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

Helen H. Hwang
MEDLI2 Principal Investigator

Deepak Bose, Todd R. White, Henry S. Wright, Mark Schoenenberger, Christopher A. Kuhl, Dominic Trombetta, Jose A. Santos, Tomo Oishi, Christopher D. Karlgaard, Milad Mahzari, and Steven P. Pennington

1NASA Ames Research Center, Moffett Field, CA
2NASA Langley Research Center, Hampton, VA
3Sierra Lobo, Inc., Moffett Field, CA
4Jacobs Technology, Inc., Moffett Field, CA
5Analytical Mechanical Associates, Inc., Hampton, VA
6Analytical Mechanical Associates, Inc., Moffett Field, CA
7Science Systems and Applications, Inc., Hampton, VA

June 2016
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
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

June 2016
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**
  - PICA Thermal Response Plugs
  - Heatshield

- **Pressure Instrumentation**
  - Hypersonic Pressure Transducers
  - Heatshield

**MEDLI2 (Mars 2020)**

- **Thermal Instrumentation**
  - PICA Aerothermal Plug
  - PICA Thermal Response Plug
  - Heatshield

- **Pressure Instrumentation**
  - SLA-561V Aerothermal Plug
  - Heatflux Sensor
  - Radiometer
  - Supersonic Pressure
  - Hypersonic Pressure
  - Backshell Pressure
  - Heatshield
  - Backshell

June 2016
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 \(-130 \, ^\circ C\)
  – 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

June 2016
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>
</tr>
<tr>
<td>Atmospheric Density</td>
<td>±5%</td>
<td>Forebody Pressure Transducers</td>
</tr>
<tr>
<td>Mach Number</td>
<td>±0.1</td>
<td>Forebody Pressure Transducers</td>
</tr>
<tr>
<td>Aftbody Pressure</td>
<td>±4 Pa</td>
<td>Aftbody Pressure Transducer</td>
</tr>
</tbody>
</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.

![Diagram](image)
• 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$_2$ (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?