Mars Climate Orbiter

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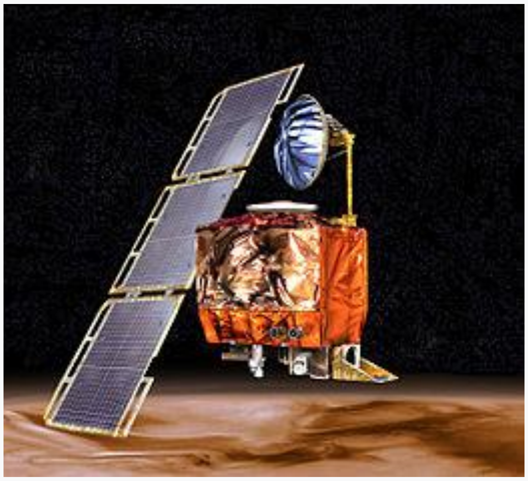


Artist's conception of the *Mars Climate Orbiter*

Mission type	Mars orbiter
Operator	NASA / JPL
COSPAR ID	1998-073A
SATCAT no.	25571
Website	mars.jpl.nasa.gov/msp98/orbiter/
Mission duration	286 days Mission failure
Spacecraft properties	
Manufacturer	Lockheed Martin

Launch mass	638 kilograms (1,407 lb)[1]
Power	500 watts
Start of mission	
Launch date	December 11, 1998, 18:45:51 UTC
Rocket	Delta II 7425
Launch site	Cape Canaveral SLC-17A
End of mission	
Last contact	23 September 1999 09:06:00 UTC
Decay date	September 23, 1999 Unintentionally deorbited
Orbital parameters	
Reference system	Areocentric
Epoch	Planned

The ***Mars Climate Orbiter*** (formerly the **Mars Surveyor '98 Orbiter**) was a 638-kilogram (1,407 lb)[1] robotic space probe launched by NASA on December 11, 1998 to study the Martian climate, Martian atmosphere, and surface changes and to act as the communications relay in the Mars Surveyor '98 program for Mars Polar Lander. However, on September 23, 1999, communication with the spacecraft was permanently lost as it went into orbital insertion. The spacecraft encountered Mars on a trajectory that brought it too close to the planet, and it was either destroyed in the atmosphere or escaped the planet's vicinity and entered an orbit around the Sun.[2] An investigation attributed the failure to a measurement mismatch between two software systems: metric units by NASA and non-metric (imperial or "English") units by spacecraft builder Lockheed Martin.[3]

Contents

Mission background[edit]

History[edit]

After the loss of *Mars Observer* and the onset of the rising costs associated with the future International Space Station, NASA began seeking less expensive, smaller probes for scientific interplanetary missions. In 1994, the Panel on Small Spacecraft Technology was established to set guidelines for future miniature spacecraft. The panel determined that the new line of miniature spacecraft should be under 1,000 kg (2,200 pounds) with highly focused instrumentation.[4] In 1995, a new Mars Surveyor program began as a set of missions designed with limited objectives, low costs, and frequent launches. The first mission in the new program was Mars Global Surveyor, launched in 1996 to map Mars and provide geologic data using instruments intended for *Mars Observer*.[5] Following Mars Global Surveyor, *Mars Climate Orbiter* carried two instruments, one originally intended for Mars Observer, to study the climate and weather of Mars.

The primary science objectives of the mission included:[6]

- determine the distribution of water on Mars
- monitor the daily weather and atmospheric conditions
- record changes on the Martian surface due to wind and other atmospheric effects
- determine temperature profiles of the atmosphere
- monitor the water vapor and dust content of the atmosphere
- look for evidence of past climate change.

