Technology Development for NASA Mars Missions

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Presentation Content

- Mars mission roadmaps
- Focus and Base technology programs
- Technology infusion
- Feed forward to future missions
Mars Technology Program (MTP)

- Code S determined that the Mars Exploration Program must have a strong technology component to enable increasingly more capable missions and science.
- Accordingly, the restructured program contains an average technology investment of ~10% over a decade.
### Mars Exploration Pathways Missions

#### 2009 - 2020

<table>
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</thead>
<tbody>
<tr>
<td><strong>Search for Evidence of Past Life</strong></td>
<td>MSL to Low Lat.</td>
<td>Scout</td>
<td><strong>Ground-Breaking MSR</strong></td>
<td>Scout</td>
<td>Astrobiology Field Lab or Deep Drill</td>
<td>Scout</td>
<td>All core missions to mid-latitudes. Mission in ‘18 driven by MSL results and budget.</td>
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<tr>
<td><strong>Explore Hydrothermal Habitats</strong></td>
<td>MSL to Hydrothermal Deposit</td>
<td>Scout</td>
<td><strong>Astrobiology Field Laboratory</strong></td>
<td>Scout</td>
<td>Deep Drill</td>
<td>Scout</td>
<td>All core missions sent to active or extinct hydrothermal deposits.</td>
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<td><strong>Search for Present Life</strong></td>
<td>MSL to N. Pole or Active Vent</td>
<td>Scout</td>
<td>Scout</td>
<td>MSR with Rover</td>
<td>Scout</td>
<td>Deep Drill</td>
<td>Missions to modern habitat. Path has highest risk.</td>
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<tr>
<td><strong>Explore Evolution of Mars</strong></td>
<td>MSL to Low Lat.</td>
<td>Scout</td>
<td><strong>Ground-Breaking MSR</strong></td>
<td>Aeronomy</td>
<td>Network</td>
<td>Scout</td>
<td>Path rests on proof that Mars was never wet.</td>
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**NOTES:**
- Missions to mid-latitudes.
- Mission in ‘18 driven by MSL results and budget.
- Missions to modern habitat. Path has highest risk.
- Path rests on proof that Mars was never wet.
Mars Technology Program Supports all NASA Mars Missions

- Mars Sample Return
- Mars Science Laboratory Lander
- Phoenix Scout
- Mars Exploration Rovers
- Mars Odyssey
- Mars Global Surveyor
- Mars Express
- Mars Reconnaissance Orbiter
- Mars Telesat Orbiter
- Scout 1
- Scout 2

MSL Focused Technology

MRO Focused Technology

MSR Focused Technology

Technology Testbed Focused Technology

Base Technology
Mars Technology Program Elements

- **Focused Technology**
  - Driven by requirements of missions such as *MSL and MSR*
  - Technology development is strongly coupled and interactive with the project early in the design phase
  - Technology must reach maturity (TRL 6) by Project PDR
  - Directed or competed
  - Day-to-day management is done by projects

- **Base Technology**
  - Is exploratory in nature
  - Provides seed corn for future mission technologies
  - Includes push technology development
  - Enables new types of missions
  - 100% competed via NASA NRA process
MRO Focused Technology

- **Electra Payload:**
  - Software reconfigurable radio system for near- and far-term Mars missions
  - Electra will be used on all Mars missions including appropriate scout missions.
  - EM delivered

- **Optical Navigation Camera:**
  - Lightweight, low power, high resolution navigation camera for all future Mars missions
  - Instrument development and flight test validation is funded by MTP
  - Protoflight unit delivery 9/04

Mass 2.5kg
Power: 2-5 watts
Accuracy: 0.1 pixel
Navigation Error: 0.5km 1-sigma
Mars Science Laboratory (MSL, 2009)
MSL Focused Technology

**Entry, Descent, and Landing:**
- Guided entry
- Engine development
- Soft landing (Skycrane)

**Surface System Technology:**
- Increased autonomy
- Longer lived actuators
- Realistic rover simulation

**Sample Acquisition & Distribution:**
- Coring/Abrading
- Sample acquisition/transfer
- Rock crushing
- Sample distribution
- Planetary protection
MSL Entry, Descent, and Landing Technologies

- Aeroshell
- Descent Engine
- EDL Guidance, Navigation, and Control
- EDL Modeling and Simulation
- High Flow Regulator for Descent Engine
- Subsonic Parachute*
- Phased Array Terrain Radar*
- POST-based End-to-End EDL Engineering Simulation for MSL
- Safe Landing and Descent Stage

*No longer in the mission baseline
Mars Testbed -1 (2011)

