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

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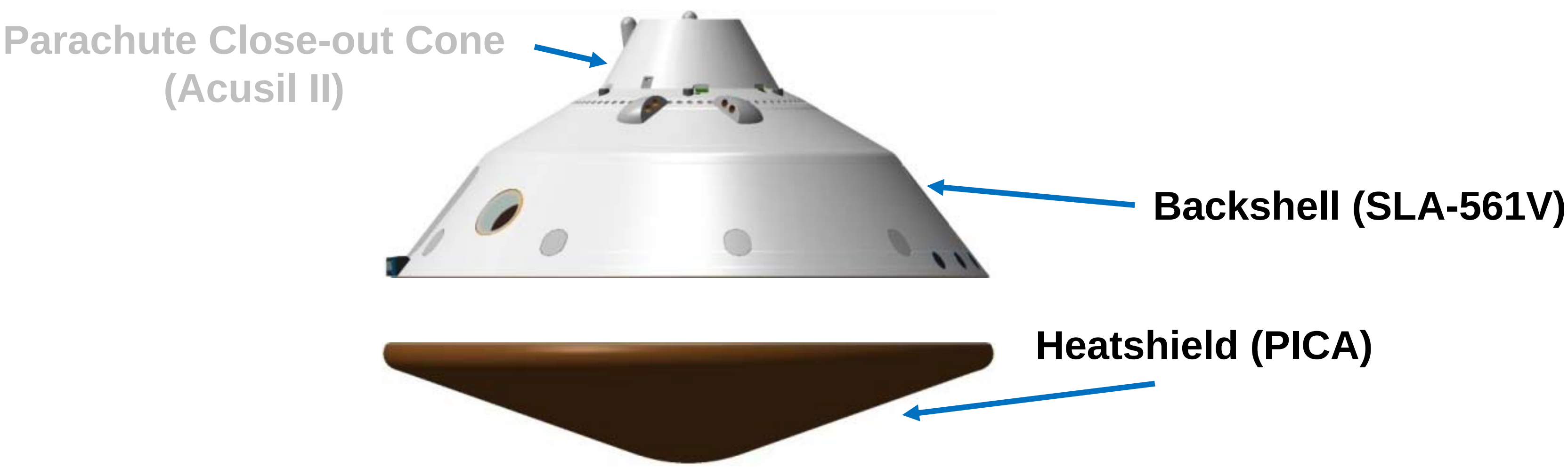
Outline

- **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**

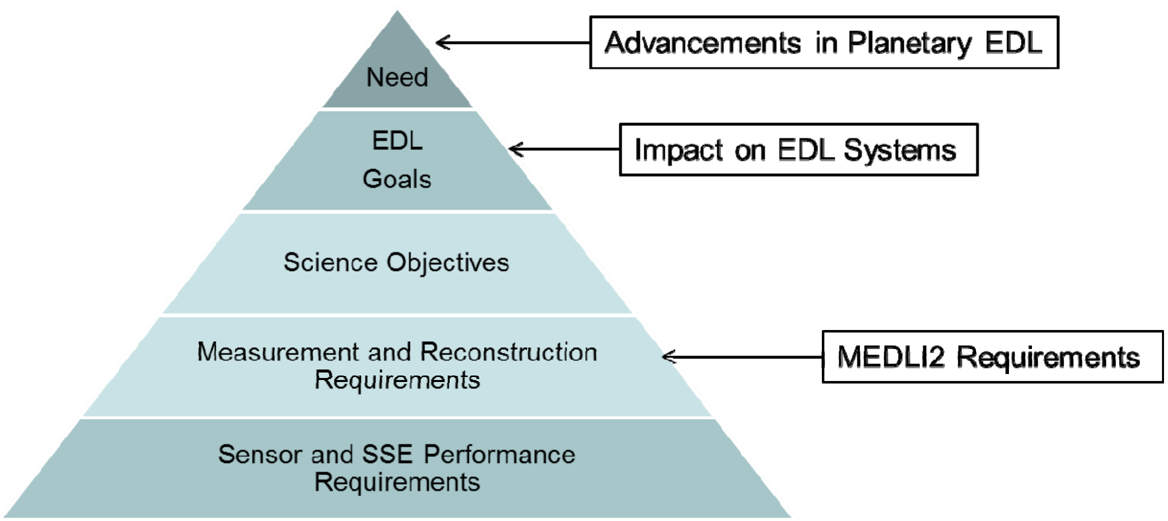
Background: Mars 2020 Entry Vehicle

- **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**

New for MEDLI2!