Spacecraft design[edit]

The *Mars Climate Orbiter* bus measured 2.1 meters (6 feet 11 inches) tall, 1.6 meters (5 feet 3 inches) wide and 2 meters (6 feet 7 inches) deep. The internal structure was largely constructed with graphite composite/aluminum honeycomb supports, a design found in many commercial airplanes. With the exception of the scientific instruments, battery and main engine, the spacecraft included dual redundancy on the most important systems.[6][7]

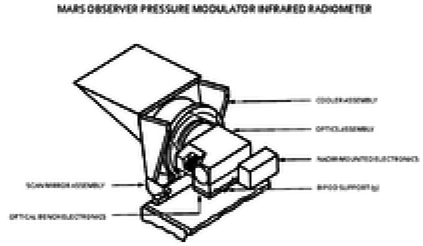
The spacecraft was 3-axis stabilized and included eight hydrazine monopropellant thrusters *(four 22 N (4.9 lb_f) thrusters to perform trajectory corrections; four 0.9 N (3.2 ozf) thrusters to control attitude)*. Orientation of the spacecraft was determined by a star tracker, two Sun sensors and two inertial measurement units. Orientation was controlled by firing the thrusters or using three reaction wheels. To perform the Mars orbital insertion maneuver, the spacecraft also included a LEROS 1B main engine rocket,[8] providing 640 N (140 lb_f) of thrust by burning hydrazine fuel with nitrogen tetroxide (NTO) oxidizer.[6][7]

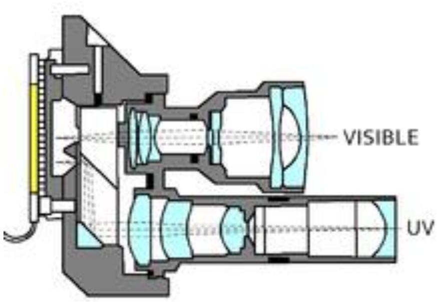
The spacecraft included a 1.3-meter (4-foot-3-inch) high-gain antenna to transceive data with the Deep Space Network over the x-band. The radio transponder designed for the *Cassini–Huygens* mission was used as a cost-saving measure. It also included a two-way UHF radio frequency system to relay communications with Mars Polar Lander upon an expected landing on December 3, 1999.[6][7][9]

The space probe was powered with a 3-panel solar array, providing an average of 500 W (0.67 hp) at Mars. Deployed, the solar array measured 5.5 meters (18 ft 1 in) in length. Power was stored in 12-cell, 16-amp-hour Nickel hydrogen batteries. The batteries were intended to be recharged when the solar array received sunlight and power the spacecraft as it passed into the shadow of Mars. When entering into orbit around Mars, the solar array was to be utilized in the aerobraking maneuver, to slow the spacecraft until a circular orbit was achieved. The design was largely adapted from guidelines from the Small Spacecraft Technology Initiative outlined in the book, *Technology for Small Spacecraft*.[6][7][10]

In an effort to simplify previous implementations of computers on spacecraft, *Mars Climate Orbiter* featured a single computer using an IBM RAD6000 processor utilizing a POWER1 ISA capable of 5, 10 or 20 MHz operation. Data storage was to be maintained on 128 MB of random-access memory (RAM) and 18 MB of flash memory. The flash memory was intended to be used for highly important data, including triplicate copies of the flight system software.[6]

Scientific instruments[edit]





The Pressure Modulated Infrared Radiometer (PMIRR) uses narrow-band radiometric channels and two pressure modulation cells to measure atmospheric and surface emissions in the thermal infrared and a visible channel to measure dust particles and condensates in the atmosphere and on the surface at varying longitudes and seasons.[11] Its principal investigator was Daniel McCleese at JPL/CALTECH. Similar objectives were later achieved with *Mars Climate Sounder* on board *Mars Reconnaissance Orbiter*. Its objectives:[12]

- Map the three-dimensional and time-varying thermal structure of the atmosphere from the surface to 80 km altitude.
- Map the atmospheric dust loading and its global, vertical and temporal variation.
- Map the seasonal and spatial variation of the vertical distribution of atmospheric water vapor to an altitude of at least 35 km.
- Distinguish between atmospheric condensates and map their spatial and temporal variation.
- Map the seasonal and spatial variability of atmospheric pressure.
- Monitor the polar radiation balance.

