# Mars Reconnaissance Orbiter Mission Description

## Mission Overview

The Mars Reconnaissance Orbiter spacecraft was launched from Cape Canaveral Air Force Station on 12 August 2005 aboard a Lockheed-Martin Atlas V-401 launch vehicle. After a five-month cruise and a two-month approach to Mars, MRO entered Mars' orbit on 10 March 2006 and began aerobraking. The primary science phase began on 8 November, 2006. The primary science phase is planned to last one Mars year (approximately two Earth years), after which an extended mission may be scheduled.

Note: This description has been written early in the Primary Science Phase of the MRO mission. It will be revised at least once by the end of the mission.

## Mission Phases

The Mars Reconnaissance Orbiter Mission is divided in time into six phases: Launch, Cruise, Approach and Orbit Insertion, Aerobraking, Primary Science, and Relay.

Launch

Launch extended from the start of the countdown to the initial acquisition, by the DSN, of the orbiter in a safe and stable configuration.

The baseline launch vehicle for the MRO mission was the Lockheed-Martin Atlas V 401. This launch vehicle was selected by NASA-KSC (Kennedy Space Flight Center) via a competitive procurement under the NASA Launch Services (NLS) contract. The Atlas V 401 was a two-stage launch vehicle consisting of the Atlas Common Core Booster and a single engine Centaur upper stage. The Centaur upper stage could perform multiple restarts of its main engine. For precise pointing and control during coast and powered flight, the Centaur used a flight control system that was 3-axis stabilized. The Atlas large payload fairing was used to protect MRO during the Atlas boost phase. This fairing had a diameter of 4.2m and a length of 12.2m.

The launch and injection of MRO occurred during the Mars opportunity of August 2005. The Atlas booster, in combination with the Centaur upper stage, delivered the MRO spacecraft into a targeted parking orbit. After a short coast, a restart of the Centaur upper stage injected MRO onto an interplanetary transfer trajectory.

Mission Phase Start Time : 2005-08-12

Mission Phase Stop Time : 2005-08-12

Cruise

Duration: About five months. The cruise phase extended from DSN initial acquisition, in a safe and stable configuration, until two months prior to the Mars Orbit Insertion (MOI) maneuver. Primary activities during cruise included spacecraft and payload checkout and calibration. These activities, along with daily monitoring of orbiter subsystems, were performed in order to fully characterize the performance of the spacecraft and its payload prior to arrival at Mars. In addition, standard navigation activities were performed during this flight phase, the first being the largest TCM performed fifteen days after launch.

Mission Phase Start Time : 2005-08-12

Mission Phase Stop Time : 2006-01-10

Approach and Orbit Insertion

This phase extended from two months prior to Mars Orbit Insertion (MOI), through MOI, and until the orbiter was checked out and ready to begin aerobraking. The orbiter was inserted into a nearly polar orbit with a period of 35 hours.

During the last sixty days of the interplanetary transit, spacecraft and ground activities were focused on the events necessary for a successful arrival and safe capture at Mars. Navigation techniques included the use of delta-DOR measurements in the orbit determination. This technique yielded a precise determination of the inbound trajectory with a series of final TCMs used to control the flight path of the spacecraft up to the MOI maneuver.

Also during the approach phase, MRO performed the Optical Navigation experiment. This involved pointing the optical navigation camera (ONC) at the moons of Mars - Phobos and Deimos, and tracking their motion. By comparing the observed position of the moons to their predicted positions, relative to the background stars, the ground was able to accurately determine the position of the orbiter.

Upon arrival at Mars on March 10, 2006, the spacecraft performed its MOI maneuver using its six main engines. MOI inserted the spacecraft into an initial, highly elliptical capture orbit. The delta-V required to accomplish this critical maneuver was 1015 m/s and took about 26 minutes to complete. For most of the burn, the orbiter was visible from the DSN stations. The signal was occulted as the orbiter went behind Mars, and appeared again a short time later. The reference MRO capture orbit had a period of 35 hours and a periapsis altitude of 300km. The orientation of the ascending node was 8:30 PM LMST. The capture orbit was been selected such that aerobraking would be completed prior to the start of solar conjunction (September 23, 2006).

