Mission Design Overview for the Mars Exploration Rover Mission

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ABSTRACT
FOR
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Extended Abstract

Introduction

In the summer of 2003, NASA will launch the next wave of robotic explorers towards the planet Mars. Specifically designed to "follow the water", two identical rovers will be delivered to the surface of Mars to remotely conduct geologic investigations. The two self sufficient mobile science laboratories will be able to traverse large distances (over half a kilometer) during their 3 month surface missions while performing in situ analysis of a number of rock and soil targets which may hold clues to past water activity. The project, appropriately named the Mars Exploration Rover (MER) project, will conduct fundamentally new observations of Mars geology, including the first micro-scale study of rock samples, as well as a detailed study of surface environments for the purpose of calibrating and validating orbital remote sensing data.

Developing a baseline strategy for successfully achieving the objectives of such an ambitious mission involves integrating a variety of activities and analyses into a coherent plan. These activities include: interplanetary trajectory and navigation design, atmospheric entry, descent, and landing (EDL) design, and mission planning, particularly with respect to developing various scenarios for operating in an unknown environment on the surface. These activities, collectively referred to as mission design, are described in chronological order as the mission progresses through six mission phases: Launch, Cruise, Approach, EDL, Post-Landing through Egress, and Surface Operations.

Mission Description

The Mars Exploration Rover project will use the 2003 launch opportunity to deliver two mobile science laboratories to different sites in the equatorial region of Mars. For at least 90 sols after the landing day, the two rovers will explore the landing sites and gather imaging, spectroscopy, composition data, and other measurements about selected Martian soils, rocks, and the atmosphere. The two identical flight systems each consist of an Earth-Mars cruise spacecraft (or cruise stage), an atmospheric entry delivery system similar to the one used to deliver the Mars Pathfinder lander to the surface of Mars in 1997, and a mobile science rover with an integrated instrument package. The launch mass for each flight system is 1063 kg. Figure 1 illustrates the various components of the MER flight system.

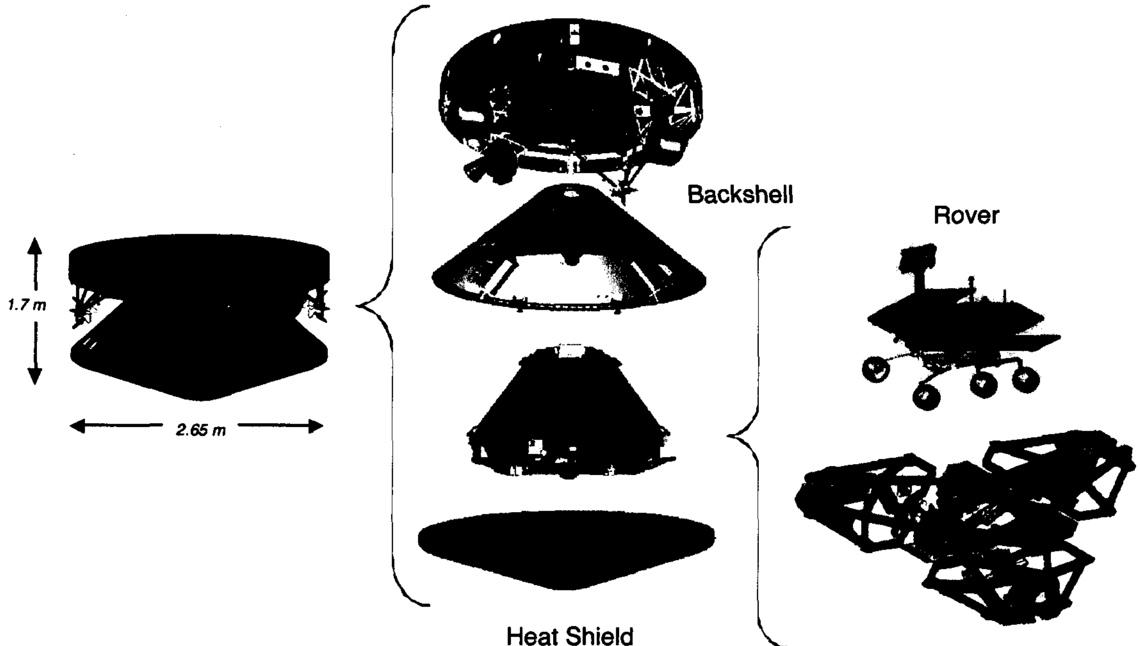


Figure 1. MER Flight System

The first Mars Exploration Rover (MER-A) will be launched using a Boeing Delta II 7925 launch vehicle from Space Launch Complex 17A (SLC-17A) at the Cape Canaveral Air Force Station (CCAFS) in Florida. The second MER mission, MER-B, will be launched using a more powerful version of the Delta II launch vehicle, the Delta II 7925H, from SLC-17B at the Cape. Both missions utilize 18-day launch periods and constant arrival dates at Mars in order to simplify operations. The launch and arrival dates are indicated below:

