

Cause of failure

On November 10, 1999, the Mars Climate Orbiter Mishap Investigation Board released a Phase I report, detailing the suspected issues encountered with the loss of the spacecraft. Previously, on September 8, 1999, Trajectory Correction Maneuver-4 was computed and then executed on September 15, 1999. It was intended to place the spacecraft at an optimal position for an orbital insertion maneuver that would bring the spacecraft around Mars at an altitude of 226 kilometers on September 23, 1999. However, during the week between TCM-4 and the orbital insertion maneuver, the navigation team indicated the altitude may be much lower than intended at 150 to 170 kilometers. Twenty-four hours prior to orbital insertion, calculations placed the orbiter at an altitude of 110 kilometers; 80 kilometers is the minimum altitude that Mars Climate Orbiter was thought to be capable of surviving during this maneuver. Final calculations placed the spacecraft in a trajectory that would have taken the orbiter within 57 kilometers of the surface where the spacecraft likely disintegrated because of atmospheric stresses. The primary cause of this discrepancy was engineering error. Specifically, the flight system software on the *Mars Climate Orbiter* was written to take thrust instructions using the metric unit [newtons](#) (N), while the software on the ground that generated those instructions used the Imperial measure [pound-force](#) (lbf). This error has since been known as the *metric mixup* and has been carefully avoided in all missions since by [NASA](#).^[16]

The MCO 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, “Small Forces,” used in trajectory models. Specifically, thruster performance data in English units [i.e. [United States customary units](#) -- *ed.*] instead of metric units was used in the software application code titled SM_FORCES (small forces). The output from the SM_FORCES application code as required by a MSOP Project Software Interface Specification (SIS) was to be in metric units of Newton-seconds (N-s). Instead, the data was reported in English units of pound-seconds (lbf-s). The Angular Momentum Desaturation (AMD) file contained the output data from the SM_FORCES software. The SIS, which was not followed, defines both the format and units of the AMD file generated by ground-based computers. Subsequent processing of the data from AMD file by the navigation software algorithm therefore, underestimated the effect on the spacecraft trajectory by a factor of 4.45, which is the required conversion factor from force in pounds to Newtons. An erroneous trajectory was computed using this incorrect data.

— *Mars Climate Orbiter Mishap Investigation Phase I Report*^[16]

The discrepancy between calculated and measured position, resulting in the discrepancy between desired and actual orbit insertion altitude, had been noticed earlier by at least two navigators, whose concerns were dismissed. A meeting of trajectory software engineers, trajectory software operators (navigators), propulsion engineers, and managers, was convened to consider the possibility of executing TCM-5, which was in the schedule. Attendees of the meeting recall an agreement to conduct TCM-5, but it was ultimately not done.