The Mars Color Imager (MARCI) is a two-camera (medium-angle/wide-angle) imaging system designed to obtain pictures of the Martian surface and atmosphere. Under proper conditions, resolutions up to 1 kilometer (3,300 ft) are possible.[13][14] The principal investigator on this project was Michael Malin at Malin Space Science Systems and the project was reincorporated on *Mars Reconnaissance Orbiter*. Its objectives:[13]

- Observe Martian atmospheric processes at global scale and synoptically.
- Study details of the interaction of the atmosphere with the surface at a variety of scales in both space and time.

- Examine surface features characteristic of the evolution of the Martian climate over time.

Camera filters[13]

Filter name	Camera Angle	Wavelength	
		(nm)	Color
UV1	Wide	280	N/A
UV2	Wide	315	N/A
MA1	Medium	445	
WA1	Wide	453	
MA2	Medium	501	
WA2	Wide	561	
MA3	Medium	562	
WA3	Wide	614	
WA4	Wide	636	
MA4	Medium	639	
WA5	Wide	765	
MA5	Medium	767	
MA6	Medium	829	N/A
MA7	Medium	903	N/A
MA8	Medium	1002	N/A

Images of the spacecraft

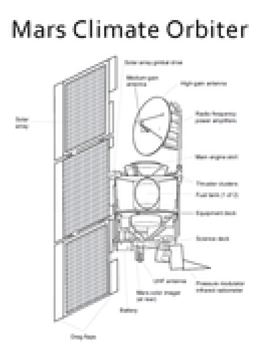
- 

Diagram of *Mars Climate Orbiter*.

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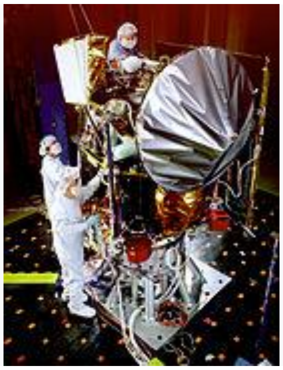
Mars Climate Orbiter during assembly.

- 

Mars Climate Orbiter undergoing acoustic testing.

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Mars Climate Orbiter awaiting a spin test in November 1998.

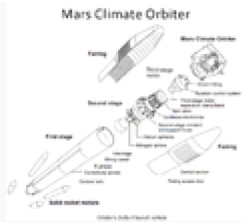
Mission profile[edit]

Timeline of travel

Date	Time (UTC)	Event
Dec 11 1998	18:45:51	Spacecraft launched
Sep 23 1999	08:41:00	Insertion begins. Orbiter stows solar array.
	08:50:00	Orbiter turns to correct orientation to begin main engine burn.
	08:56:00	Orbiter fires pyrotechnic devices which open valves to begin pressurizing the fuel and oxidizer tanks.
	09:00:46	Main engine burn starts; expected to fire for 16 minutes 23 seconds.
	09:04:52	Communication with spacecraft lost
	09:06:00	Orbiter expected to enter Mars occultation, out of radio contact with Earth.[n 1]
	09:27:00	Expected to exit Mars occultation.[n 1]
Sep 25 1999		Mission declared a loss. Reason for loss known. No further attempts to contact.

Launch and trajectory[edit]

The *Mars Climate Orbiter* probe was launched on December 11, 1998 at 18:45:51 UTC by the National Aeronautics and Space Administration from Space Launch Complex 17A at the Cape Canaveral Air Force Station in Florida, aboard a Delta II 7425 launch vehicle. The complete burn sequence lasted 42 minutes bringing the spacecraft into a Hohmann transfer orbit, sending the probe into a 9.5 months, 669 million km (416 million mi) trajectory.[6][9] At launch, *Mars Climate Orbiter* weighed 638 kg (1,407 lb) including propellant.[1]

