Mars Science Laboratory

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Mars Rover Family Portrait
MARS SCIENCE STRATEGY: Follow the Water!

Common Thread

WATER

LIFE

Determine if Life Ever Arose on Mars

CLIMATE

Characterize the Climate

GEOLGY

Characterize the Geology

HUMAN

Prepare for Human Exploration

When? Where? Form? Amount?
**MSL Payload**

**REMOTE SENSING**
- **MastCam** (M. Malin, MSSS) - Color imaging, atmospheric opacity
- **ChemCam** (R. Wiens, LANL/CNES) – Chemical composition; remote micro-imaging

**CONTACT INSTRUMENTS (ARM)**
- **MAHLI** (K. Edgett, MSSS) - Microscopic imaging
- **APXS** (R. Gellert, U. Guelph, Canada) - Chemical composition

**ANALYTICAL LABORATORY (ROVER BODY)**
- **SAM** (P. Mahaffy, GSFC/CNES) - Chemical and isotopic composition, including organics
- **CheMin** (D. Blake, ARC) - Mineralogy

**ENVIRONMENTAL CHARACTERIZATION**
- **MARDI** (M. Malin, MSSS) - Descent imagery
- **REMS** (J. Gómez-Elvira, CAB, Spain) - Meteorology / UV
- **RAD** (D. Hassler, SwRI) - High-energy radiation
- **DAN** (I. Mitrofanov, IKI, Russia) - Subsurface hydrogen

<table>
<thead>
<tr>
<th>Wheel Base:</th>
<th>2.2 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of Deck:</td>
<td>1.1 m</td>
</tr>
<tr>
<td>Height of Mast:</td>
<td>2.2 m</td>
</tr>
</tbody>
</table>

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### MSL - MER Mission Comparison

<table>
<thead>
<tr>
<th></th>
<th>MSL</th>
<th>MER</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV/Launch Mass</td>
<td>Atlas V/4000 kg</td>
<td>Delta II/1050 kg</td>
</tr>
<tr>
<td>Prime Mission</td>
<td>1 yr. cruise/2 yrs. surface</td>
<td>7 mo. cruise/3 mo. surface</td>
</tr>
<tr>
<td>Payload</td>
<td>10 instruments (80 kg)</td>
<td>5 instruments (~5 kg)</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>Surface Power</td>
<td>RTG at 2500 W-hr/sol</td>
<td>Solar Panels at &lt;900 W-hr/sol</td>
</tr>
<tr>
<td>Rover Mass</td>
<td>950 kg (allocation)</td>
<td>170 kg (actual)</td>
</tr>
<tr>
<td>Rover Range</td>
<td>&gt;20 km</td>
<td>&gt;600 m (few km actual)</td>
</tr>
</tbody>
</table>
Previous and MSL Landing Sites

- Phoenix
- Viking 1
- Viking 2
- Pathfinder
- Mawrth Vallis
- Opportunity
- Holden
- Eberswalde
- Gale Crater
- Spirit
Eberswalde Crater (24° S, 327° E, -1.5 km) contains a clay-bearing delta formed when an ancient river deposited sediment, possibly into a lake.

Gale Crater (4.5° S, 137° E, -4.5 km) contains a 5-km sequence of layers that vary from clay-rich materials near the bottom to sulfates at higher elevation.

Holden Crater (26° S, 325° E, -1.9 km) has alluvial fans, flood deposits, possible lake beds, and clay-rich sediment.

Mawrth Vallis (24° N, 341° E, -2.2 km) exposes layers within Mars’ surface with differing mineralogy, including at least two kinds of clays.
**MSL Mission Overview**

**CRUISE/APPROACH**
- 9-10 month cruise
- Spinning cruise stage
- Arrive N. hemisphere summer

**ENTRY, DESCENT, LANDING**
- Guided entry and controlled, powered “sky crane” descent
- 20 × 25-km landing ellipse
- Discovery responsive for landing sites ±30º latitude, <0 km elevation
- ~1000-kg landed mass

