The Mars Science Laboratory (MSL) Entry, Descent and Landing Instrumentation (MEDLI) Hardware

Michelle M. Munk, Alan Little, Chris Kuhl, Deepak Bose, and Jose Santos

23rd AAS/AIAA Spaceflight Mechanics Meeting

12 February 2013
Agenda

- MEDLI Objectives and Overview
- MEADS: Mars Entry Atmospheric Data System
  - Description
  - Unique Challenges/Testing
- MISP: MEDLI Integrated Sensor Plug
  - Description
  - Unique Challenges/Testing
- SSE: Sensor Support Electronics
- Conclusions
MEDLI: MSL Entry, Descent and Landing Instrumentation (2006-2012)

- MEDLI consists of 7 pressure ports, 7 integrated sensor plugs, and support electronics
- Gathered engineering data during entry and descent for future Mars missions
- Partnership between NASA Mission Directorates to build, fly, and analyze data

The MEDLI instrumentation makes MSL the first extensively instrumented heatshield ever sent to Mars
MEDLI Objectives

Measure Pressure
- Confirm spacecraft aerodynamics
- Independently measure attitude
- Determine density profile
- Determine wind component

Measure Temperature
- Verify heating levels on spacecraft surface
- Determine recession amount and rate
- Validate material response at Mars conditions

The better we understand the Mars entry environment, the better we can design the next spacecraft
MEADS: Requirements

Fundamental objectives:
(1) Do no harm to MSL
(2) Obtain good measurements

<table>
<thead>
<tr>
<th>Objective</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconstruct basic surface pressure</td>
<td>None specified</td>
</tr>
<tr>
<td>Reconstruct Angle of Attack</td>
<td>± 0.5° when P &gt; 1.75 kPa</td>
</tr>
<tr>
<td>Reconstruct Angle of Sideslip</td>
<td>± 0.5° when P &gt; 1.25 kPa</td>
</tr>
<tr>
<td>Reconstruct Dynamic Pressure</td>
<td>± 2% when P &gt; 0.85 kPa</td>
</tr>
</tbody>
</table>
## MISP: Requirements

<table>
<thead>
<tr>
<th>Objective</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconstruct aeroheating</td>
<td>± 30 W/cm$^2$</td>
</tr>
<tr>
<td>Determine leeside turbulent heating levels and augmentation</td>
<td>± 30 W/cm$^2$</td>
</tr>
<tr>
<td>Determine time of boundary layer transition onset</td>
<td>2 seconds</td>
</tr>
<tr>
<td>Determine presence, if any, of stagnation point heating augmentation</td>
<td>± 30 W/cm$^2$</td>
</tr>
<tr>
<td>Measure subsurface material temperature response</td>
<td>± 12%</td>
</tr>
<tr>
<td>Determine total TPS recession</td>
<td>± 0.635 cm (0.25”)</td>
</tr>
<tr>
<td>Measure depth of isotherm in TPS</td>
<td>720°C ± 80°C and ± 0.8mm</td>
</tr>
</tbody>
</table>
MEDLI Locations in MSL Vehicle
MEDLI — The Path to Mars!

Heatshield

MEADS Port

Electronics Box

MEADS Transducer

Launch – 26 Nov 2011
MSL Entry, Descent and Landing (EDL) Sequence

MSL/MEDLI Enter Martian Atmosphere: E+0 min ~6 August 1:24 AM EDT

MEDLI is taking data and MSL is storing the data on the rover for transmission to Earth

MEDLI Powered Off: E+5 Min ~6 August 1:29 AM EDT

Altitude is DIMU altitude above ground. Velocity is DIMU velocity relative to the ground.
Mars Entry Atmospheric Data System (MEADS)

- Modified off-the-shelf transducers from Stellar Technologies, Inc. (STI)
- Diaphragm-type transducers with 0.5% full scale repeatability
- ~305 grams, 0-10 mV output, 0-5 psia
- Data is sampled at 8 Hz from entry interface to heatshield separation
- Transducer heads are located near pressure taps to minimize lag
- Electronics located within dedicated Sensor Support Electronics (SSE) box due to low temperatures during cruise
MEADS: Arcjet Testing

