An Overview of the Mars Reconnaissance Orbiter Mission

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Abstract–The Mars Reconnaissance Orbiter (MRO) will be launched in August 2005 by an intermediate-class, expendable launch vehicle from Cape Canaveral Air Station, USA. It will deliver to Mars orbit a payload to conduct remote sensing science observations, characterize sites for future landers, and provide critical telecom/navigation relay capability for follow-on missions. The mission is designed to provide both global and targeted observations from a low 200 by 400 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 infrared high-resolution images of the planet's surface. 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 ends on December 31, 2010, approximately 5.5 years after launch.

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Introduction

The understanding of Martian evolution and the processes occurring on its surface today are in flux. The Viking mission enabled a major step forward in our knowledge of the planet, but at the same time generated new questions and mysteries that today's missions are still attempting to answer. The overarching goal of NASA's Mars Exploration Program (MEP) is to address some of those mysteries in order to determine whether life ever existed on Mars. The scientific objectives established by the have four major themes linked by a common strategy. The themes are:

- Search for evidence of past or present life;
- Understand the climate and volatile history of Mars;
- Understand the geology and geophysics of the Martian surface and subsurface; and
- Assess the nature and inventory of resources on Mars in anticipation of human exploration.

The strategy that links these themes is the search for water. Water is key to the origin, development, and sustenance of life as we know it on Earth. It is a crucial aspect of the planet's climate and a major agent in the modification of its surface over geologic time. Water is a resource that can be exploited in the future when humans go to Mars.

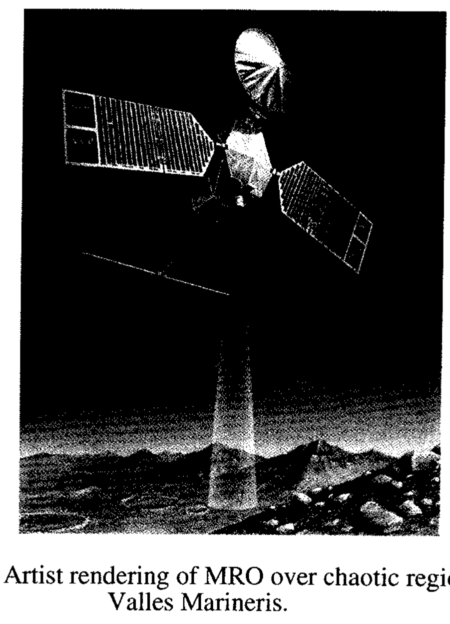

Figure 1. Artist rendering of MRO over chaotic region of Valles Marineris.

By capitalizing on advances in spacecraft technology and launch vehicle capability, NASA MEP is planning more ambitious missions in the upcoming decade to address these critical themes. Landers launched in 2003 and 2007 will provide unprecedented in situ measurements of surface properties; however, these measurements cover relatively small geographic areas on the Martian surface. To expand the critical measurement suite and extrapolate these ground truth measurements from landing sites to the entire planet, the MRO mission is planned for launch in 2005. An artist rendering of the MRO spacecraft in Mars orbit is shown in Figure 1.

Imaging the surface at a resolution five times better than any prior mission, MRO will dramatically expand our understanding of Mars. The reference science payload for the mission consists of a high-resolution imager (capable of resolving $\leq$30 cm/pixel at 200 km altitude), a visible/near infrared imaging spectrometer, an atmospheric sounder, a subsurface radar sounder, and a context optical imager. The engineering payload consists of the telecommunications package, that will provide a proximity link to the surface and approach navigation support, and an optical navigation camera that will demonstrate precision entry navigation capability for future landers.

In addition to conducting detailed global and local science investigations, the payload suite will characterize sites for future landers. In this role, the images from the payload suite perform double duty. They will both image potentially hazardous terrain and obstacles in candidate landing sites as well as identify interesting mineral and geological formations that are attractive targets for a lander to visit.

The downlink data rate from Mars to Earth has always constrained the total science return from Mars missions. Driven by limited onboard power, the physical size of the aperture, and launch vehicle capability, the overall science return from many recent missions has been strangled. The MRO mission takes advantage of advances in launch vehicle capability and spacecraft technology, such as increased onboard data throughput and solid-state data storage, to increase by an order of magnitude the returned data volume and, consequently, the coverage and resolution of the surface. Enabling this level of returned data volume challenges not only spacecraft design but also the ability to process and distribute the data products on the ground.

2. Requirements

The science and engineering payloads support three broad objectives: science investigation, site characterization, and telecommunications (relay) support.

