MER/MSL Mars Rovers – Case Studies

- Background on Mars rover development
- Mars Exploration Rovers
- Mars Science Laboratory
Viking Panoramas (1976)
Mars Rover (circa 1990)
Mars Pathfinder (1997)
Mars Pathfinder Rover ("Sojourner")
Grousers on Pathfinder Wheels
1998 - A Bad Year at Mars

- Mars Climate Orbiter - Accidentally entered Mars atmosphere because of English-metric conversion error
- Mars Polar Lander - Known software bug shut down landing engines several hundred feet above the surface
- Two Deep Space 2 penetrators disappeared - some speculation they were on wrong frequency for MGS relay
Mars Exploration Rovers 2003

- Fly two missions
- Reuse demonstrated technologies from Mars Pathfinder (aeroshell, airbag landing system)
- All instruments are on the rover (no base station)
- “Follow the water”
- Extend technology for later missions - drive at least 600 m
- Take one PanCam panorama
- Operate for 90 sols
- Solar powered
FOR MER PROJECT USE ONLY

DO NOT DUPLICATE OR DISTRIBUTE
MER Warm Electronics Box (WEB)
MER WEB at Start of ATLO
MER Mast
Mars Pathfinder Obstacle Detection

MER Camera Systems
Wheels and IDD
MER Wheel Suspension and Treads
Instrument Deployment Device

Robotic Arm

[Diagram of robotic arm]

Microscopic Imager
Rock Abrasion Tool
Mössbauer Spectrometer
APXS

[Diagram of robotic arm with instruments]
When RATs Go Bad...
Rocker-Bogey Suspension (side view)
Rocker-Bogey Suspension (isometric)
Rocker-Bogey in Action (Rocky 4)
MER Wheel Design

FLYING HIGH Chris Baker, Next Intent’s manufacturing manager, displays one of the now-famous wheels, each of which is made out of a single piece of airplane-quality aluminum.
Spirit Lands in Gusev Crater
Spirit Looks Towards Columbia Hills
Opportunity Lands in Eagle Crater
Opportunity Landing Targeting

Mars approach DSN tracking

Surface Odyssey & DSN Doppler

Descent DSN Doppler (cut off at chute deploy)
Sometimes the Bounces Go Your Way...
...Opportunity Scores a Hole in One
Opportunity at Endurance Crater
Mini-TES Map of Hematite
Instrument Deployment Device
Instruments on the End of IDD
RATting the Rocks
Opportunity Finds Blueberries
Burns Cliff (inside Endurance Crater)
The Floor of Endurance Crater
Odyssey Finds its Heat Shield...
...and Something Else Unexpected
Opportunity Self-Portrait
Spirit Self-Portrait
Mars Rover Evolution
Three Generations of Mars Wheels
Mars Science Lander 2009 Concept
Mars Science Laboratory
Project Introduction

Richard Cook
Project Manager

December 7, 2005
Project Objectives
Project Overview

Salient Features
Mobile Science Laboratory
One Mars Year surface operational lifetime (669 sols/687 days)
Discovery Responsive over wide range of latitudes and altitudes
Controlled Propulsive Landing
Precision Landing via Guided Entry

Science
Mission science will focus on Mars habitability
Next generation analytical laboratory science investigations
Remote sensing/contact investigations
Suite of Environmental Monitoring Instruments
Science Objectives

1. Characterization of geological features, contributing to deciphering geological history and the processes that have modified rocks and regolith, including the role of water;

2. Determination of the mineralogy and chemical composition (including an inventory of elements such as C, H, N, O, P, S, etc. known to be building blocks for life) of surface and near-surface materials;

3. Determination of energy sources that could be used to sustain biological processes;

4. Characterization of organic compounds and potential biomarkers in representative regolith, rocks, and ices;

5. Determination the stable isotopic and noble gas composition of the present-day bulk atmosphere;

6. Identification potential bio-signatures (chemical, textural, isotopic) in rocks and regolith;

7. Characterization of the broad spectrum of surface radiation, including galactic cosmic radiation, solar proton events, and secondary neutrons; and

8. Characterization of the local environment, including basic meteorology, the state and cycling of water and CO2, and the near-surface distribution of hydrogen.
Technology Objectives

1. demonstration of improved landing precision through the use of guided entry; and
2. demonstration of a landing system capable of accessing a significant fraction of the surface of Mars.
Level 1 Requirements (1 of 2)

- The project shall launch a mobile surface mission to Mars during the 2009 opportunity from the Eastern Test Range.

- The project shall deliver a flight system to be launched on a launch vehicle competitively selected under the NASA Launch Services contract compatible with both Atlas 5 and Delta IV intermediate-class launch vehicles.

- The project system shall be able to land at altitudes of up to +2.0 km relative to the MOLA aeroid.

