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Editor's Note: The loss of NASA's Mars Climate Orbiter (MCO) in 1999 is commonly attributed to a mix-up between English and metric units. The failure in fact has more complex roots, as recounted below.

The Loss of Mars Climate Orbiter

Attitude Control Burns and Navigation.

En route to Mars, the MCO experienced asymmetric solar wind pressure and had to frequently fire its thrusters to unload the reaction wheels. The thruster pulse and duration are converted to ΔV vectors, using ground software inherited from the successful Mars Global Surveyor (MGS) program.

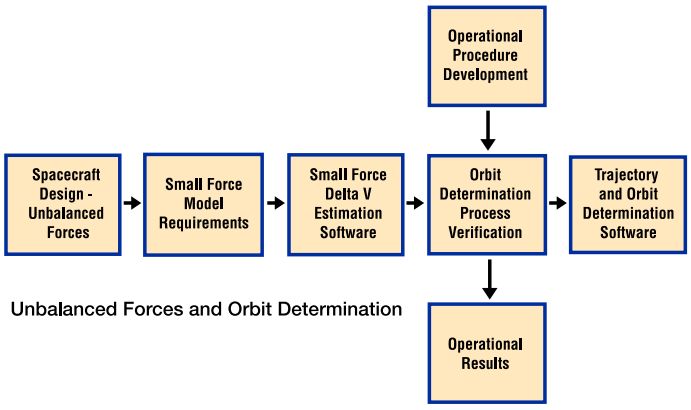
Software Revision Mistake.

The MGS model specified thruster input in Newton-sec, but the thruster vendor used lb-force-sec. To make them match, MGS engineers inserted a 4.45 conversion factor into the vendor's equation.

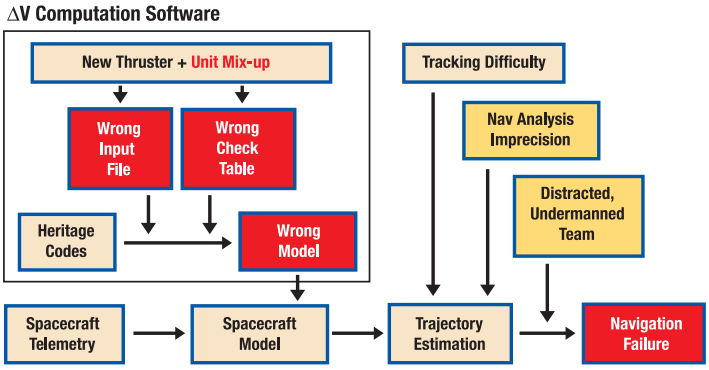
The MCO project had to modify this model because it used a different thruster from the same vendor, who continued to use English units. Overlooking the interface specification and seeing no warning in the code comments, the MCO engineers simply swapped the vendor equations without carrying the conversion factor forward.

Verification Process Escape.

Considered as "non-mission critical," the ground software was not rigorously reviewed; the "truth" table, computed manually for acceptance testing, contained the same mistake. Interface with the navigation function was informally tested, only to ensure that it could move across servers.



Unbalanced Forces and Orbit Determination



Complex Cause of MCO Failure

Navigation Difficulties.

The MCO program was run very lean, with only one, occasionally two, navigation engineers. Two months before orbit insertion, radar returns projected a path too close to Mars. Unfortunately, as the probe closed in Mars, unfavorable observation geometry from Earth reduced tracking precision. The flight team, confident of their navigation ability, decided against raising the orbit.

Not until aerobraking, after Martian gravity had captured the probe, was it possible to calculate the MCO's true position. Only then did the controllers realize it was 100 kilometers off course!

Avoiding Problem Repeats.

The successful reflight listed both English and metric units on all interface control documents, adopted a more robust navigation method, and used six full-time navigators.

Lessons Learned.

- Any software, including ground software, that commands a satellite is mission critical.
- Validate changes in mission-critical software with more vigor than the original development. Rigorous formal testing is essential.
- Always specify the units in requirements and interface specifications.
- Generate expected results used in verification tests independently, in accordance with system requirements.

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