MRO Science Investigation

In support of detailed science investigations, the orbiter will conduct remote sensing of the surface for one Martian year (approximately 687 Earth days). The science measurements will enable the following theme-related objectives to be achieved:

- Understand the present climate and geology of Mars and the processes that control them:
  - Characterize the seasonal cycles of water, dust, and carbon dioxide;
  - Characterize the Martian atmosphere in terms of its thermal structure, mass transport, and interaction with the surface;
  - Map in detail surface stratigraphy and composition;
  - Probe the subsurface of Mars to survey its geologic variability and to search for evidence of present day near-surface liquid water and ice;
  - Explore the subsurface structure of the polar caps and adjacent layered terrain.
- Understand the past climate of Mars and the role of water:
  - Search for sites showing evidence of aqueous mineralization;
  - Observe detailed geomorphology and stratigraphy of key locales to characterize features indicating the presence of liquid water on the surface of Mars at some point in the planet's history.
- Identify regions and locales of exceptional scientific interest for future exploration:
  - Remotely explore hundreds of local areas on Mars at unprecedented spatial and spectral resolution;
  - Search the surface and subsurface for anomalous regions of high scientific interest.

MRO will also produce the climate science data sets that were to have been provided by the Mars Climate Orbiter (MCO) payload. When combined with data sets from two other Mars missions, NASA's Mars Global Surveyor (MGS) and ESA's Mars Express, MRO will also help characterize diurnal, seasonal, and interannual climate variability by observing at different local times and during a different Mars year than the other two missions.

MRO Site Characterization

- Enhance future mission success by finding the sites of greatest interest and scientific promise:
  - *Find exciting new sites* for exploring the surface or subsurface;
  - *Characterize all key sites* to support the design and implementation of future missions.

Only a small percentage of the Martian surface will have been surveyed at high spatial resolution (resolutions <10 m/pixel) by the time of the MRO launch. Thus, a primary goal for MRO is to find and characterize the locales on Mars that will become the primary targets for future spacecraft missions to Mars. This examination of the surface will serve two purposes: to identify hazards to landers and to locate scientifically interesting sites for in situ investigations. Figure 2 depicts the resolution differences between the best images of the surface from orbit to date and that planned for MRO.

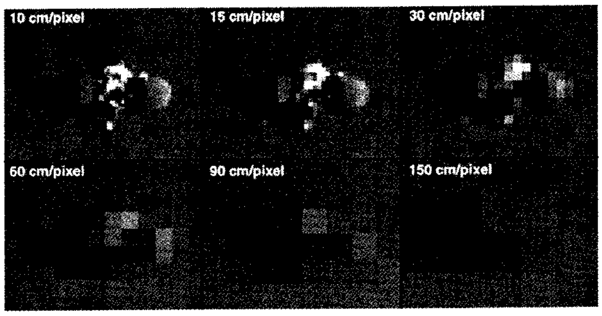

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Figure 2. Differences in resolution of features on Martian surface. 150 cm/pixel is the best any camera has achieved to date. 30 cm/pixel is the required MRO resolution.

MRO Relay Support

- Relay data from other Mars missions while MRO is operating at Mars:
  - Increase the amount of data that can be returned from landed assets by using MRO as a telecommunications relay spacecraft;
  - Reduce the power required for data return from landed assets by allowing power needed for direct-to-Earth communications to be split between orbital relay and enhanced surface activities (e.g., roving, drilling, observing);
  - Provide a navigational capability that can enhance the accuracy of Mars atmospheric entry or Mars orbit insertion.

The third major objective is to provide a relay link from the surface of the planet back to Earth and to support incoming missions with navigation measurements. Future landers will require accurate entry into the Martian atmosphere in order to support the tight landing area requirements. MRO will provide Doppler measurements by receiving the traditional downlink signal from the incoming spacecraft, thereby providing a measurement of spacecraft position and velocity that is independent of Earth-based tracking. After landing, one of the largest problems is getting high data volume off the surface of Mars and back to Earth. Carrying an UHF transceiver common to other spacecraft such as Mars Express, MRO is part of a new telecommunications infrastructure that will dramatically increase the bandwidth from the surface of Mars to Earth.

3. PAYLOAD DESCRIPTION

Science Instruments

To achieve the scientific objectives outlined above requires the development of many new science instruments. The instruments are functionally divided into global mappers, regional surveyors, and high-resolution, targeted imagers. The MRO science payload will include the following instruments:

- High-Resolution Imager
- Visible-Near Infrared Imaging Spectrometer
- Atmospheric Sounder
- Wide-Angle Color Imager
- Shallow Subsurface Sounding Radar
- Context Imager

The Wide-Angle Color Imager and Atmospheric Sounder are reselections of investigations flown on the MCO spacecraft, and the experiments are designed to achieve the climate objectives outlined earlier. These two instruments are the global mappers. They are mounted on the nadir facing deck and have science views both to nadir and the limb. Both instruments have relatively low data rates. The sounder operates continuously throughout the orbit. Although specific allocations have not been made, together they are expected to use 10% or less of the available data bandwidth. The Wide Angle Camera will conduct low spatial resolution observations of the atmosphere and the surface in six multicolor channels. The Mars Climate Sounder (previously called PMIRR) profiles the atmosphere through a combination of limb and on-planet sounding with 5 km vertical resolution.