• Unknown at outset whether a port could survive in ablating TPS

• Developmental arcjet testing in SLA, then PICA, at Boeing Large Core Arc Tunnel (LCAT)

• Investigated port sizes from 0.05” to 0.2”, with sleeve/liner and without

• Active pressure measurements during arcjet test to show data quality

• Established shear post-test port and surface shape as qualification criteria

• Qualification included stagnation and shear

Tested 110+ PICA models
MEADS: Unique Hardware Testing

MEADS assemblies

SSE

MEADS Assembly

elbow

Fixture plate
MEDLI Integrated Sensor Plug (MISP)

• Each plug is 1.3” diameter by 1.14” long PICA cylinder

• Each plug contains
  – 4 Type-K thermocouples (TCs)
  – One Hollow aErothermal Ablation Temperature (HEAT) sensor designed to track ablation process through the thickness

• The four thermocouples nominally installed at depths of 0.1”, 0.2”, 0.45”, and 0.7” from the top surface
MISP: Arcjet Testing

- Conducted stagnation and shear
- Qualification: 6” models with aeroshell structure included
- Constructed and integrated with flight materials and processes

82 W/cm², 0.33 Pa

270 W/cm², 0.27 Pa
MISP: Environmental Testing

- Arcjet samples cold-soaked in liquid nitrogen to simulate cruise
- Pyroshock and vibration testing required unique fixture to simulate flight boundary conditions
SSE: Sensor Support Electronics

- Contains analog, digital, and shield boards
- Placed under MMRTG to stay warm during cruise
- Mounted on wire rope isolators to attenuate launch vibration loads
- Powers MISP and MEADS, sends MEDLI data to rover compute element (RCE)
MEDLI: Integration
Summary

• The MEDLI instrumentation made MSL the first extensively instrumented heatshield ever sent to Mars
• The MEDLI hardware development was challenging due to the environments it had to withstand
  – Heavy launch vibration
  – Extreme cold during cruise
  – Entry heating environment
• A unique collaboration between NASA mission directorates, NASA centers, and industry partners made MEDLI an unqualified success
• Ultimately, the MEDLI hardware was designed, built and tested to achieve the two fundamental objectives:
  1) Do no harm to MSL
  2) Return high-quality data
MEDLI Successfully Completes Mission

Image taken by MARDI after heatshield separation.

Thanks to the entire MEDLI team!
Backup
MEADS: Requirements

Fundamental objectives:
(1) Do no harm to MSL
(2) Obtain good measurements

<table>
<thead>
<tr>
<th>Objective</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconstruct basic surface pressure</td>
<td>None specified</td>
</tr>
<tr>
<td>Reconstruct Angle of Attack</td>
<td>± 0.5° when P &gt; 1.75 kPa</td>
</tr>
<tr>
<td>Reconstruct Angle of Sideslip</td>
<td>± 0.5° when P &gt; 1.25 kPa</td>
</tr>
<tr>
<td>Reconstruct Dynamic Pressure</td>
<td>± 2% when P &gt; 0.85 kPa</td>
</tr>
</tbody>
</table>
MISP: Requirements

<table>
<thead>
<tr>
<th>Objective</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconstruct aeroheating</td>
<td>± 30 W/cm²</td>
</tr>
<tr>
<td>Determine leeside turbulent heating levels and augmentation</td>
<td>± 30 W/cm²</td>
</tr>
<tr>
<td>Determine time of boundary layer transition onset</td>
<td>2 seconds</td>
</tr>
<tr>
<td>Determine presence, if any, of stagnation point heating augmentation</td>
<td>± 30 W/cm²</td>
</tr>
<tr>
<td>Measure subsurface material temperature response</td>
<td>± 12%</td>
</tr>
<tr>
<td>Determine total TPS recession</td>
<td>± 0.635 cm (0.25”)</td>
</tr>
<tr>
<td>Measure depth of isotherm in TPS</td>
<td>720°C ± 80°C and ± 0.8mm</td>
</tr>
</tbody>
</table>
MEDLI Locations in MSL Vehicle