Mission	Launch Period Open	Launch Period Close	Mars Arrival
MER-A	May 30, 2003	June 16, 2003	January 4, 2004
MER-B	June 25, 2003	July 12, 2003	January 25, 2004

The two launch periods are separated by 8 days. In addition, each launch day has two instantaneous launch opportunities providing a high probability of liftoff within the back-to-back MER launch periods. The launch and arrival dates, which result in short, Type I trajectories to Mars (i.e. transfer angles less than 180°), were selected to satisfy a number of competing requirements and constraints, including staying within the performance constraints of the launch vehicles and maintaining line-of-sight visibility with Earth during EDL.

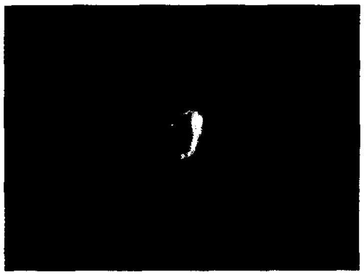
The MER mission is divided up into six distinct mission phases:

Phase	Definition	MER-A Open Phase Start	MER-B Open Phase Start
Launch	Launch to thermally stable, positive energy balance state	May 30, 2003	June 25, 2003
Cruise	End of Launch phase to Entry-45 days	May 31, 2003	June 26, 2003
Approach	Entry-45 days to Entry	November 20, 2003	December 11, 2003
EDL	Entry to end of critical deployments on Sol 1	January 4, 2004	January 25, 2004
Post-Landing Through Egress (PLTE)	End of EDL to receipt of Direct-to-Earth transmission on Sol 4	January 4, 2004	January 25, 2004
Surface Operations	End of PLTE to EOM	January 8, 2004	January 29, 2004
End-of-Mission (EOM)	Successful receipt of last scheduled UHF data return the night of Sol 91	April 6, 2004	April 27, 2004

During the approximately 7 month interplanetary flight, the MER spacecraft will be spinning at 2 rpm. As a result, periodic spin axis pointing updates will be required to maintain communications with Earth and to ensure adequate illumination of the cruise stage solar panels by the Sun for power as the relative positions of the Earth and Sun change during flight. In addition, flight system capabilities to be used during the Approach, EDL, and Surface Operations phases will be checked out during the Cruise phase.

Accurate navigation and delivery at Mars is critical to the success of the MER mission. Six Trajectory Correction Maneuvers (TCMs) are planned during the Cruise and Approach phases to remove the aimpoint bias introduced at launch (required to satisfy planetary protection requirements at Mars) and accurately deliver the rovers to their intended entry conditions. The delivery accuracy requirements for MER are much tighter than previous missions in order to ensure not only the safety and robustness of the flight system during atmospheric entry and descent, but also the safety of the vehicle upon impact with the ground. Smaller delivery errors result in smaller landing ellipses on the surface, which in turn make it easier to select safe, but also scientifically interesting sites.

Previous missions have relied almost exclusively on the use of two-way Doppler and range data to navigate their way to Mars. The MER mission, however, has taken advantage of the development of a new and improved ΔVLBI (Delta Very Long Baseline Interferometry) system within the Deep Space Network (DSN). By augmenting the traditional line-of-sight navigation measurements with angular, plane-of-sky measurements, delivery errors at Mars can be significantly reduced. As a result, the MER mission has baselined an intensive campaign of ΔVLBI measurements in order to meet the stringent entry flight path angle (FPA) delivery requirements. For all of the landing sites currently under consideration, the entry FPA delivery uncertainties are all less than or equal to ±0.25 deg (3σ) about a nominal inertial entry FPA of -11.5 deg assuming a final TCM at Entry - 2 days.



Similar to the Mars Pathfinder mission, the MER entry trajectory will follow an unguided, ballistic descent. It will rely on a heatshield and parachute to slow its descent through the Martian atmosphere, fire retro-rockets to reduce its landing speed, and finally deploy airbags to cushion its impact with the surface. After the airbag assembly rolls to a stop, the lander will retract the airbags, right itself, and deploy the lander petals. The rover will then perform critical solar array deployments. If completely successful up to this point, the rover will also attempt to deploy the non-critical (for immediate survival) camera mast and high gain antenna (HGA).

