Mars 2020 Entry, Descent, and Landing Instrumentation 2 (MEDLI2)

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Outline

• Intro
• Goals and Objectives
• Science Requirements
• Sensors and Development Challenges
  – Pressure Transducers
  – Thermocouples
  – Heat Flux Sensors and Radiometer
• Sensor Testing: Qualification and Calibration
  – Pressure Transducers
  – Thermocouples
  – Heat Flux Sensors and Radiometer
• System Architecture and Operation
• Reconstruction Targets
  – Pressure Measurements
  – Thermal Measurements
• Summary
Background: Mars 2020 Entry Vehicle

- The Mars 2020 Entry, Descent, and Landing Instrumentation 2 (MEDLI2) is the EDL sensor suite for the flagship-class Mars 2020 mission.
- The Mars 2020 mission is a rover mission utilizing investments in Mars Science Laboratory (MSL) technologies.
  - The entry vehicle, including the heatshield, is nearly “build to print”.
  - Entry environments will be similar, if not more benign, than for MSL.
MEDLI2 Science Goals

- MEDLI2 goals are to acquire flight data, in order to:
  - Define entry aerothermal environments and reduce aerothermal uncertainties
  - Reduce entry vehicle thermal protection system (TPS) mass
  - Improve future aerocapture and EDL performance

- MEDLI2 science objectives are to:
  - Reduce design margins and prediction uncertainties for aerothermal environments and TPS response
  - Reduce uncertainty and enable validation of the aerodynamic database
MEDLI2 Science Objectives/Requirements

Aerothermal and TPS:
- Reconstruct forebody aerothermal heating
- Determine forebody TPS temperatures
- Reconstruct aftbody aerothermal heating
- Measure aftbody heat flux

Aerodynamics and Atmosphere:
- Reconstruct hypersonic and supersonic aerodynamic axial force coefficient
- Reconstruct wind relative vehicle attitude
- Reconstruct atmospheric density and winds
- Reconstruct vehicle Mach number

New for MEDLI2!
MEDLI2 Expands Scope of Instrumentation

**MEDLI on MSL (2012)**
- 7 Hypersonic Pressure Transducers
- 7 Instrumented Plugs
  - 4 Thermocouples
  - 1 HEAT sensor
- 1 Sensor Support Electronics Box

**MEDLI2 on Mars 2020**
- Pressure Transducers: 1 Hypersonic, 6 Supersonic, and 1 Backshell
- 11 Instrumented PICA Plugs
- 6 Instrumented SLA Plugs
- 3 Heat Flux Gauges (including 1 Radiometer)
- 1 Sensor Support Electronics Box
MEDLI2 Instrumentation Layout

**MEDLI (MSL 2012)**

**Thermal Instrumentation**
- MISP 1
- MISP 2
- MISP 3
- MISP 4
- MISP 5
- MISP 6
- MISP 7

**Pressure Instrumentation**
- MEADS 1
- MEADS 2
- MEADS 3
- MEADS 4
- MEADS 5
- MEADS 6
- MEADS 7

**Heatshield**

**MEDLI2 (Mars 2020)**

**Thermal Instrumentation**
- PICA Aerothermal Plug
- PICA Thermal Response Plug
- SLA-561V Aerothermal Plug
- Heatflux Sensor
- Radiometer

**Pressure Instrumentation**
- Supersonic Pressure
- Hypersonic Pressure
- Backshell Pressure

**Heatshield**

**Backshell**

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MEDLI2 Forebody Pressure Measurement

- One pressure transducer to measure stagnation point pressure during hypersonic flight for reconstruction of atmospheric density, and $C_A$
  - MEDLI flight spare
  - Target range: 1650 Pa – 35 kPa
  - Target accuracy: 1% of reading
- Six pressure transducers measure surface pressure in the range relevant for supersonic flight
  - Target range: 650 Pa – 7 kPa
  - Target accuracy: 1% of reading
- The supersonic port locations are based on a constrained-optimization process to minimize error in the reconstruction of angles of attack and side-slip
Supersonic Pressure Sensor Proof-of-Concept

- **Driving requirement:**
  - Heatshield during cruise phase estimated to be as low as −130 °C
  - No commercially available sensor can withstand the temperature range required

- **Proof of concept sensor constructed**
  - Disassemble and remove foil-backed strain gauge
  - Replace with COTS semiconductor piezoresistive unit
  - 12-point calibration conducted

- **Gain of more than 60 times of effective output signal compared to unmodified sensor**

- **Based on this concept, custom sensors will be assembled for flight**

- **Extensive testing and calibration scheduled for later this year**
MEDLI2 Aftbody Pressure Measurement

- Science Objectives:
  - Improve backshell pressure model
  - Estimate backshell contribution to drag

- One pressure sensor in the afterbody
  - Target Range: 40 – 700 Pa
  - Target Accuracy: 4 Pa

- The current port location is defined based on available wind tunnel data and CFD analysis

- Further refinement of the location will occur based on the results of recently completed ballistics range test

From: John Van Norman
Science objectives: Measure baseline heating, transition to turbulence, and turbulent heating footprint

Forebody thermal instrumentation includes 11 PICA plugs with embedded thermocouples
- Three plugs (1-3) with three thermocouples each to measure in-depth thermal response
- Eight plugs (4-11) with one thermocouple for aerothermal reconstruction

