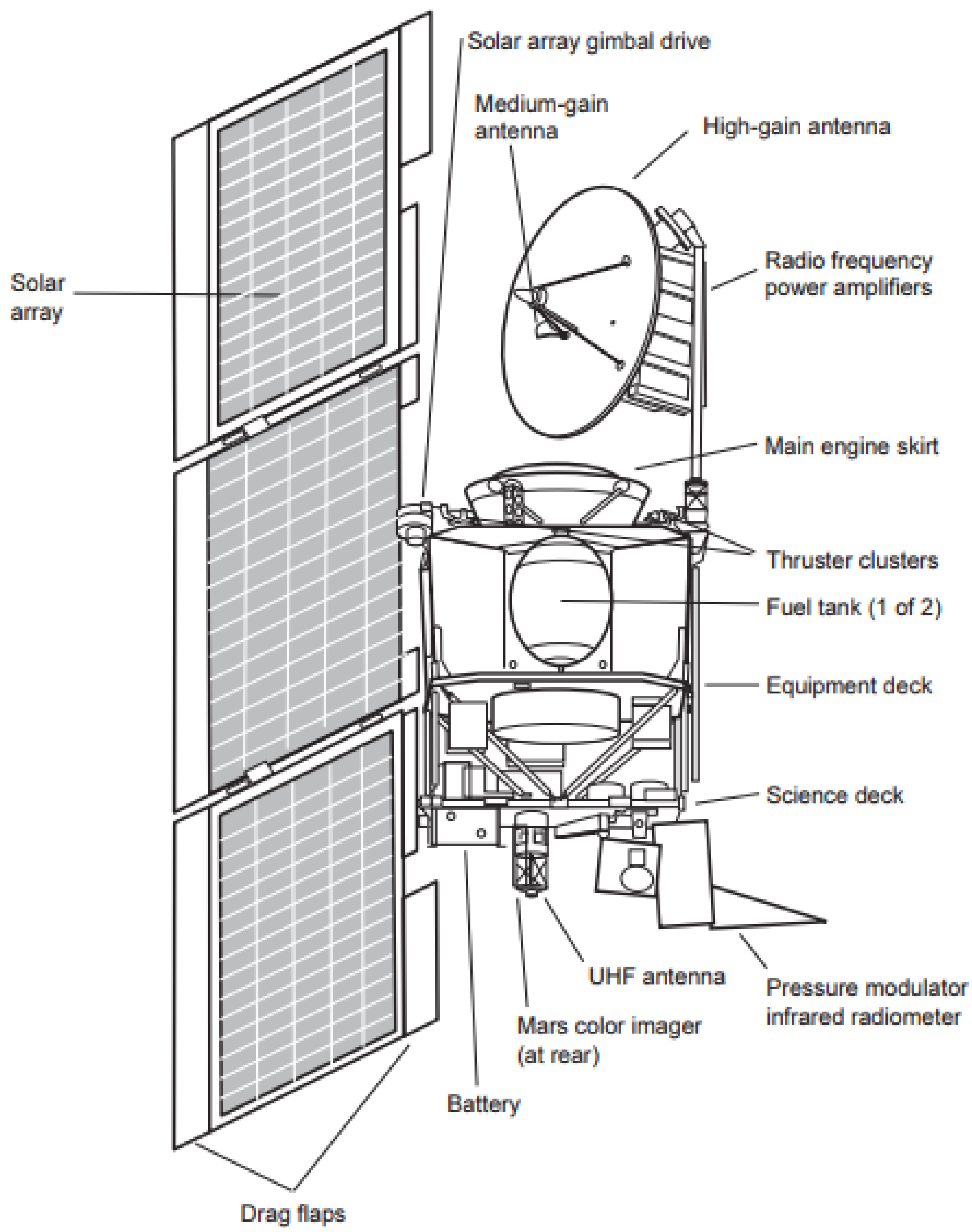

Figure 2: MCO Spacecraft

A brief information about MCO (Mars Climate Orbiter)

1. Nation	United States of America (USA)
2. Objective(s)	Mars Orbit
3. Spacecraft	MCO
4. Spacecraft Mass	1,407 pounds (638 Kilograms)
5. Mission Design and Management	NASA / Jet Propulsion Laboratory
6. Launch Vehicle	Delta 7427-9.5 (no. D264)
7. Launch Date and Time	Dec. 11, 1998 / 18:45:51 UT
8. Launch Site	Cape Canaveral, Fla. / Launch Complex 17A
9. Scientific Instruments	1. Pressure Modulated Infrared Radiometer (PMIRR) 2. Mars Color Imaging System (Two Cameras) (MARCI)
10. Spacecraft Launch Day	11/12/1998
11. Spacecraft Lost Day	23/09/1999

2. Description of the failure

Mars Climate Orbiter was successfully launched and intended to study the Martian climate. However, the probe failed before Mars orbital insertion. The Mars Climate Orbiter's Mishap Investigation Board obstinate that the core reason for the loss of spacecraft was the failure in utilizing metric units. The thruster performance data was to be in SI (metric) units rather than English units in a software file entitled "Small Forces".