In contrast to the Mars Pathfinder mission, both MERs will land early in the Martian afternoon while the Earth is still in view, allowing the transmission of so-called M-FSK (Multiple-Frequency Shift Key) signal tones, coded to indicate the accomplishment of critical steps during the EDL timeline. (For comparison, Mars Pathfinder landed during the early Martian morning without the possibility of direct-to-Earth (DTE) communication). In addition to the X-band DTE signals, the Mars Global Surveyor (MGS) spacecraft will be called into duty to relay descent information via a UHF link. This link begins after bridle deployment and continues through impact with the Martian surface (and perhaps for a few minutes longer while MGS is still in view of the lander).

It will take at least through Sol 4 to complete the Post-Landing Through Egress phase. Egress of the 185 kg rover consists of a carefully choreographed series of steps by the rover, each initiated by the ground only after verification that the previous step has been successfully executed. The main egress activities for Sols 2-4 are deployment of the rover mobility system, severing the final cable connections with the lander, and surveying the Martian landscape with a stereo panoramic camera (Pancam) and infrared imager (Mini-Thermal Emission Spectrometer) for a safe egress path.

The Surface Operations phase is planned to run through Sol 91. Daily communication with Earth occurs through the rover's X-band LGA/HGA system. Communications will be augmented whenever Mars Odyssey or MGS overflights make UHF relays possible. Each rover will use a stereo pair of Navigation cameras (Navcams) in addition to the Pancam on the mast, to image prospective travel paths and science targets. Front and rear mounted stereo hazard cameras

(Hazcams) will assist the rover in autonomously traversing to a desired site. The rovers are capable of traveling as far as 40 meters in a single sol.

In addition to the long-range, remote sensing instruments mounted on the rover solar array deck, the rover is equipped with a 5 degree-of-freedom (DOF) arm, known as the Instrument Deployment Device (IDD). The IDD supports another set of instruments designed to closely observe or contact rock and soil targets. The four devices on the science turret at the end of the IDD are a Mössbauer spectrometer (MB), an Alpha Particle X-ray Spectrometer (APXS), a Microscopic Imager (MI), and a Rock Abrasion Tool (RAT). The IDD instruments will provide composition data about selected surface soil and rocks, including their elemental chemistry, iron content, and fine-scale morphology. The rock abrasion tool will remove the outer surfaces of rocks, to allow analysis of the freshly exposed, less weathered material. Surface operations will be directed by the flight team, in order to the select rock and soil targets that reveal the most about Martian development and to maximize science return.

Since the rover is solar powered, the life of the rover is driven by Mars' diurnal cycle, and thus, linked directly to sunrise and sunset. During the middle of a typical Martian day, called a sol, the rover might drive towards a target and/or take remote sensing data of the surface or of the atmosphere. It typically takes at least two, and often three sols to place an instrument on a specific target after the target has been selected by the flight team using remote sensing images. Mission scenarios show that each rover will be able to take detailed in-situ measurements of up to half a dozen individual targets during the 90 sol mission.

Towards the end of the Surface Operations phase, both power and telecommunications capabilities will be decreasing, as the Earth and the Sun become more distant from Mars, dust falls on the solar panels, the batteries lose capacity, and the Sun moves further North past the landing site latitude. The rover's ability to drive significant distances and the amount of time that the rover can stay awake each day will diminish with time. Eventually, somewhere near Sol 91 it is expected that the rover will be unable to store up enough thermal or battery energy to prevent its components' overnight temperatures from falling below their flight allowable levels. This will sooner or later result in failure of one or more of these components, silencing the rover forever.

A high-level overview timeline for the MER missions is given in Figure 2. The timing of the phases of the two missions are shown, relative to geometric data for Earth, Mars and Sun, and also relative to important concurrent events on other flight missions. The other flight missions shown on this timeline share part of the Mars viewperiod from Earth, which means that DSN assets must be allocated to support all of them. The Earth and Sun ranges indicate that, after the opposition in late August 2003, the distances to Earth and Sun increase rapidly throughout the remainder of both MER missions. This illustrates why both power and telecommunications resources decrease over time, leading to declining capability and data return until the end of surface operations.