New targeting instruments include a High Resolution Imager and a Visible-Near IR Spectrometer. The Imager will observe selected areas at resolutions five times better than instruments having flown prior to MRO. These instruments require precise along track timing, as well as cross tracking pointing of up to 30° from the orbiter to enable imaging of a vast number of high priority targets on the surface.

The High Resolution Imager observes targeted swaths of Mars which are a few kilometers wide and tens of kilometers long at unprecedented spatial resolutions, varying from 30 to 60 cm/pixel as the spacecraft altitude varies from 200 to 400 km in its near-polar, moderately elliptical orbit. The periapsis will walk around the planet in a 60-day cycle, providing opportunities to view nearly all sites from altitudes less than 250 km. Prior to the arrival of MRO, the highest spatial resolution achieved by previous spacecraft (MGS and Mars Express) will have been ~ 1.5 m.

The MRO Imaging Spectrometer will have a spatial resolution on the order of 25 to 50 m from an altitude of 200 to 400 km, as compared to a resolution of a few hundred meters for the Mars Express instrument. The 200 km swath width is >5 km. This scale enables a search for evidence of prior hot springs, thermal vents, or lakes and ponds. If water were present for an extended time in such regions, it should have left deposits of minerals whose spectral signature can be detected at near-infrared wavelengths. The spectrometer's resolution and 0.4 to 3.6 microns wavelength range permits observations for these features.

Another camera, called the Context Imager, will provide panchromatic context imaging for the high-resolution targeted observations by observing simultaneously with the High Resolution Imager and the Imaging Spectrometer, but at an intermediate resolution of 4 m/pixel at 200 km and a swath width of 20 km. MRO's radar sounder operates at frequencies near 10 MHz. This radar complements measurements by the radar on Mars

Express, which will operate at lower frequencies, and plans to penetrate up to a few kilometers into the ground. The depth of penetration for the MRO radar (< 1 km) will be shallower than that of the Mars Express radar, and so MRO will probe the near-surface structure and composition. The radar will have vertical and horizontal resolutions of 10 m and 2 km, respectively The detection of anomalous regions, which may reflect ground ice or even subsurface liquid water, will help to focus the targeting of surface observations from MRO and support the design of future landed missions. In addition, the profiling of the Martian permanent polar caps by the MRO and Mars Express radars will yield new, more definitive observations with regard to subsurface structure and the presence or absence of liquid water near the icy surface. The context imager and the radar are the two regional investigation instruments.

Science Investigations Using Engineering Hardware

In addition to the instrument investigations, there are several facility investigations utilizing data generated from spacecraft hardware. Tracking the spacecraft while it is in both the aerobraking phase and the primary science phase provides the opportunity to map the gravity field in great detail. Better knowledge of the gravity field provides greater insight into the geological structures of the surface and near-surface and into the geophysical processes that produce them. Using the ultrastable oscillator in conjunction with spacecraft downlink enables investigation of the atmosphere through the use of radio occultation data. Finally, the recording of accelerometer data allows for determination of atmospheric drag effects during the period in which the spacecraft aerobrakes into its primary science orbit, providing a unique characterization of atmospheric structure at high altitudes (~100 km). This approach enables an understanding of high altitude processes, such as the loss of water vapor to space, and a characterizing of the environment that future missions will encounter.

One of the more challenging aspects of MRO's operations in its science campaign will be the choice of localized regions for high spatial resolution images. This selection will be done using data sets from previous missions like MGS, Odyssey, and Mars Express and using data from MRO itself. In addition, MRO will target past landing sites, such as Viking, Pathfinder, and the Mars Exploration Rovers, both to characterize these sites further and to compare the remotely sensed and in situ data. Landed investigations have the greater measurement sensitivity than near-field and in situ instrumentation can provide, while the orbiter benefits from its regional and global reach. This mutual validation of the landed and orbital remote sensing data is an important part of the MEP. With its unprecedented spatial and spectral resolutions, MRO science instruments can close the resolution gap between orbital and landed measurements, while continuing to characterize hundreds of globally distributed targets throughout its mission.