- The project system shall be capable of landing and operating at sites between 60°N and 60°S latitude selected as late as one year before launch without compromising overall mission safety.

- The project system shall be able to land with an error of 10 km or less radially from a designated point on the surface of Mars (excluding any uncontrolled effects of winds during parachute descent) utilizing a guided atmospheric entry.

- Accommodate the NASA selected payload.
• The project system shall provide data communication throughout critical events at a rate sufficient to determine the state of the spacecraft in support of fault reconstruction to relay assets provided by the Mars Program or to the Deep Space Network.

• The project system shall acquire scientific data about the rover’s local region and conduct mobile in-situ analysis with the rover and its scientific payload on the surface of Mars for at least one martian year.

• The project shall deliver to Mars a rover with the capability of a total traverse path length of at least 20 km.

• The project system shall be able to select, acquire, process, distribute, and analyze at least 74 samples of rock, rock fragments, and/or regolith.

• The project shall conduct near real-time public release of imagery and other science/technology data via the Internet and will provide regular releases for public information purposes.
• The project shall launch a mobile surface mission to Mars during the 2009 opportunity from the Eastern Test Range

• The project shall deliver a flight system to be launched on a launch vehicle competitively selected under the NASA Launch Services contract compatible with both Atlas 5 and Delta IV intermediate-class launch vehicles.

• The project system shall be able to land at altitudes of up to +1.5 km relative to the MOLA areoid.

• The project system shall be capable of landing and operating at sites between 45°N and 45°S latitude selected as late as one year before launch without compromising overall mission safety.

• The project system shall be able to land with an error of 20 km or less radially from a designated point on the surface of Mars (excluding any uncontrolled effects of winds during parachute descent) utilizing a guided atmospheric entry.

• The project shall accommodate the NASA selected payload specified in Section 4.2. Any change in this complement would take into consideration the ability of the remaining payload complement to meet the threshold of the first three science goals (described in Section 2.1) and the mission success criteria (described in Section 4.3).
• The project system shall provide data communication throughout critical events at a rate sufficient to determine the state of the spacecraft in support of fault reconstruction to relay assets provided by the Mars Program or to the Deep Space Network.

• The project system shall acquire scientific data about the rover’s local region and conduct mobile in-situ analysis with the rover and its scientific payload on the surface of Mars for at least 335 sols.

• The project shall deliver to Mars a rover with the capability of a total traverse path length of at least 10 km.

• The project system shall be able to select, acquire, process, distribute, and analyze at least 28 samples of rock, rock fragments, and/or regolith.

• The project shall conduct near real-time public release of imagery and other science/technology data via the Internet and will provide regular releases for public information purposes.
Mission Success Criteria (1 of 2)

• Land safely on the surface of Mars

• Provide mobility capability of at least 50m/sol on the surface of Mars any day requested (monthly average)

• Periodically archive a copy of verified, validated, and calibrated data acquired by the mission to the Planetary Data System within six months after receipt of data on Earth.
Characterize the landing region by conducting the following sets of investigations at levels equal to or above those necessary to fulfill their science objectives for 335 sols after landing; (Note that the balance of actual utilization of the various instruments will depend on the nature of the materials and environments actually encountered on the surface of Mars and evaluation of each instrument’s usefulness in the context of the scientific opportunities as they evolve during the mission);

- Remote imaging for target identification and navigation with one of the two stereoscopic imaging systems (Mastcam or engineering Navigation Cameras), and,
- Microscopic imaging with one of the two available instruments (MAHLI or Chemcam RMI), and,
- Chemical composition analysis with one of two available instruments (APXS or ChemCam LIBS), and,
- Return data from a total of 28 distinct samples analyzed by either available sample analysis investigation (CheMin and/or SAM)
Project Constraints

• Meet Planetary Protection Category IV-C requirements
• Land at sites selected approximately 1 year before launch
• Complete the Project within the not-to-exceed cost established in the commitment.
• Provide UHF communications capability compatible with existing and planned orbiting assets at Mars, including MRO and Odyssey
• Formulate and implement the Project consistent with the JPL Flight Project Practices and Design Principles
Technical Overview
# MSL-MER Comparison