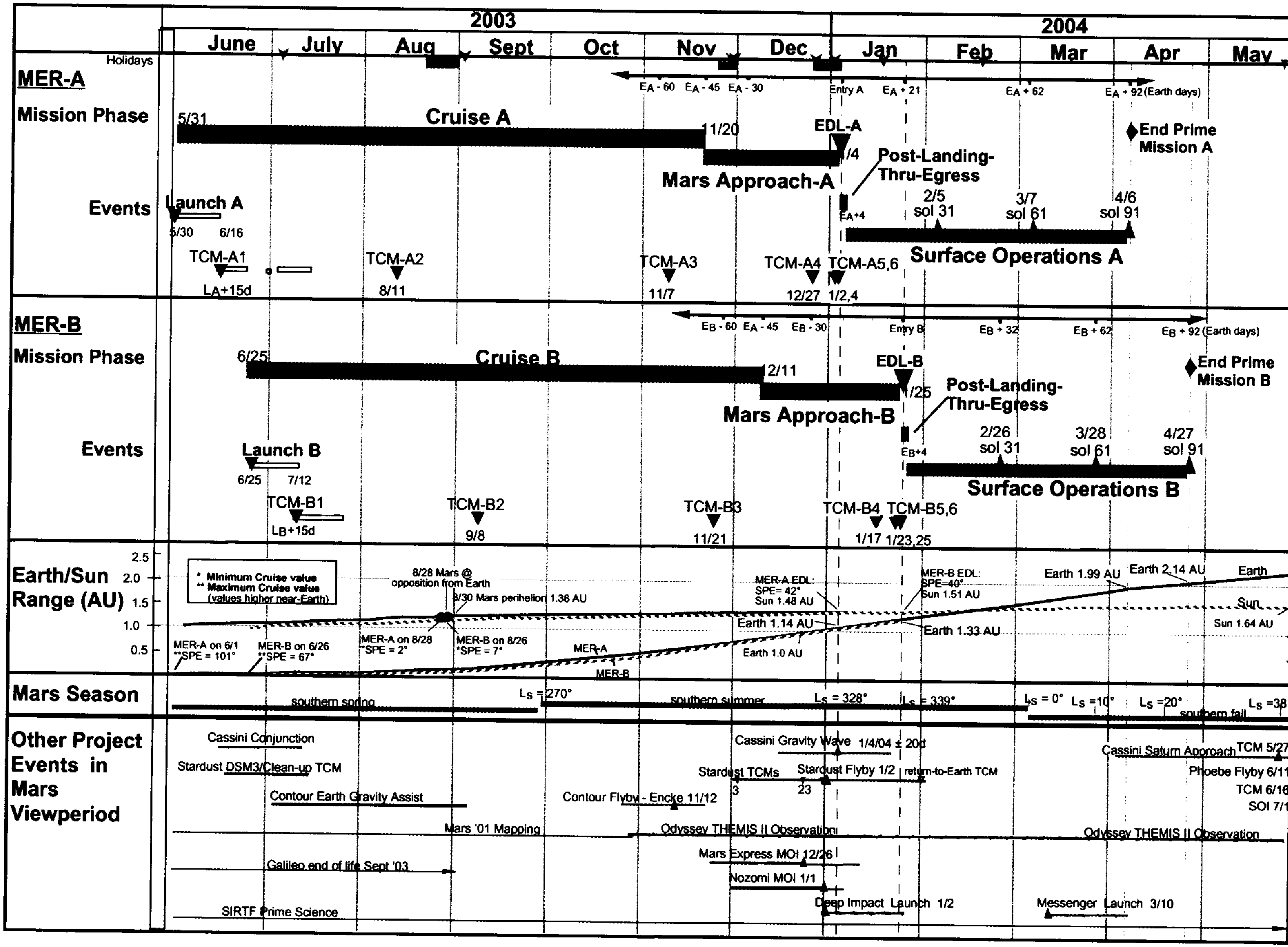


Figure 2. MER Mission Timeline

Short Abstract

In the summer of 2003, NASA will launch the next wave of robotic explorers towards the planet Mars. Specifically designed to "follow the water", two identical rovers will be delivered to the surface of Mars to remotely conduct geologic investigations. The two self sufficient mobile science laboratories will be able to traverse large distances while performing in situ analysis of a number of rock and soil targets which may hold clues to past water activity. Developing a baseline strategy for the Mars Exploration Rover (MER) mission involves integrating a variety of activities into a coherent plan, including: interplanetary trajectory and navigation design, atmospheric entry, descent, and landing (EDL) design, and mission planning. These activities, collectively referred to as mission design, are described in chronological order as the mission progresses through six mission phases: Launch, Cruise, Approach, EDL, Post-Landing through Egress, and Surface Operations.