- Testbeds will be used to develop and test those technologies that will enable human missions to Mars
- NASA is currently developing requirements for these missions
- Some of the candidate technologies are:
  - Aerocapture
  - pin-point landing
  - ISRU
  - Instruments to characterize Martian environment for safety for human missions
  - Subsurface access
  - Water extraction
  - Engineering instrumentation to characterize the atmosphere
  - Mach 3 parachute
  - Mid L/D probes
Mars Sample Return (MSR, 2013, or 2016)
Mars Sample Return Mission

Scenario

Launch: Nov. 2013
Delta 4050H
(Max C₃ = 9.3)
(inj capability = 7868 kg)

MOI = Mars Orbit Insertion
MAV = Mars Ascent Vehicle
OS = Orbiting Sample (container)
ERV = Earth Return Vehicle (same as Orbiter)
EEV = Earth Entry Vehicle

Orbiter carries lander to Mars
Orbiter releases lander to aim-point & deflects for MOI at -1 hour.
MOI, then aerobrake for 6 months, then rendezvous/capture OS
After 2 weeks of sample collection, MAV launches, releases OS
After 435 days at Mars, ERV departs for Earth (Nov.2015)
ERV releases EEV at -4 hr (~Stardust)
ERV deflects away from Earth
Sample Returned: July 2016

After 435 days at Mars, ERV departs for Earth (Nov.2015)
After 2 weeks of sample collection, MAV launches, releases OS
MOI = Mars Orbit Insertion
MAV = Mars Ascent Vehicle
OS = Orbiting Sample (container)
ERV = Earth Return Vehicle (same as Orbiter)
EEV = Earth Entry Vehicle

Earth
MSR Focused Technology

Forward and Back
Planetary Protection

Rendezvous and Capture

Covered sampling tool

Earth Entry Vehicle

Mars Ascent Vehicle

Mars Returned Sample Handling
Astrobiology Field Laboratory
(AFL, 2013 or 2018)

Technology:
• More autonomy in rover technology
• More autonomy and functionality for sample preparation and distribution

Exploration Metrics
• 800-1000 day landed mission
• 25 km linear traverse capability @ 0.25 km/sol (4 hours)
• Repeatable 4 (rock corer) and 25 (drill) day cycles
• 2.5 m drilling depth (3-5 holes) @ 0.3 m/sol
• 100 samples for the organic analysis/biosignature detection suite (pyrolysis and liquid phase organic extraction systems)
Base Technology

• These are “push” technologies to enable increased capability in future missions
• 100% competed
• Seven areas have been identified as high priority technology areas for Mars missions
• Currently, 87 tasks are within the Base Program

- Proximity Telecom/Navigation
- Rover Technology
- Subsurface Access
- Planetary Protection
- Advance EDL
- Low Cost Mission Technologies
- Mars Science Instruments
Technology Infusion