Engineering Instruments

The engineering instruments consists of the telecommunications package (called *Electra*) that provides the proximity link to the surface and approach navigation support, and an optical navigation camera that demonstrates precision entry navigation capability for future entry vehicles. The telecommunications package provides a near omni-directional coverage of both surface and orbiting assets. It contributes navigational-related data in the form of one-way Doppler measurements through the use of its Ultra Stable Oscillator and two-way Doppler measurements through the use of a transponder on the corresponding spacecraft or landed asset. It also provides one- and two-way ranging measurements.

Working at UHF band, the transceiver supports forward and return simplex and full-duplex links. It is a store and forward system enabling communications with assets not in view of the Earth. The mass allocations for the different payload elements are in shown in Table 1.

Table 1. Payload description and mass allocation.

Name	Type	Resolution @ 200 km	Swath @ 200 km	Other	Mass (kg) w/o margin	Orbital Average Power (W)
HiRise	Optical Targeted	25 cm/pixel	5 km	3 colors	31	< 50
CRISM	Optical Targeted	12 m/pixel	6.4 km	0.4 - 4.0 μm	23	30
Context Imager	Optical Regional	4 m/pixel	20 km	Panchromatic Minus Blue	4	4
Sounding Radar (SHARAD)	Regional	< 1000 m (w) < 20 m (v)	20 km (w) 1 km (v)	20 MHz Center 10 MHz Bandwidth	12	< 50
MARCI WA	Optical Mapping	1 to10 km/pixel	limb-to-limb	0.25 - 0.75 μm	1	3
MCS	Atmospheric Mapping	~ 5 km vertical	0-80 KM	12 - 50 μm 0.3 - 3.0 μm	6	8
OpNav	Optical Targeted	24 μrad/pixel Phobos/Deimos	--	0.45 - 0.6 μm	3	3
Electra	Radio	--	--	UHF	15	40
TOTAL					95	n/a
Legend:	Science	Engineering				

4. Mission Design

The 2005 Mars launch opportunity is the most demanding one of the decade from the point of view of required injection energy. With a required injection energy (C_3) of 18.1 km^2/s^2 to a declination of the launch asymptote of 40° for a throw mass of 1800 kg, the mission requires one of the new intermediate class expendable launch vehicles: Atlas 3 or 5, or Delta IV. The launch period is three weeks long beginning August 8 and ending August 28, 2005. The seven-month type 1 trajectory results in an arrival period with a duration of nine days from March 3-11, 2006. The mission overview of events is shown in Figure 3 a and b.

