The tragic failure of the Mars Climate Orbiter (MCO) programme

In September 1999, after a journey to Mars lasting nearly 10 months, the Mars Climate Orbiter broke up and burned up in the Martian atmosphere. On a day when NASA engineers and onlookers were preparing to celebrate, with champagne in hand and holding their breath.

Reality on Earth, however, dealt a harsh blow; the rush and cost-cutting had not paid off, and above all, the banal fact that one part of the design team had used the metric system whilst the other had used imperial units for their work, and this *„forgot"* to discuss this with one another.

The Mars Climate Orbiter (MCO) programme

The **Mars Climate Orbiter (MCO)** programme was developed as part of NASA's Mars Surveyor '98 programme, the aim of which was the long-term study of Mars's atmosphere, climate and surface changes. The probe was designed as an interplanetary weather satellite that would have monitored dust, water vapour and seasonal changes over the course of a full Martian year (approximately two Earth years). In addition, a key task was to relay data from the Mars Polar Lander to Earth.



The spacecraft was designed and built by Lockheed Martin Astronautics on behalf of NASA and was launched on 11 December 1998 from Cape Canaveral on a Delta II launch vehicle.

The Mars Climate Orbiter's (MCO) journey to Mars took a total of 286 days, or approximately nine and a half months. The probe was placed into a so-called Type 2 orbit, which meant that it travelled more

than 180 degrees around the Sun before reaching Mars; this allowed for a slower arrival velocity, as the Sun's gravity slowed the spacecraft down.

Subsequent analyses revealed that a navigation error occurred during every single orbit correction and during the minor thruster firings used to maintain the probe's stability. As these were minor deviations individually, they did not appear critical during the daily routine, but they accumulated over the course of the nine-month journey, resulting in a deviation of 170 kilometres. Members of the navigation team noticed during the journey that the probe's orbit was not exactly where it should have been. They raised their concerns with their superiors, but because the reports were not submitted in accordance with official protocol, management did not attach much importance to them, and no substantive action was taken.

The mission was based on the **"Faster, Better, Cheaper"** (*faster, better, cheaper*), which led to the teams being overburdened, communication being patchy, and several important checks simply being omitted or rushed. By the time the engineers calculated, 24 hours before arrival, that the probe's altitude was critical (just 57–110 km instead of the planned 226 km), it was already too late to adjust the trajectory.

The Mars Climate Orbiter (MCO) reached Mars on 23 September 1999. On that day, at 09:00:46 UTC, the probe fired its main engine to slow down and enter orbit around the planet. At 09:04:52, the probe passed behind Mars, which, according to the plan, should have resulted in a temporary loss of radio contact. However, this moment occurred 49 seconds earlier than expected.

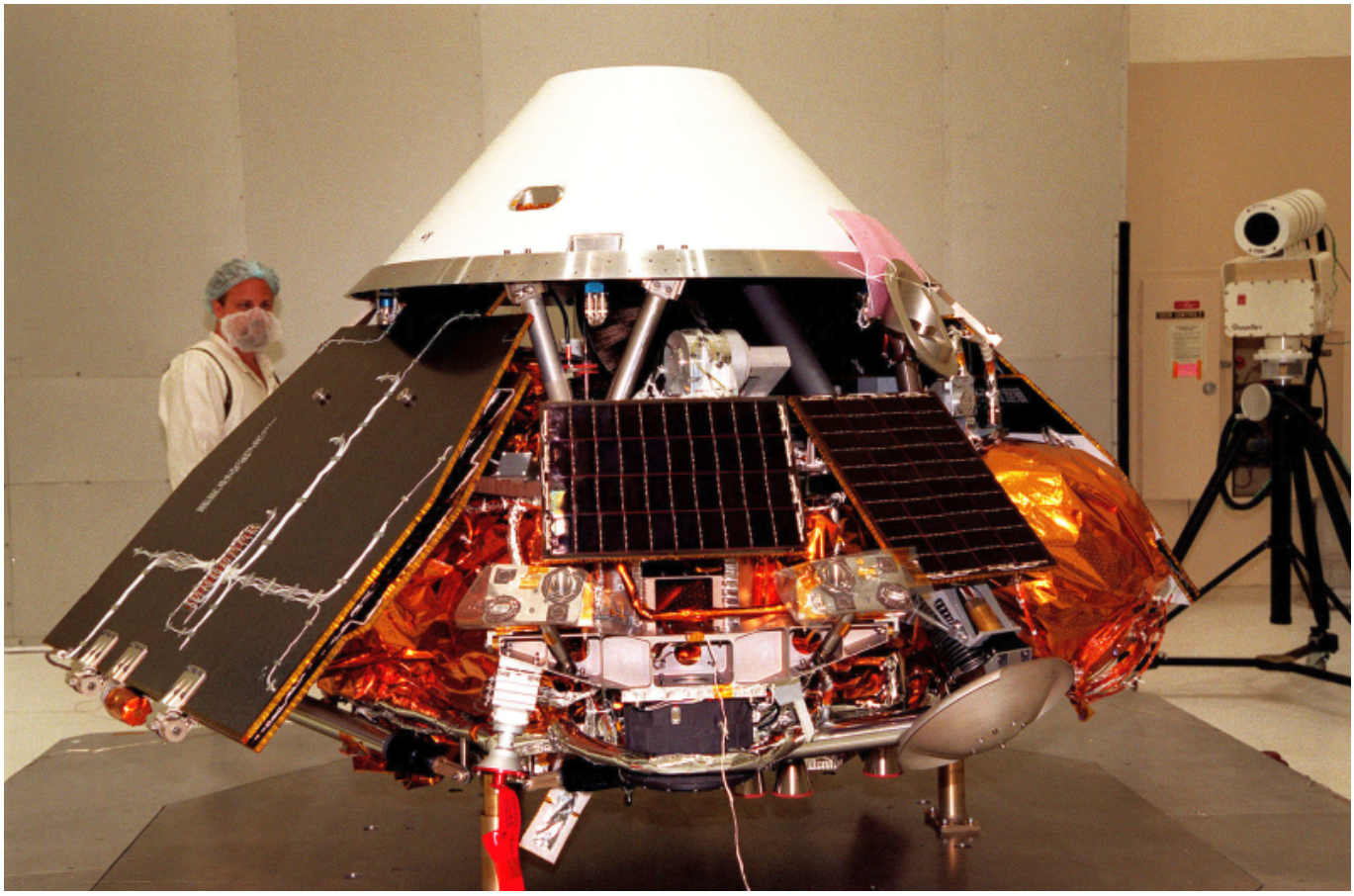
Due to the earlier navigation error, the probe approached the surface at an altitude of just 57 km, rather than the planned 140–150 km. At this low altitude, the Martian atmosphere was already too dense: the high speed, the resulting friction and the heat probably tore the probe to pieces and burned it up.