- **MTP’s effectiveness is measured by its success in technology infusion into Mars missions**
- **Factors enabling technology infusion are:**
  - Careful selection of technologies based on future mission needs
  - Technology funding contingent upon well defined and measured performance matrices
  - Technology integration/validation to demonstrate capabilities
- **Ten technologies were successfully infused into Mars Exploration Rover (MER) mission**
- **MRO mission will fly two new technologies:**
  - Electra UHF proximity radio
  - Optical Navigation Camera (ONC)
<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
<th>Funding Source</th>
<th>PI/Technologist</th>
</tr>
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<tbody>
<tr>
<td>Stereo Vision</td>
<td>Provides 3-D terrain maps for rovers, manipulators, and human operators.</td>
<td>NASA (Code R), DARPA</td>
<td>Larry Matthies, Mark Maimone</td>
</tr>
<tr>
<td>Long Range Science</td>
<td>Provides increased traverse range of rover operations, improved traverse accuracy, landerless and distributed ground operations with a large reduction in mass.</td>
<td>NASA (MTP)</td>
<td>Samad Hayati, Richard Vafeiadis, Paul Backès, Jeff Norris, Jeff Barlow, David Edwards</td>
</tr>
<tr>
<td>Science Activity Planner</td>
<td>Provides downlink data visualization, science activity planning, merging of science plans from multiple scientists.</td>
<td>NASA (Code R and MTP)</td>
<td>Paul Backès, Jeff Norris</td>
</tr>
<tr>
<td>Viz - 3D Terrain</td>
<td>Enables the science team to operate a rover simulation with an interactive time of day shadow command and specification.</td>
<td>NASA (Code R)</td>
<td>Larry Matthies, Mark Maimone</td>
</tr>
<tr>
<td>FIDO: Field Integrated Design and Operations Rover</td>
<td>Developed TRLS 4-6 rover system designs, advancing NASA capabilities for Mars exploration.</td>
<td>NASA (MTP)</td>
<td>Paul Schenker, Eric Baumgartner, Ron Li, Mark Powell, Mark Maimone, Paul Backès, Joan Walton, Richard Ewell</td>
</tr>
<tr>
<td>Rover Collision Prevention Software</td>
<td>Computes statistically efficient algorithm for predicting and preventing collisions between manipulator and rover/terrain.</td>
<td>NASA (MTP)</td>
<td>Eric Baumgartner, Chris Leger</td>
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<tr>
<td>Descent Image Motion Estimation System (DIMES)</td>
<td>Performs traversability analysis on 3-D range data to predict vehicle safety at all nearby locations; robust to partial sensor data and imprecise position estimation. Configurable for avoiding obstacle during long traverse or for driving toward rocks for science analysis.</td>
<td>NASA (Code R and MTP)</td>
<td>Mark Maimone, Andrew Johnson, Yang Chen et al.</td>
</tr>
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<td>Parallel Telemetry Processor (PTp)</td>
<td>An enhanced situational awareness tool to provide mission management, scientists and engineers with insight into the status of mission operations.</td>
<td>NASA (Code R)</td>
<td>John Schreiner, Joan Walton, John Bresina, Roni Volpe</td>
</tr>
<tr>
<td>Rover Localization and Mapping</td>
<td>Grid-based estimation of surface traversability.</td>
<td>NASA (Code R and MTP)</td>
<td>Guillaume Brat, Guillaume Brat</td>
</tr>
<tr>
<td>MAPGEN and Constraint Editor</td>
<td>Provides a system to capture and handover science intent information across multiple shifts - previous process required continuous team member presence of same people in long monolithic uplink - not sustainable from a human factors standpoint.</td>
<td>NASA (Code R)</td>
<td>Roxana Wales, Jay Trimble, Melissa Mallin, Guillaume Brat, Richard Ewell</td>
</tr>
<tr>
<td>MERboard</td>
<td>Replaced flip chart based manual Sol Tree process with computer tool, capability for re-planning.</td>
<td>NASA (Code R)</td>
<td>Jay Trimble, Melissa Mallin, Guillaume Brat, Richard Ewell</td>
</tr>
<tr>
<td>Fatigue Countermeasures</td>
<td>Procedures, scheduling techniques and countermeasures for operating on &quot;Mars-time.&quot;</td>
<td>NASA (Code R)</td>
<td>John Bresina, John Trimble, Melissa Mallin</td>
</tr>
<tr>
<td>Lithium-Ion Batteries</td>
<td>Significant mass and volume savings (3-4X) compared to the SOA Ni-Cd and Ni-H2 batteries.</td>
<td>NASA (Code R)</td>
<td>Mark Maimone, Richard Ewell</td>
</tr>
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Technology Infusion into MER
Science Activity Planner (SAP)

• SAP is the primary science operation tool for MER and is used on daily basis
  • Developed as a ground operations software, started in 1995
  • Provides downlink data visualization, science activity planning, merging of science plans from multiple scientists
  • Public outreach version, called **Maestro**, along with actual Spirit and Opportunity data sets, is available for download from MER mission main web page; hundreds of thousands of public downloads in first month of the mission

• **FUTURE USERS and APPLICATIONS**
  • ’07 Phoenix – downlink data visualization and robotic arm command generation
  • ’09 Mars Science Laboratory – downlink data visualization and science goal specification

• **Winner of NASA’s best software award for FY ’04**
Technology Feed Forward to Mars Missions
Entry, Descent, and Landing Example

MRO ('05)
Optical Navigation Camera is used to perform Optical Navigation - Demonstrates improved entry accuracy

MSL ('09)
Guided Entry technology improves landing accuracy by an order of magnitude. Skycrane technology enables robust landing of larger payloads than MER rover

Testbed Mission ('11)
Terrain based navigation and optimized descent in conjunction with optical navigation and guided entry demonstrates 100 meter pin-point landing capability

MSR ('13)
Above technologies provide ability to return samples from very specific regions of Mars or samples cached by MSL
NASA is pursuing an aggressive, science-driven agenda of robotic exploration of Mars with a series of orbiters and landers. These missions carry science instruments selected to answer questions the planetary science community has posed to better characterize the planet (See Mars Exploration Program Analysis Group, MEPA). The overarching objective is increased understanding with regard to Life, Climate, Geology, and Preparation for Human Exploration.

Many new technologies need to be developed and infused into future Mars missions, which demand the following capabilities:

- Better landing accuracy with active hazard-detection-and-avoidance capability
- Access to high-priority sites with terrain too complex for landing current rovers
- Increased mobility to sample diverse geological sites and reach targets of interest
- Longer-lived surface systems to allow for year-long surface exploration
- Technologies to access the subsurface and acquire samples for in situ analysis
- New and improved science instruments
- In situ sample acquisition, preparation, and distribution systems
- Increased autonomy to enable increased science return
- Planetary protection techniques
- Sample-return technologies for bringing samples to Earth for analysis.

The Mars Technology Program (MTP) is responsible for technology-development