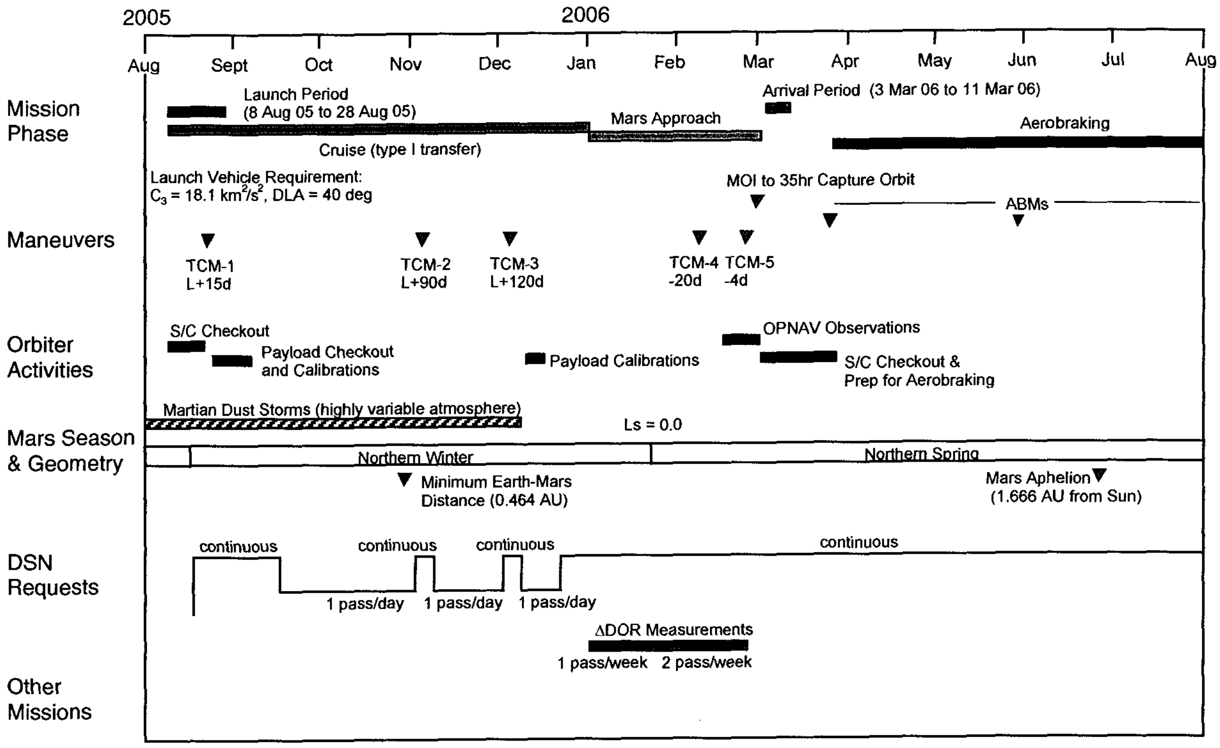


Figure 3a. MRO mission overview - The period covered is from launch through start of aerobraking.

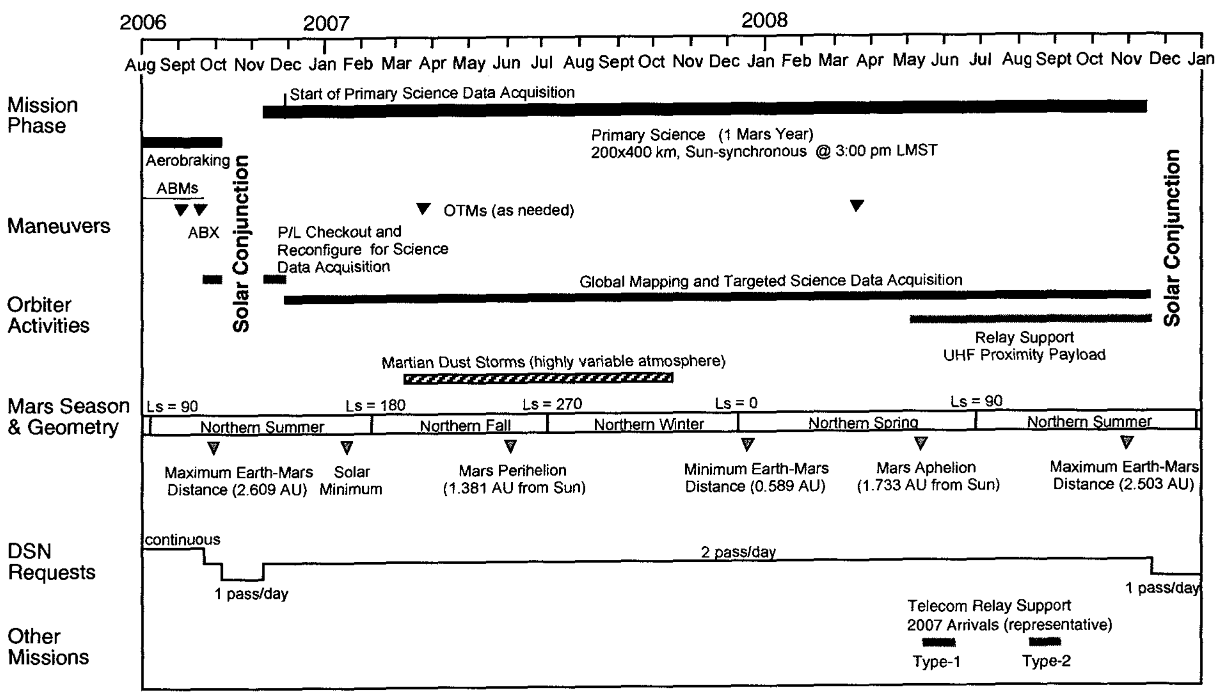


Figure 3b. MRO Mission overview covering from aerobraking through the end of the primary science phase. (Relay phase not shown)

The interplanetary cruise trajectory is ballistic and requires no large deep space maneuvers. Several (five at present) small trajectory change maneuvers are planned for this phase. During cruise, orbiter and instrument checkout and calibration are performed.

On approach to Mars, the OpNav camera images the moons of Mars against the star background. This data is not critical to the success of the MRO Mars orbit insertion but it does provide data for confirmation of algorithms and software code for the camera's use in future missions. No additional instruments will be operated on Mars approach.