- 

Exploded diagram of Delta II launch vehicle with *Mars Climate Orbiter*

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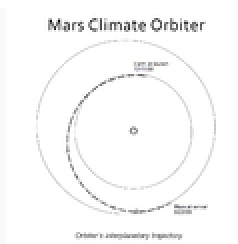
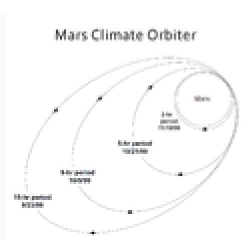
Launch of *Mars Climate Orbiter* by NASA on a [Delta II](#) 7425 launch vehicle

- 

Interplanetary trajectory of *Mars Climate Orbiter*

- 

Aerobraking procedure to place *Mars Climate Orbiter* into orbit around Mars

Encounter with Mars[edit]

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This image of Mars on September 7, 1999 is the only image acquired by the *Orbiter*.

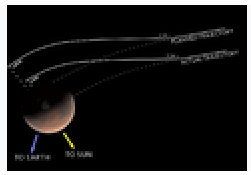
- 

Diagram comparing the intended and actual trajectories of the *Orbiter*

See also: Exploration of Mars

Mars Climate Orbiter began the planned orbital insertion maneuver on September 23, 1999 at 09:00:46 UTC. *Mars Climate Orbiter* went out of radio contact when the spacecraft passed behind Mars at 09:04:52 UTC, 49 seconds earlier than expected, and communication was never reestablished. Due to complications arising from human error, the spacecraft encountered Mars at a lower than anticipated altitude and it was either destroyed in the atmosphere or re-entered heliocentric space after leaving Mars' atmosphere.[2] *Mars Reconnaissance Orbiter* has since completed most of the intended objectives for this mission.

Cause of failure[edit]

> The problem here was not the error; it was the failure of NASA's systems engineering, and the checks and balances in our processes, to detect the error. That's why we lost the spacecraft.
>
> —**Edward Weiler, NASA associate administrator for space science**, IEEE Spectrum: Why the Mars Probe went off course

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 (TCM-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 km (140 miles) 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 km (93 to 106 miles). Twenty-four hours prior to orbital insertion, calculations placed the orbiter at an altitude of 110 km (68 miles); 80 km (50 miles) is the minimum altitude that *Mars Climate Orbiter* was thought to be capable of surviving during this maneuver. Post-failure calculations showed that the spacecraft was on a trajectory that would have taken the orbiter within 57 km (35 miles) of the surface, where the spacecraft likely skipped[dubious – discuss] violently on the uppermost atmosphere and was either destroyed in the atmosphere or re-entered heliocentric space.[2]

The primary cause of this discrepancy was that one piece of ground software supplied by Lockheed Martin produced results in a United States customary unit, contrary to its Software Interface Specification (SIS), while a second system, supplied by NASA, expected those results to be in SI units, in accordance with the SIS. Specifically, software that calculated the total impulse produced by thruster firings produced results in pound-force seconds. The trajectory calculation software then used these results – expected to be in newton seconds (incorrect by a factor of 4.45)[15] – to update the predicted position of the spacecraft.[16]

Still, NASA does not place the responsibility on Lockheed for the mission loss; instead, various officials at NASA have stated that NASA itself was at fault for failing to make the appropriate checks and tests that would have caught the discrepancy.[17]

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 because they "did not follow the rules about filling out [the] form to document their concerns". A meeting of trajectory software engineers, trajectory software operators (navigators), propulsion engineers, and managers was convened to consider the possibility of executing Trajectory Correction Maneuver-5, which was in the schedule. Attendees of the meeting recall an agreement to conduct TCM-5, but it was ultimately not done.[17]

Project costs[edit]

According to NASA, the cost of the mission was $327.6 million total for the orbiter and lander, comprising $193.1 million for spacecraft development, $91.7 million for launching it, and $42.8 million for mission operations.[18]

See also[edit]

- ***Spaceflight portal***

- List of missions to Mars
- List of artificial objects on Mars
- List of software bugs
- Metrication

Notes[edit]

1. ^ Jump up to:a b Planned but unaccounted for event.

References[edit]

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