Mission Phase Start Time : 2006-01-10

Mission Phase Stop Time : 2006-03-10

Aerobraking

One week after MOI, aerobraking operations commenced. During this time period, the orbiter used aerobraking techniques to supplement its onboard propulsive capability and to reduce its orbit period to that necessary for the primary science orbit (PSO). Aerobraking consisted of 4 distinct phases: a walk-in phase, a main phase, a walkout phase and a transition to the PSO. During the walk-in phase, the spacecraft established initial contact with the atmosphere as the periapsis altitude of the orbit was slowly lowered. This phase continued until the dynamic pressures and heating rate values required for main phase, or steady state aerobraking, were established. During main phase, large scale orbit period reduction occurred as the orbiter was guided to dynamic pressure limits. Main phase continued until the orbit lifetime of the orbiter reached 2 days. (Orbit lifetime is defined as the time it takes the apoapsis altitude of the orbit to decay to an altitude of 300km.) When the orbit lifetime of the orbiter reached 2 days, the aerobraking walkout phase began. During the walkout phase, the periapsis altitude of the orbit was slowly increased as the 2 day orbit lifetime of the orbiter was maintained. Once the orbit of the orbiter reached an apoapsis altitude of 450km, the orbiter terminated aerobraking by propulsively raising the periapsis of its orbit out of the atmosphere.

Because the PSO had nodal orientation requirements, the aerobraking phase of the MRO mission had to proceed in a timely manner and be completed near the time the desired nodal geometry was achieved. After approximately 4.5 months of aerobraking, the dynamic pressure control limits were reset such that the orbiter will fly to the desired 3:00 pm LMST nodal target.

Once the orbit apoapsis altitude was reduced to 450 km, the orbiter terminated aerobraking by raising periapsis to a safe altitude and begin a transition to the Primary Science Phase. The aerobraking phase was concluded on 30 August 2006, during the spacecraft's 445th orbit. The periapsis of the transition orbit rotated around Mars from over the equatorial latitudes to the North Pole. When periapsis reached the North Pole, apoapsis was reduced propulsively to 255 km and orbit rotation stopped - the orbit was frozen with periapsis over the South Pole and apoapsis over the North Pole. The SHARAD antenna and the CRISM cover were deployed, the instruments were checked out and remaining calibrations were performed. The payloads collected data in their normal operating modes to ensure that the end-to-end data collection and processing systems worked as planned. Orbiter activities in preparation for science were then temporarily suspended during a four week period surrounding solar conjunction.

Mission Phase Start Time : 2006-03-17

Mission Phase Stop Time : 2006-08-30

Primary Science

The 255 x 320 km Primary Science Orbit (PSO) is a near-polar orbit with periapsis frozen over the South Pole. It is sun-synchronous with an ascending node orientation that provides a Local Mean Solar Time (LMST) of 3:00 p.m. at the equator. Because of the eccentricity of the Mars orbit around the Sun, true solar time varies by nearly 45 minutes over the course of one Mars year.

The Primary Science Phase of the mission began after solar conjunction and after turn-on and checkout of the science instruments in the Primary Science Orbit. The phase started on 8 November 2006, will extend for one Mars year, and will conclude prior the next solar conjunction near the end of 2008.

The science investigations are functionally divided into daily global mapping and profiling, regional survey, and globally distributed targeting investigations. The global mapping instruments are the MCS and the MARCI. The targeted investigations are HiRISE, CRISM, and CTX. The survey investigations are CRISM and CTX (in survey modes), and SHARAD. The global mapping instruments require nadir pointing, low data rate, and continuous or near-continuous operations. The global mapping investigations are expected to use less than 5% of the expected downlink data volume. The targeted and survey instruments are high data rate instruments and will require precise targeting in along-track timing and/or cross-track pointing for short periods of time over selected portions of the surface. It is expected that more than 95% of the available downlink data volume will be used for targeted and survey investigations. All instruments can take data simultaneously.