MRO approaches the planet toward the South Pole with 3 km/s of excess hyperbolic velocity. Mars Orbit Insertion (MOI) requires 1100 m/s delta V to insert into a 35-hour highly elliptical orbit with a periapsis altitude of 300 km and an ascending node at 9:00 p.m. local mean solar time (LMST). Six months have been allocated to perform aerobraking to reach the final primary science sun-synchronous orbit of 200 x 400 km. The final science orbit is near polar with an inclination of 92.8°. During the aerobraking phase, the orbit equator crossing time moves from the 9:00 p.m. arrival node to the science node of 3:00 p.m. ± 15 min (both ascending). The main advantage of the 200 x 400 km elliptical orbit over the 400 km near-circular orbit used on previous missions is the potential increase in ground spatial resolution by up to a factor of 2. High-resolution observing can still be targeted globally since the gravity field of Mars will move the periapsis latitude around the planet, as shown in Figure 4. In the baseline orbit, the periapsis rotates once around the planet every 60 days. The equator crossing time is a compromise between the desires of the visible imaging objectives, which favor later crossing times (e.g., 4:00 p.m.) for the surface contrast provided by low sun angles, and those of the spectrometer objectives, which favor a midday crossing to increase the amount of reflected light, i.e., better signal-to-noise.

The primary science phase will last approximately one Martian year (687 Earth days). During this phase, there will be 16 hours per day of coverage provided by the Deep Space Network 34 m stations via X-band. The Martian year of coverage enables all seasons to be covered, thereby satisfying one of the key science objectives. The completion of the primary science phase ends formal operation of the instruments, and the science investigators have six months to complete processing of all their data and provide the complete data set to the Planetary Data System for archiving. Science investigation may continue after this point but only if an extended mission is approved. Orbiter design allows for simultaneous operation of the UHF relay and the science instruments. Upon completion of the science phase, the relay phase, lasting one Mars year, will commence when the orbiter will support landers and incoming spacecraft. At the end of its useful life, the orbiter will be transferred to a circular 430 km orbit to satisfy planetary quarantine requirements. The prime mission will end on December 31, 2010, roughly 5.5 years after launch. However, the spacecraft will be loaded with enough propellant to last for ten years of operation.

Both after aerobraking is completed and near the end of the primary science orbit, superior conjunction will interrupt communications between the orbiter and Earth. Conservatively, communications will be lost for approximately one month. During that period the spacecraft will be safed, although a study will be performed later this year to see if the orbiter can maintain limited data acquisition for the global mapping instruments.

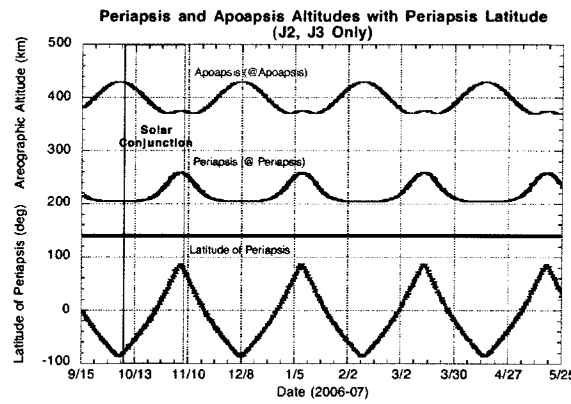


Figure 4. Variation in both latitude of periapsis and altitudes over a typical nine-month span

5. Mission Operations

Mission planning, navigation, sequence and command generation, and real-time operations are conducted by a combined team from JPL, the orbiter contractor, and the instrument providers. The MRO ground system will receive and distribute the raw data from the stations to the appropriate organizations. The orbiter contractor provides engineering support, including trend analysis, anomaly investigation and recovery, orbiter health and welfare monitoring, performance calibration, and engineering sequence and command request generation. The Principal Investigators (PIs) provide science command request and perform data processing and analysis from their home institution.

The mission will use X-band and has baselined the use of 34 m BWG stations. The 70 m stations will be used for emergencies and to enhance science return whenever it can be reserved. The comparison of data rates over the different earth to mars distances to the 34 m and the 70 m stations are shown in Figure 5.