A combination of Type R and Type K TCs
- **Near surface:**
  - Type R: -50 to 1480 °C, for depths < 0.1 inches
  - Target Accuracy: ±15 W/cm²
- **In-depth:**
  - Type K: -270 to 1260 °C, for depths ≥ 0.1 inches
  - Target Accuracy: ±50 °C
MEDLI2 Aftbody Thermal Instrumentation

- **Science objectives:**
  - Aeroheating (both reconstructed and direct measurement)
  - Measure radiative vs. total heating

- **Aftbody instrumentation includes 6 SLA-561V thermal plugs, 2 heat flux gauges, and 1 radiometer**

- **Each plug will have 1 or 2 Type K thermocouple for aerothermal reconstruction**
  - Range: -270 to 1260 °C
  - Target Accuracy: ±3 W/cm²

- **Heat flux gauges will directly measure total heating**
  - Target Range: 0 – 15 W/cm²
  - Target Accuracy: ±1 W/cm²

- **Radiometer will measure radiative heating at location predicted to be have peak radiative component**
  - Target Range: 0 – 15 W/cm²
  - Target Accuracy: ±1 W/cm²
Heat Flux Sensors and Radiometer

- Heat flux sensors and radiometer are Schmidt-Boelter gauges
- Radiometer is a heat flux sensor with a sapphire window at the sensing element tip
  - Sapphire blocks convective heating component
  - Wide view angle (−150°) combined with highly radiating aftbody flowfield will lead to substantial signal
  - Sapphire window optical properties will be measured
  - Deposition of ablation products on window may alter readings—how large is this effect?
## Reconstruction Targets

<table>
<thead>
<tr>
<th>Quantity of Interest</th>
<th>Reconstruction Target</th>
<th>Relevant Sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forebody Reconstructed Heating</td>
<td>±15 W/cm²</td>
<td>Forebody Thermocouples</td>
</tr>
<tr>
<td>Boundary Layer Transition</td>
<td>±1 second</td>
<td>Forebody Thermocouples</td>
</tr>
<tr>
<td>In-depth Temperatures</td>
<td>±50 °C</td>
<td>Forebody Thermocouples</td>
</tr>
<tr>
<td>Aftbody Reconstructed Heating</td>
<td>±3 W/cm²</td>
<td>Aftbody Thermocouples</td>
</tr>
<tr>
<td>Aftbody Heat Flux</td>
<td>±1 W/cm²</td>
<td>Heat Flux Sensor/Radiometer</td>
</tr>
<tr>
<td>Axial Force Coefficient</td>
<td>±2%</td>
<td>All Pressure Transducers</td>
</tr>
<tr>
<td>Vehicle Attitude</td>
<td>±0.5 degrees</td>
<td>Supersonic Pressure Transducers</td>
</tr>
<tr>
<td>Atmospheric Winds</td>
<td>±10 m/s</td>
<td>Supersonic Pressure Transducers</td>
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<tr>
<td>Atmospheric Density</td>
<td>±5%</td>
<td>Forebody Pressure Transducers</td>
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<tr>
<td>Mach Number</td>
<td>±0.1</td>
<td>Forebody Pressure Transducers</td>
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<tr>
<td>Aftbody Pressure</td>
<td>±4 Pa</td>
<td>Aftbody Pressure Transducer</td>
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</table>
Pressure Measurements
Reconstruction Methodology

- Algorithm is a weighted, least-squares (WLS) method to calculate best-fit estimates of atmospheric conditions based on inertial state of vehicle and a model of surface pressure.
- Linear covariance tool maps input uncertainties to nonlinear WLS algorithm to output uncertainties.
  - Predicts ability to meet science requirements for accuracy for angle of attack, density, Mach number, wind states, etc.
• Similar to MEDLI, plan is to utilize inverse techniques to reconstruct surface heating
  – Whole-time domain least squares method that minimizes the sum of squared differences between TC data and predicted temperatures
  – For MEDLI, surface chemistry calculations could not be included due to inaccuracies of the PICA equilibrium gas-surface chemistry model. Surface heating estimates assumed no recession

• Improvements to reconstruction methods include:
  – Finite-rate chemistry model for PICA in CO\textsubscript{2} (developed by NASA’s Entry System Modeling project) to estimate surface film coefficient as a function of time
  – Characterization of variations in material properties in flight-lot PICA to better estimate heating (e.g., thermal conductivity)
  – Merging multiple data sources for heating reconstruction in order to incorporate heat flux sensor measurements
Summary (and some parting thoughts)

- MEDLI2 builds upon the success of MEDLI, and extends the scope of measurements significantly
  - Aftbody measurements (pressure, near-surface thermal, direct heat flux, radiation)
  - Supersonic pressure measurements
  - Increased number of forebody thermal near-surface measurements

- Reducing the design margins for future Mars missions will continue to be critical
  - For small robotic missions, every kg counts, and being able to shave a few kg from the aftbody can result in increased delivered payload
  - For human-scale missions, every kg counts, plus robustness is also an issue. Being able to predict how the entry vehicle will perform with greater accuracy will be necessary

- With a successful Mars 2020 mission, MEDLI2 will be able to impact future Mars missions by reducing margins, improving models, with a better understanding of the uncertainties and risk
Questions?