**SURFACE MISSION**
- Prime mission is one Mars year
- Latitude-independent and long-lived power source
- 20-km range
- 85 kg of science payload
- Acquire and analyze samples of rock, soil, and atmosphere
- Large rover, high clearance; greater mobility than MPF, MER

**LAUNCH**
- Nov. 2011
- Atlas V (541)
Entry
Energy Dissipation Via: Aerodynamic Drag / Aerothermodynamic heating
Velocity Range: 12,000 mph → 1,000 mph
Peak Temperature: 1447°C

Parachute Descent
Energy Dissipation via: Aerodynamic Drag
Velocity Range: 1,000 mph → 200 mph

Powered Descent
Energy Dissipation Via: Rocket Thrust
Velocity Range: 200 mph → 4-40 mph

Landing
Energy Dissipation Via: Viscous Damping
Velocity Range: 4 – 40 mph → 0.0 mph
## EDL Overview – Event Timeline

<table>
<thead>
<tr>
<th>Event</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruise Stage Separation</td>
<td>E-10 min</td>
</tr>
<tr>
<td>Despin (2 rpm → 0 rpm)</td>
<td></td>
</tr>
<tr>
<td>Cruise Balance Mass Jettison</td>
<td></td>
</tr>
<tr>
<td>Turn to Entry Attitude</td>
<td></td>
</tr>
<tr>
<td><strong>Entry Interface</strong></td>
<td>E+0, r = 3522.2 km</td>
</tr>
<tr>
<td><strong>Exo-atmospheric</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Entry</strong></td>
<td></td>
</tr>
<tr>
<td>Peak Heating</td>
<td></td>
</tr>
<tr>
<td>Peak Deceleration</td>
<td></td>
</tr>
<tr>
<td>Heading Alignment</td>
<td></td>
</tr>
<tr>
<td>Deploy Supersonic Parachute</td>
<td>h = ~10 km MSL M = 2.0</td>
</tr>
</tbody>
</table>

- Cruise Stage Separation: The spacecraft's stage is separated, preparing for the descent phase.
- Despin: The spacecraft's spin rate is reduced from 2 rpm to 0 rpm.
- Cruise Balance Mass Jettison: Unnecessary mass is jettisoned to balance the spacecraft's weight.
- Turn to Entry Attitude: The spacecraft's attitude is adjusted for entry.
- Entry Interface: The spacecraft enters the Martian atmosphere.
- Exo-atmospheric: The spacecraft transitions from exo-atmospheric to entry.
- Entry: The spacecraft continues its descent through the Martian atmosphere.
- Peak Heating: The spacecraft experiences peak heating due to friction with the atmosphere.
- Peak Deceleration: Deceleration reaches its peak as the spacecraft slows down.
- Heading Alignment: The spacecraft aligns its heading for the final approach.
- Deploy Supersonic Parachute: The spacecraft deploys its supersonic parachute to slow down further.

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**MSL Sky Crane V+V Program Review**

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**ADS - 10**
EDL Overview – Event Timeline (cont.)

Supersonic Parachute Descent
- Heatshield Separation
- Entry Balance Mass Jettison
- Radar Activation and Mobility Deploy
- MLE Warm-Up
- Backshell Separation
  - $h = \sim 8 \text{ km MSL}$
  - $M \approx 0.7$
  - $h = \sim 800 \text{ m AGL}$

Powered Descent
- Cut to Four Engines
- Rover Separation
- Rover Touchdown

Sky Crane
- Deploy Supersonic Parachute

Flyaway
- 2000 m above MOLA areoid

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Assembly High Bay
Cruise System Solar Thermal Vacuum Test
Arm Operations
Rover Z-Axis Vibe
NX Design and Simulation - MSL Mapping

System Design and Configuration - parts and assembly models, drawings, WIP data management, top assembly configuration, viewing

- Thermal Analysis & Performance – modeling, test predictions and correlation

- Cabling – design and routing of round wire and flex

System Loads & Dynamics - parts stress, FEM, testing

- Separation Events – clearances, dynamics, validation tests

- Motion – deployments, range of motion, swept volumes, interferences

Mass Properties – CG determination

- View Factors – Obscurations, FOVs

Released Products – data mgmt
Based on UGNX solid model design geometry, a full system surface model was generated in TMG. Both a thermal mesh and a flow mesh were created for the rover with emphasis on the HRS.
Rover Thermal Design & System Model