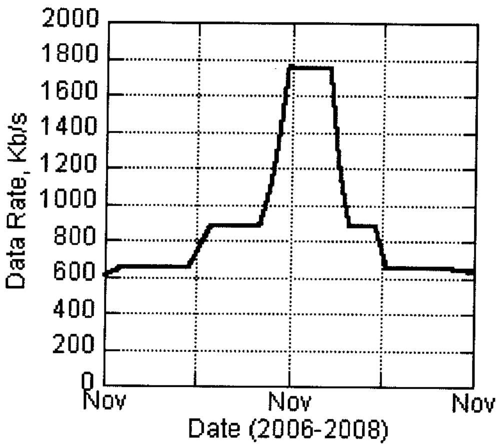


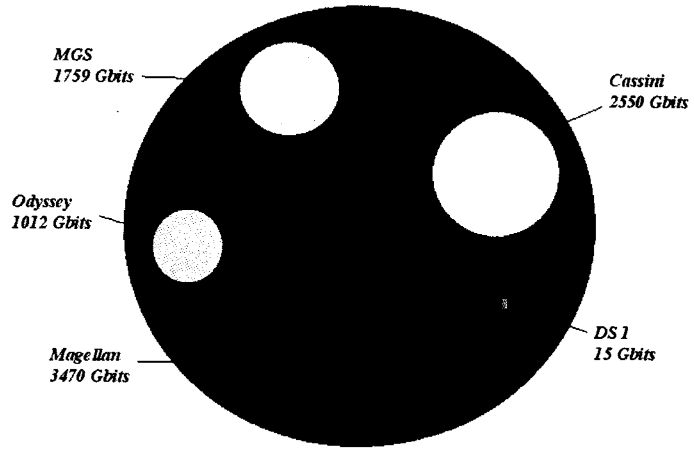
Figure 5. Comparison of data return rate to both a 34 m (lower line) and a 70 m (upper line) antenna as function of Mars-to-Earth distance.

Tracking capability includes one- and two-way coherent Doppler, ranging, commanding, and telemetry transfer. During the cruise phase, coverage is planned for one 8-hour pass per day, except around the TCMs, where coverage will be continuous. For Mars orbit insertion and the aerobraking phase, coverage is continuous. The primary science phase requires two 8-hour passes; while in the relay phase only one pass/day is planned.

A unique aspect of the MRO mission is the volume of data generated in comparison to other planetary missions. For the current mission concept, the average daily volume varies from 16 to 126 Gb/day, depending on the Earth-to-Mars range. At the maximum range of 2.67 AU, the minimum data rate to a 34 m DSN antenna is 500 kb/s. At these rates and volumes, MRO will return over ten times the data volume of Cassini and almost 25 times that of Odyssey, as shown in Figure 6.

This data volume creates a challenge not only in flight but on the ground. A study is planned for later this year to determine the most economical way for data to be processed and distributed, given the recent advances in data transfer. The present baseline, a decentralized approach, distributes the raw instrument data to the PI's processing facility, has that facility conduct the processing, and then redistributes the data to co-investigators. All major products are sent to the Planetary Data Centers for archiving. In the second concept, a centralized facility is used to process all the data. This facility uses software developed and controlled by the PIs but hosted on machines at this central site. After processing, the higher level data are transmitted to the PI's for analysis. In both cases, the project copies the raw data as it comes from the stations and archives it. The cost of transmission and of processing and maintaining the platforms are key factors in the trade study. The capability of the Planetary Data Archive System to handle these data volumes is presently under examination.

Figure 6. Comparison of total data returned during prime



science phases of various planetary missions.

6. Orbiter Description

The Orbiter for this mission is a new design which builds upon the lessons learned through 40 years of Mars Exploration. The design focuses on operability, aerobraking robustness and high rate communications.

The Orbiter is captured into Mars orbit via a propulsive maneuver. This is accomplished using 6 monopropellant hydrazine thrusters. The number was selected to minimize gravity losses and to allow for tolerance of a single engine failure.

The Orbiter must undergo hundreds of passes through the upper atmosphere during aerobraking. Therefore, the Orbiter design utilizes symmetric solar arrays that are swept back during atmospheric drag passes. This configuration allows for three axes of passive stability, ensuring vehicle safety even in the event of an anomaly. The very large area (~ 40 square meters) allows for very shallow passes and very large aeroheating margins.

In order to support the demands of the science payload, the Orbiter I/O system is designed to move large amounts of data via low-voltage differential signal serial ports capable of transferring up to 100 Mb/s peak. This data path can be shared by any combination of the instruments.

The payloads have access to 128 Gb of volatile mass memory allowing for storage of large volumes of data. In addition, payloads may utilize up to 20 MIPS of processing power from the spacecraft computer. The computer will use a new version of the RAD750 central processor that has been developed for use on other JPL missions such as

Deep Impact. The computer, like many spacecraft systems, will be redundant to avoid mission loss due to single point failures.

The data is returned to Earth via high. medium and low gain antennas. The high gain antenna (HGA) will be 3.0 meters in diameter. The Small Deep Space Transponder developed by JPL and General Dynamics is used at X-band. When coupled to a 100W traveling wave tube amplifier, very high data rates and thus very high data volumes can be achieved. Rates range from ~ 500 kbps at maximum Mars-to-Earth range to 2.0 Mbps at minimum range into a Deep Space Network 34 meter antenna. Higher rates may be possible depending upon the availability of the 70 meter antennas and the needs of other spacecraft. Two 8hr/day passes are expected during the primary science phase. Engineering telemetry is available during all mission critical events at greater than 40 bps. The transponders will include Ka-band transmit capability which when mated to a 35W amplifier capable of data rates comparable to the X-band system. It is expected that this system will be employed periodically to demonstrate Ka-band communications and to supplement the science data return.