As a result, the Mars Surveyor Operation Project's System Interface Specification software was instructed to use thrust units as pounds-seconds (lbf-s) instead of Newton-seconds (N-s) which led to the computation of spurious trajectory path. Consequently, the spacecraft entered the Martian atmosphere at a lower altitude resulting in the destruction of spacecraft in the upper atmosphere or re-entered into a heliocentric orbit.

Additionally, untraveled changes in spacecraft velocity, anomalous nature of navigation team with the spacecraft, interruption of 5th trajectory maneuver correction, inadequate system engineering process, the improper link between project elements, lack of navigation team staffing and training including faulty verification and validation process were also considerable factors for loss of Mars Climate Orbiter spacecraft.

3. Analysis of the Causes and Impacts

3.1 Outline

The MCO Mishap Investigation Board (MIB) has determined that the root cause for the loss of the MCO spacecraft was the failure to use metric units in the coding of a ground software file used in trajectory models. Specifically, thruster performance data in English units rather than metric units were utilized in the software application code titled SM_FORCES (Small Forces). A file called Angular Momentum Desaturation (AMD) contained the output data from the SM_FORCES software. The data within the AMD file was required to be in metric units per existing software interface documentation, and therefore the trajectory modelers assumed the data was provided in metric units per the requirements.

During the 9-month journey from Earth to Mars, propulsion maneuvers were periodically performed to remove angular momentum buildup in the onboard reaction wheels (flywheels). These Angular Momentum desaturations (AMD) events occurred 10-14 times more often than was expected by the operations navigation team. This was because the MCO solar array was asymmetrical relative to the spacecraft body as compared to Mars Global Surveyor (MGS) which had symmetrical solar arrays.

This asymmetric effect significantly increased the Sun-induced (solar pressure-induced) momentum buildup on the spacecraft. The increased AMD events coupled with the fact that the angular momentum (impulse) data was in English, rather than metric units, resulted in 7 small errors being introduced in the trajectory estimate throughout the 9-month journey. At the time of Mars insertion, the spacecraft trajectory was approximately 170 kilometers lower than planned. As a result, MCO either was destroyed in the atmosphere or re-entered heliocentric space after leaving Mars' atmosphere.