Toward the end of the primary science phase, other Mars missions launched in the 2007 opportunity will begin to arrive. Phoenix, the first of the Mars Program's Scout missions has been selected to launch in the 2007 Mars opportunity. Phoenix, a lander mission that will collect and analyze subsurface ice and soil material, will arrive in late May 2008. Phoenix will need MRO to characterize its prime landing site choices early in the Primary Science Phase. MRO will provide relay support for Entry, Descent, and Landing (EDL) activities and for telecommunications late in the PSP after Phoenix arrives at Mars. Phoenix and MRO will also coordinate some observations to maximize science return to the Mars Exploration Program. Another mission, the Mars Science Laboratory (MSL) is currently proposed for launch in 2009, with arrival in 2010, during the MRO Relay Phase.

MSL will need MRO to provide and characterize candidate landing sites using observations taken during the MRO PSP. (Final certification of the prime MSL landing sites may require limited observations by the science payload in 2009 during the Relay phase. However, this has not been committed to by MRO) MRO will also provide EDL support and relay telecommunications for MSL. During the primary science phase, periodic instrument calibrations will be performed to verify the measurement characteristics, stability and health of the instruments. At the conclusion of the Primary Science Phase, these calibrations will be repeated, so that the final instrument characteristics are known.

NASA may approve, as resources and on-orbit capability permit, continuation of science observations beyond the Primary Science Phase until end of the Relay Phase (also End of Mission). The orbiter will remain in the Primary Science Orbit during the Relay Phase.

Mission Phase Start Time : 2006-11-08

Mission Phase Stop Time : 2008-11-09

Relay

MRO will provide critical relay support to missions launched as part of the Mars Exploration Program after MRO. For spacecraft launched in the 2007 opportunity, this relay support will occur before the end of the MRO Primary Science Phase. Following completion of the Primary Science Phase, MRO will continue to provide critical relay support for Mars missions until its end of mission.

While all of the missions that MRO will support have not yet been selected, Phoenix, the first of the Mars Program's Scout missions has been selected to launch in the 2007 Mars opportunity. Phoenix, a lander mission that will collect and analyze soil samples, will arrive in late May 2008. It will need science imaging support for site characterization and selection and relay support for its Entry, Descent and Landing activities and for its science data return. Another mission, the Mars Science Laboratory (MSL) is proposed for the 2009 Mars opportunity. MSL will also need science imaging support for site characterization and selection and relay support for EDL and science data return. The MRO Mission Plan describes the generic support activities for any mission as well as current early planning in support of Phoenix and MSL. Activities regarding site characterization and selection will be described as part of the Primary Science Phase, and activities regarding relay support will be described as part of the Relay Phase.

The orbiter has been designed to carry enough propellant to remain operational for 5 years beyond the end-of-mission (EOM) on December 31, 2010 to support future MEP missions. As this is beyond the EOM, no activities have been planned for this time period. To ensure that the orbiter remains in a viable orbit during this time, its orbit altitude will be increased at EOM to about 20 km inside the orbit of the Mars Global Surveyor spacecraft.

The MRO approach to planetary protection differs from any previous Mars orbiter. The NASA requirements for planetary protection, NPG8020.12B, allow a class III mission, like MRO, to use either the 'probability of impact/orbit lifetime' or a 'total bio burden' approach. Implementing the Level 1 MRO requirements with the instruments selected via the NASA AO requires low orbits whose lifetimes are incompatible with a 'probability of impact/orbit lifetime' approach to Planetary Protection. Therefore, MRO is implementing the requirements of NPG8020.12B using the 'total bio-burden' approach. This approach has been documented in the MRO Planetary Protection Plan (D-23711). The details of cleaning requirements are documented in the MRO Planetary Protection Implementation Plan, MRO 212-11, JPL D-22688. The MRO launch targets will be biased away from a direct intercept course with Mars to ensure a less than 1 in 10,000 chance of the launch vehicle upper stage entering Mars atmosphere.