<table>
<thead>
<tr>
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<th>MSL</th>
<th>MER</th>
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<tbody>
<tr>
<td>LV/Launch Mass</td>
<td>Delta 4/Atlas V/3600 kg</td>
<td>Delta II/1050 kg</td>
</tr>
<tr>
<td>Design Mission Life</td>
<td>1 yr cruise/2 yrs surface</td>
<td>7m cruise/3 mo surface</td>
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<tr>
<td>Redundancy</td>
<td>Redundant Surface, Single String Cruise/EDL</td>
<td>Limited/Dual Mission</td>
</tr>
<tr>
<td>Payload</td>
<td>10 instruments (75 kg)</td>
<td>5 instrument (~9 kg)</td>
</tr>
<tr>
<td>Sample Acquisition</td>
<td>Arm + RAT + Corer + Scoop</td>
<td>Arm + RAT</td>
</tr>
<tr>
<td>Sample Processing</td>
<td>Rock Crusher</td>
<td>None</td>
</tr>
<tr>
<td>EDL System</td>
<td>Guided Entry/Skycrane</td>
<td>MPF Heritage/Airbags</td>
</tr>
<tr>
<td>Heatshield Diam</td>
<td>4.5 m</td>
<td>2.65 m</td>
</tr>
<tr>
<td>EDL Comm</td>
<td>UHF + Partial DTE or DTE</td>
<td>DTE + Partial UHF</td>
</tr>
<tr>
<td>Rover Mass</td>
<td>775 kg (allocation)</td>
<td>170 kg (actual)</td>
</tr>
<tr>
<td>Rover Range</td>
<td>&gt;20 km</td>
<td>&gt;5 km</td>
</tr>
<tr>
<td>Surface Power</td>
<td>RTG*/2500 Whr/sol</td>
<td>Solar/&lt;900 Whr/sol</td>
</tr>
<tr>
<td>Surface Comm</td>
<td>X-band DTE + UHF</td>
<td>X-band DTE + UHF</td>
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* - PreDecisional, RTG selection is contingent on NEPA/PD proces
MSL Rover Size Comparison

JPL 2009 MSL Rover

2005 MINI Cooper S

11/04/2008
Launch Configuration

- 5m Fairing with 4.65 m internal envelope.
- 66 inch payload interface to MSL Spacecraft.
- RTG integration access
- Heat Rejection System (HRS) loading access
- Requested fairing cleanliness for PP
- Emergency de-fueling access
Cruise Configuration (Ghost View)

- Spinning cruise configuration
  - 2RPM
  - Spun up by Launch Vehicle
- Cruise Mission Time = 9 months (TBR)
- Launch of Delta IV or Atlas V class Vehicle

- HRS venting prior to CS release
- MGA and LGA DTE during cruise
Event Timeline 1/2

Cruise Stage Separation  E-10 min

Despin (2 rpm © 0 rpm)

Cruise Balance Mass Jettison

Turn to Entry Attitude

Entry Interface  E+0, r = 3522.2 km

Peak Heating  E + 86 s

Peak Deceleration  E + 99 s

Heading Alignment  v = 900 m/s  E + 170 s

Deploy Supersonic Parachute  h = ~10 km MSL  M = 2.0 (v=450 m/s)  E + 225 s

Exo-atmospheric  Entry
Heatshield Separation
h = ~8 km MSL
M = 0.7
E + 247 s
Entry Balance Mass Jettison
Radar Activation and Mobility Deploy
E + 252 s
MLE Warm-Up
E + 307 s
Backshell Separation
h = ~800 m AGL
E + 309 s
Cut to Four Engines
E + 323 s
Rover Separation
E + 341 s
Rover Touchdown
E + 341 s
Flyaway
2000 m above MOLA areoid
Power H Descent Vehicle (deployed)
Rover Engineering Capabilities

- Radioisotope Power Source (Proposed)
- RTG fluid loop
- Heat Exchanger
- Rear HAZCAMs
- Mobility System (6 wheel drive, 4 wheel steer)
- Rover Chassis/thermal enclosure
- Comm to Mars Orbit (UHF Band)
- X-Band LGA
- Comm to Earth (X-Band HGA)
- NAVCAMs (MER heritage)
- Remote Sensing Mast (RSM)
- Sample Processing and Handling (SPAH)
- Robotic arm for contact science and sample acquisition (SA)
- Front HAZCAMs (MER heritage)
- HAZCAMs (MER heritage)
- X-Band LGA
Remote Sensing (Mast)
ChemCam – Laser Induced Breakdown Spectrometer
MastCam - Color Stereo Imager

Contact Instruments (Arm)
MAHLI - Microscopic Imager
APXS - Proton/X-ray Backscatter Spectrometer

Analytical Laboratory (Front Chassis)
SAM - Gas Chromatograph/Mass Spectrometer/
Tunable Laser Spectrometer
(Sample Composition / Organics Detection)
CheMin - X-ray Diffraction / Florescence
(Sample Mineralogy)

Environmental Characterization
(Body-mount)
MARDI - Descent Imager
REMS - Meteorological monitoring
RAD - Surface Radiation Flux Monitor
(future human health & safety)
DAN - Neutron Backscatter subsurface hydrogen
(water/ice) detection
MSL High Fidelity Ground Testbed
MSL Wheel (Pristine)
MSL Wheel (Well-Loved)
JPL MSL Wheel Test Fixture