The imaging instruments necessitate a spacecraft bus that is capable of highly accurate and stable pointing. The Orbiter is capable of pointing <0.7 mrad (3 sigma, roll) and <1.0 mrad (3 sigma, pitch and yaw) with its reaction-wheel based attitude control system. The instruments will be mounted on a nadir facing deck for the normal "pushbroom" mode. The orbiter attitude control system will have the ability to point up to 30° off-nadir via shaped slews several times per orbit allowing for targeting and motion compensation. Fuel needs (once in orbit) will be limited to momentum desaturation. The Orbiter will be loaded with enough fuel for a 10 year lifetime, allowing for an extended mission phase.

The Orbiter will be built by Lockheed Martin Space Systems Astronautics Operations of Denver, CO. Lockheed Martin has been JPL's partner in Mars exploration for such missions as Mars Global Surveyor and the currently aerobraking 2001 Mars Odyssey.

7. Implementation

The MRO mission is managed by the Jet Propulsion Laboratory, and its implementation relies heavily on the capabilities of industry and academia. The orbiter contractor develops the bus, performs payload accommodations, and provides launch and operations support. The launch vehicle is procured by the Kennedy Space Center via the newly defined NASA Launch Services contract. The major elements of the payload are competed via an Announcement of Opportunity issued by NASA Headquarters.

8. Schedule

Starting in December 2000, the project is in Formulation Phase for 19 months. This phase is divided into Phase A, which lasts until January 2002 when the Preliminary Mission and System Review is held, and Phase B, which extends 6 months until completion of the Preliminary Design Review in July 2002. The Implementation Phase extends for approximately three years until the August 2005 launch plus 30 days. The cruise phase lasts for seven months, Mars Orbit Insertion and aerobraking another six months, the primary science mapping phase for one Martian year (~two Earth years), and the relay phase for another Martian year.

9. Summary

MRO represents the first in the new generation of Mars missions utilizing the capability provided by the new class of intermediate class launch vehicles. It enables resolution of the Martian surface at an order of magnitude beyond any other mission. Its global viewing and targeted instruments provide critical data to support both a myriad of scientific investigations and site characterization for future landers. The engineering payload provides support to future missions by testing the experimental optical navigation camera and by operating telecommunications relay equipment.

10. Acknowledgements

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11. Bibliography

Jim Graf received a BSE from Princeton University in 1972 and an MS from Colorado State University in 1976. He has been employed in various space-related developments for 28 years, ranging from the development of ion thruster technology to the management of the Quick Scatterometer Mission, an Earth orbiting satellite that was ready to launch within one year of formal go-ahead. He is the recipient of NASA's Outstanding Leadership Medal and an Aviation Week's 1999 Laurel for Space. Currently, he is the manager of the Mars Reconnaissance Orbiter Project.

Ross Jones has a B.S. degree from Purdue University and a M.S. degree from Massachusetts Institute of Technology in Aeronautical and Astronautical Engineering and has been with the Jet Propulsion Laboratory for 22 years. Currently Mr. Jones is the project system engineer for the Mars Reconnaissance Orbiter [MRO] project. Prior to MRO assignment, he was MUSES CN project manager at JPL. Mr. Jones was the supervisor of the Advanced Flight Systems Group in the Mission and System Architecture Section from 1990 to 1997 during which time he was the leader in the creation of the concept of microspacecraft for planetary missions. Mr. Jones has also worked in the Mission Design Section and Power Systems Sections at JPL. Mr. Jones has authored 20 papers on various aspects of advanced mission and technology concepts for planetary exploration

Dan Johnston received a B.S. in Aerospace Engineering from the University of Texas in 1984 and an MSE from the University of Texas in 1989. Since joining JPL in 1989, he has participated in the development and flight operations phases of the Mars Observer and Mars Global Surveyor missions. He is a recipient of NASA's Exceptional Achievement Medal for the aerobraking operations planning of Mars Global Surveyor. Prior to joining JPL, Dan worked for McDonnell Douglas Astronautics in Houston, TX in support of STS (Shuttle) rendezvous flight planning. Currently, he is the Mission Design Manager of the Mars Reconnaissance Orbiter Project.

Howard J. Eisen received a B.S. and an M.S. in Aeronautics and Astronautics and a B.S. in Physics from M.I.T. He has worked on a variety of missions orbiting the Earth and landing on Mars including the Mars Pathfinder Sojourner Rover. He is the recipient of the JPL Award for Excellence in Leadership and has twice been awarded the NASA Exceptional Achievement Medal. He is currently the MRO Flight System Manager.