The End-of-Mission (EOM) is planned for December 31, 2010 just prior to the third solar conjunction of the mission. The orbiter will perform a propulsive maneuver to place itself in a higher orbit to increase the orbit lifetime and enable extended mission operations.

Mission Phase Start Time : 2008-11-09

Mission Phase Stop Time : 2010-12-31

Extended Mission Phase Dates

Extended Science Phase (ESP) 2008-11-09 to 2010-09-30

Extended Mission 1 (EM1) 2010-10-01 to 2012-09-30

Extended Mission 2 (EM2) 2012-10-01 to 2014-09-30

Extended Mission 3 (EM3) 2014-10-01 to 2016-09-30

Extended Mission 4 (EM4) 2016-10-01 to 2019-09-30

Extended Mission 5 (EM5) 2019-10-01 to 2022-09-30

Extended Mission 6 (EM6) 2022-10-01 to 2025-09-30

## Mission Objectives The driving theme of the Mars Exploration Program is to understand the role of water on Mars and its implications for possible past or current biological activity. The Mars Reconnaissance Orbiter (MRO) Project will pursue this 'Follow-the-Water' strategy by conducting remote sensing observations that return sets of globally distributed data that will: 1) advance our understanding of the current Mars climate, the processes that have formed and modified the surface of the planet, and the extent to which water has played a role in surface processes; 2) identify sites of possible aqueous activity indicating environments that may have been or are conducive to biological activity; and 3) thus identify and characterize sites for future landed missions.

## The MRO payload is designed to conduct remote sensing science observations, identify and characterize sites for future landers, and provide critical telecom/navigation relay capability for follow-on missions. The mission will provide global, regional survey, and targeted observations from a low 255 km by 320 km Mars orbit with a 3:00 P.M. local mean solar time (ascending node). During the one Martian year (687 Earth days) primary science phase, the orbiter will acquire visual and near-infrared high-resolution images of the planet's surface, monitor atmospheric weather and climate, and search the upper crust for evidence of water. After this science phase is completed, the orbiter will provide telecommunications support for spacecraft launched to Mars in the 2007 and 2009 opportunities. The primary mission will end on December 31, 2010, approximately 5.5 years after launch.

Science Questions Addressed

The MRO mission has the primary objective of placing a science orbiter into Mars orbit to perform remote sensing investigations that will characterize the surface, subsurface and atmosphere of the planet and will identify potential landing sites for future missions. The MRO payload will conduct observations in many parts of the electromagnetic spectrum, including ultraviolet and visible imaging, visible to near-infrared imaging spectrometry, thermal infrared atmospheric profiling, and radar subsurface sounding, at spatial resolutions substantially better than any preceding Mars orbiter. In pursuit of its science objectives, the MRO mission will:

- Characterize Mars' seasonal cycles and diurnal variations of water, dust, and carbon dioxide.

- Characterize Mars' global atmospheric structure, transport, and surface changes.

- Search sites for evidence of aqueous and/or hydrothermal activity.

- Observe and characterize the detailed stratigraphy, geologic structure, and composition of Mars surface features.

- Probe the near-surface Martian crust to detect subsurface structure, including layering and potential reservoirs of water and/or water ice.

- Characterize the Martian gravity field in greater detail relative to previous Mars missions to improve knowledge of the Martian crust and lithosphere and potentially of atmospheric mass variation.

- Identify and characterize numerous globally distributed landing sites with a high potential for scientific discovery by future missions.

In addition, MRO will provide critical telecommunications relay capability for follow-on missions and will conduct, on a non-interference basis with the primary mission science, telecom and navigation demonstrations in support of future Mars Exploration Program (MEP) activities. Specifically, the MRO mission will:

- Provide navigation and data relay support services to future MEP missions.

- Demonstrate Optical Navigation techniques for high precision delivery of future landed missions.

- Perform an operational demonstration of high data rate Ka-band telecommunications and navigation services.