The control centre waited in vain for the signal to reappear on the far side of Mars, but contact was never re-established. Over the following days, more than 40 command files were sent to *to "wake it up"*, but on 25 September the mission was officially declared a loss.

The investigation began almost immediately after contact was lost, at the end of September 1999. The analysis took place on several levels to determine the cause of the failure and to try to prevent a similar incident with the forthcoming *Mars Polar Lander* from failing. It was too late.

MPL

The **Mars Polar Lander (MPL)** reached Mars on 3 December 1999, but it too vanished without a trace during the landing manoeuvre, and contact with it was never re-established. This was the second major loss for the **Mars Surveyor '98** programme, following the failure of the Mars Climate Orbiter.



The most likely scenario in this case was a software fault. When the probe deployed its landing legs during descent, the resulting vibration was mistakenly interpreted by the onboard computer as the vehicle having already touched down. As a result of this false signal, the software shut down the braking rockets whilst the probe was still at an altitude of approximately 40 metres. The probe thus crashed into the surface in free fall and was destroyed.

Investigations

The investigation was carried out by three independent groups: Firstly, the Jet Propulsion Laboratory (JPL) conducted its own internal investigation, which had already identified the probable cause of the fault by 30 September 1999. NASA also established an independent investigation committee, led by Arthur G. Stephenson, then the director of the Marshall Space Flight Centre. A group comprising external experts and JPL staff was formed to investigate system-level faults. The committee published its first report (Phase I) on 10 November 1999, in which it concluded the following: Metric units were not used consistently when coding the software file named 'Small Forces'. Lockheed Martin provided the acceleration data in imperial units (ft/s²), whilst JPL's navigation software expected metric values (m/s²). In other words, one team used metric units whilst the other used imperial units, and this *„forgot"* to coordinate with one another. This rather trivial error led to the destruction of the probe, which was worth 327.6 million dollars (610–630 million dollars at today's value).

The so-called *'end-to-end'* testing, which would have verified the entire process of data transfer between the software systems. The flow of information between the navigation team and the engineers was inadequate; the navigators reported that the desired orbit had been reached, but their observations were not taken seriously. The committee found that the navigation team was understaffed and had not received adequate training on the specific characteristics of the spacecraft in question.

The “Faster, Better, Cheaper” strategy

According to the report, the mission’s excessive workload and tight budget contributed to superficial quality control. The strategy *„Faster, Better, Cheaper”* philosophy was fundamentally shaken. It became clear that excessive cost-cutting and tight deadlines came at the expense of safety and quality control.



Following the investigations, comprehensive end-to-end data transfer tests were made mandatory, and the exclusive use of the metric system was mandated globally for all future spacecraft. Although reports of direct redundancies rarely left the agency, the management of the Mars programme was completely restructured, redundancies did occur, and much stricter engineering oversight was introduced.

Following the twin failures (MCO and Polar Lander), NASA suspended its Mars missions for two years in order to rebuild the programme from the ground up, which ultimately led to the highly successful Mars Odyssey and Mars Exploration Rovers (Spirit and Opportunity) missions.

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2026, MCO, Mars Climate Orbiter, tech, USA, NASA, Lockheed Martin Astronautics, 1999, Faster, Better, Cheaper, Mars Polar Lander, MPL, Jet Propulsion Laboratory, JPL, Small Forces, end-to-end test, Dan Goldin

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