3.2 Root Cause Analysis

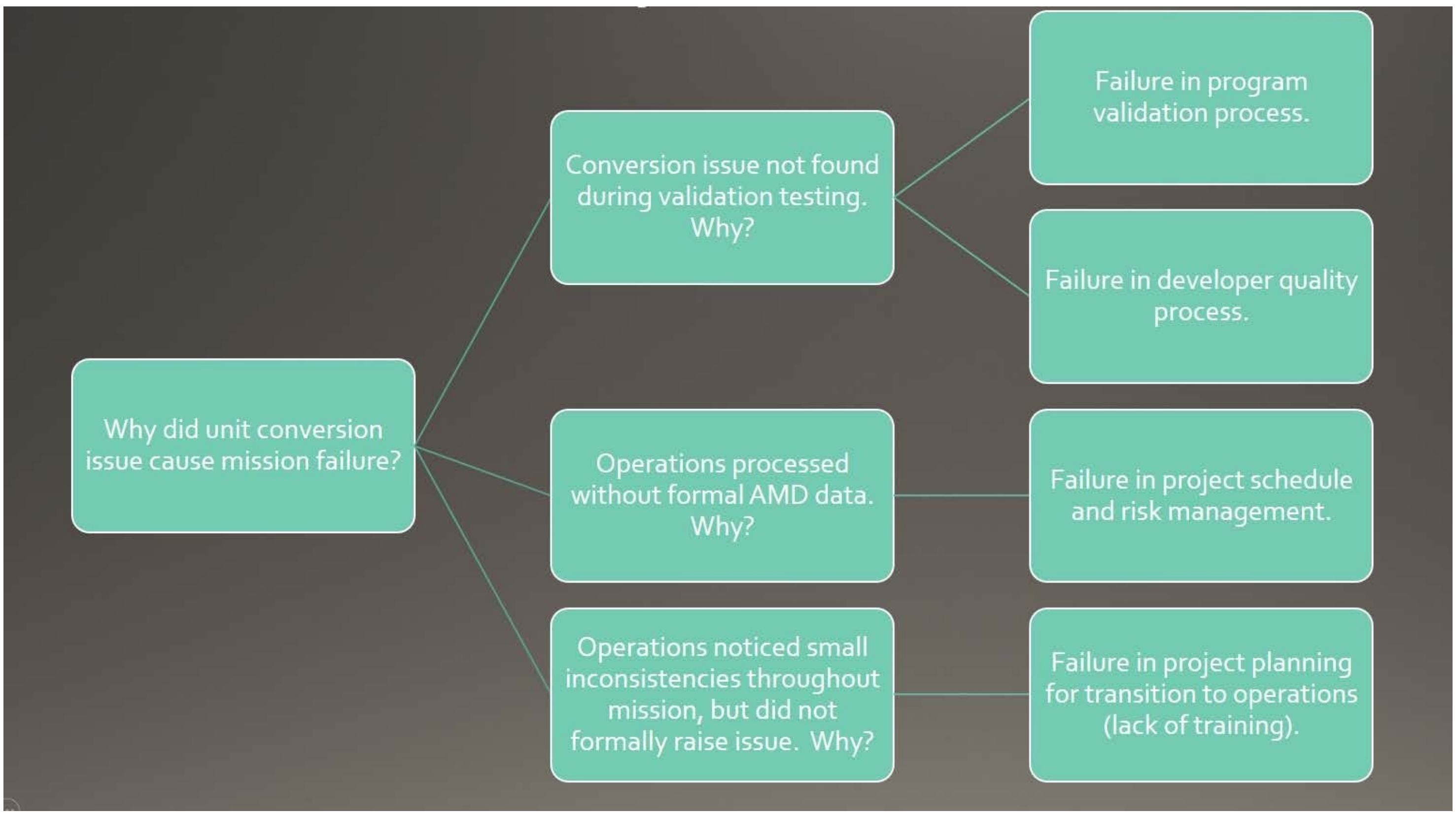

Figure 2: Root Cause Analysis

3.3 Poor Requirements Engineering & Software Engineering Practices

- Causes for this hazard can be stated in the terms of Poor Requirements Engineering & Software Engineering Practices as follows.

- **Problem 1 – Failure in the Program Validation Process**

  - *System integration testing failed to validate that the interface of the AMD file was satisfied correctly.*

- **Problem 2 – Failure in the Developer Quality Process**

  - *The developer had a clear specification that indicated the units required for the AMD file. But the quality process needed to have enforced some sort of review that would catch something as critical as the requirements of the interface.*

- **Problem 3 – Failure in the Project Schedule and Risk Management**

  - *Project Management attempted to mitigate the late schedule of the developer providing an AMD (Angular Momentum Desaturation)* file *with a manual interaction.*
  - *Given the criticality of this system function, it was not clear that the risk was properly quantified.*
  - *Mitigation plan was not thorough enough to require validation of AMD interface upon receipt of late system function.*

- **Problem 4 – Failure in the Project Planning (Lack of Training) for transition to operations**

  - *Operations team responsible for utilizing AMD interface was not part of original program development.*
  - *Thorough background training on the specifications of the system was not provided.*
  - *This lack of background knowledge contributed to the issue of operations noticing minor inconsistencies in the data without realizing the larger consequence to the system.*

4. Suggested Improvements to Requirements / Software Engineering Practices

- **Make Tests Fundamental**

➢ *In a big project, it's sufficient to thoroughly test each individual part of a machine, instrument or software. It's crucial to also test the way each component interacts with the others. We can't skimp on tests. A failure to detect an issue could compromise the whole project.*

- **Take all the measures available to reduce risks, in uncertain circumstances**

➢ *The uncertainties regarding the probe's position called for the prudent move of making a final trajectory correction. That choice wouldn't have threatened the mission in any case, so it was really due.*

- **Decision-making responsibility should be clear at every step of the project**

➢ *The risk in dealing with a big project is that responsibility is somehow spread out among different teams, so that everyone trusts that someone else is going to make a particular decision.*

- **Upstream opinions should be evaluated carefully**

➢ *It's not nice to hear that something could go very wrong, but project managers should have enough technical knowledge to recognize when the dissent is just a matter of hairsplitting or if it is grounded on rational reasons.*

- **The more complex the project is, the more we should worry about the communication between the teams**

➢ *In big projects, it is difficult to have a global vision of what's going on. To avoid inconsistencies, it's really essential to share information between the involved teams.*

5. Conclusion References

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