Designed to operate after launch for at least 5.4 years, the MRO orbiter will use a new spacecraft bus design provided by Lockheed Martin Space Systems Company, Space Exploration Systems Division in Denver, Colorado. The orbiter payload will consist of six science instruments and three new engineering payload elements listed as follows:

*Science Instruments*

- HiRISE, High Resolution Imaging Science Experiment

- CRISM, Compact Reconnaissance Imaging Spectrometer for Mars

- MCS, Mars Climate Sounder

- MARCI, Mars Color Imager

- CTX, Context Camera

- SHARAD, Shallow (Subsurface) Radar

*Engineering Payloads*

- Electra UHF communications and navigation package

- Optical Navigation (Camera) Experiment

- Ka Band Telecommunication Experiment

To fulfill the mission science goals, seven scientific investigations teams were selected by NASA. Four teams (MARCI, MCS, HiRISE, and CRISM) are led by Principal Investigators (PI), each responsible for the provision and operation of a scientific instrument and the analysis of its data. The MARCI PI and Science Team also act to provide and operate, as Team Leader (TL) and Team Members, the CTX facility instrument that will provide context imaging for HiRISE and CRISM, as well as acquire and analyze independent data in support of the MRO scientific objectives. The Italian Space Agency (ASI) will provide a second facility instrument, SHARAD, for flight on MRO. ASI and NASA have both selected members of the SHARAD investigation team. In addition to the instrument investigations, Gravity Science and Atmospheric Structure Facility Investigation Teams will use data from the spacecraft telecommunications and accelerometers, respectively, to conduct scientific investigations.

The MRO shall accomplish its science objectives by conducting an integrated program of three distinct observational modes:

- Daily global mapping and profiling observations

- Regional survey observations, and

- Globally distributed, targeted observations

These observation modes will be intermixed and often overlapping. Some instruments have more than one observational mode. In addition, many targeted observations will involve nearly simultaneous, coordinated observations by more than one instrument. This program of scientific observation will be carried out for one Mars year or more in order to characterize the full seasonal variation of the Martian climate and to target hundreds of globally distributed sites with high potential for further scientific discovery.

Mission Success Criteria

The following mission success criteria have been established for the MRO Project. The mission success criteria are described and controlled in the MRO Project Implementation Plan.

For Full Mission Success, the following criteria must be met:

- Operate the orbiter and all six (6) science instruments in the Primary Science Orbit in targeting, survey and mapping modes, as appropriate, over the one Mars year of the Primary Science Phase; conduct the gravity and accelerometer investigations. Each science instrument shall have capabilities that meet or exceed their respective science instrument requirements.

- Return, over the one-Mars-year Primary Science Phase, representative data sets for each instrument for a total science data volume return of 26 Tbits or more. Included in the returned data volume shall be information describing hundreds of globally distributed targets.

- Process, analyze, interpret, and release data in a timely manner, including archival of acquired data and standard data products in the PDS within 6 months of acquisition or as negotiated in the Science Data Management Plan (JPL D22218).

- Conduct relay operations for U.S. spacecraft launched to Mars in the 2007 and 2009 opportunities.

For Minimum Mission Success, the following criteria must be met:

- Operate the orbiter and its science payload in targeting, survey and mapping modes, as appropriate, in the Primary Science Orbit during the one-Mars-year of the Primary Science Phase; conduct gravity and accelerometer investigations. Science instruments shall have capabilities that meet their respective science instrument requirements.

- Return 10 Tbits of science data from HiRISE or CRISM or from their combined operations, plus 5 Tbits of representative science data over the one-Mars-year Primary Science Phase from at least 3 of the 4 other instruments (CTX, MARCI, MCS, SHARAD); conduct gravity and accelerometer investigations. Included in the returned data volumes shall be information describing 100 or more globally distributed targets.

- Process, analyze, interpret, and release data in a timely manner, including archival of acquired data and standard data products in the PDS.

- Conduct relay operations for U.S. spacecraft launched to Mars in the 2007 and 2009 opportunities.