- Active Thermal Design
  - Surface Heat Rejection System (SHRS)
  - Heaters controlled by FSW or mechanical thermostats and commandable heaters

- Passive Thermal Design
  - Paints (top deck, chassis walls, hot/cold plates are white)
  - SLI blankets (bellypan and UHF antenna)
  - Thermal straps (CheMIN)

- Detailed model of HRS and RAMP mounted Electronics interfaces
- All major external components coarsely represented for radiation blockage
- HRS valve logic modeled using Fortran subroutine with Flight valve data interfacing to TMG
Rover Solar Thermal Test
Test Profile

MSL Rover STT Timeline

- Shroud temp (°C)
- RAMP Avg. Temp (°C)
- MMRTG (W)

Timeline events:
- Case 1A: Pumpdown
- Case 1B: EQCM
- Case 3: Function #1 at -55°C
- Case 5: Cold Thermal Balance at -105°C
- Case 6A: Function #2 at -105°C
- Case 6B: Warm up Htr Char & High Avionics Pwr
- Case 7: Function #3 Cold Vac at -105°C
- Case 8: Function #4 Actuator Heat-to-Loss
- Case 9: Hot Thermal Balance at -80°C
- Case 10: Function #5 SAM
- Case 11: Backfill & Door Open
- Case 12: Acceleration Warmup to 0°C & Camera Function #6
- Case 13: Function #7 at 0°C
- Case 14: Function #8
- Case 15: Hot Diurnal
- Case 16: Hot Diurnal
- Case 17: Backfill & Open Chamber

Temperature (deg C) vs. Time (hours)
MSL has EIGHT major separation events and two post landing deployments.
Skycrane Full Motion Drop
Rover Separation and Mobility Deploy Dynamics

Phase 1: Initial Deployment
Phase 2: Steady State Deployment
Phase 3: Mobility Deployment and Snatch
Phase 4: Ready For Touchdown
Phase 5: Touchdown

Skycrane Initial Conditions
- dV/dt
- PDV Tilt angle
- PDV X rate
- PDV Y rate
- PDV Z rate
- Vel X
- Vel Y
- Vel Z

Margin Summary
- BUD
- Mobility

Ready for TD States: 3 sigma results
- Vv
- Vh
- Chassis Pitch angle
- Chassis Roll angle
- Chassis Pitch rate
- Chassis Roll rate
- Chassis Yaw rate
- Rocker angle
- Bogie angle
- Rocker rate
- Bogie rate

Touchdown Initial Conditions
- Vel h
- Vel v
- Chassis Pitch rate
- Chassis Roll rate
- Chassis Yaw rate
- Rocker angle
- Bogie angle

TD Performance Metrics
- Mobility margins
- Overturning stability

Traditional Dichotomy
- A) Planar Rigid Slopes
- B) Rock Strike
What’s Next for JPL with NX?

• Seamless integration of Design and Analysis Data in Design Reviews

• All Mechanical GSE in NX/TC Eng for interference checking with swept volumes.

• Increased integration of physics-based dynamics analysis, including quantification of margins and uncertainty.

• Full utilization of cable design and routing. “Virtual” cable mockups.
Closing Comments

• A strong partnership between the project engineers and the software developers isn’t just good business practice, it’s essential to engineering success.

• Successful evolution into a new CAE environment is a shared responsibility between application engineers and software suppliers.
  • It depends not just on new programs/capabilities, but achieving user confidence to migrate work practices. This is best achieved working hand in hand on real applications.

• The corporate environment must encourage utilization of the new environment to overcome the complexity-conundrum.
  • Complex problems will drive users to try new capabilities, but may pose more challenges to success.
  • Less challenging problems pose no necessity to do something new but offer greater chances of success.
Thank You!

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Las Vegas, NV
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http://plmworld.org/