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**

MEDLI2 Expands Scope of Instrumentation

MEDLI on MSL (2012)

7 Hypersonic Pressure Transducers

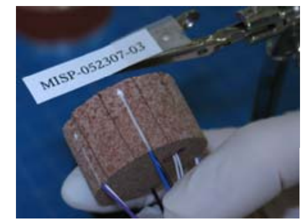
7 Instrumented Plugs
- **4 Thermocouples**
- **1 HEAT sensor**

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

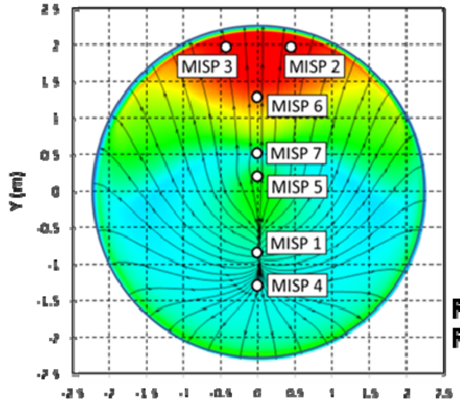
3 Heat Flux Gauges (including 1 Radiometer)

1 Sensor Support Electronics Box

MEDLI2 Instrumentation Layout

MEDLI (MSL 2012)

Thermal Instrumentation

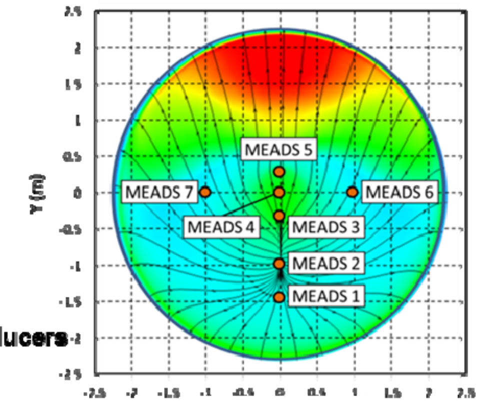


PICA Thermal Response Plugs

Heatshield

Pressure Instrumentation

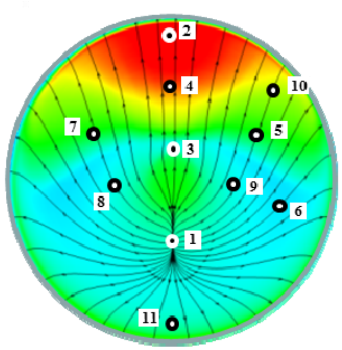
Hypersonic Pressure Transducers



Heatshield

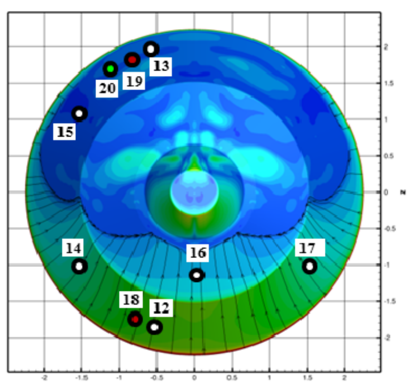
MEDLI2 (Mars 2020)

Thermal Instrumentation



- PICA Aerothermal Plug
- PICA Thermal Response Plug

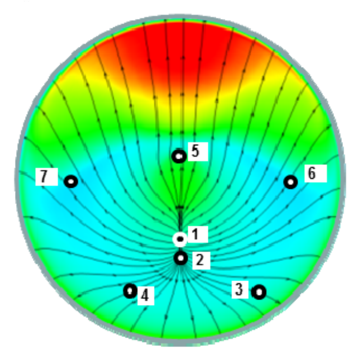
Heatshield



- SLA-561V Aerothermal Plug
- Heatflux Sensor
- Radiometer

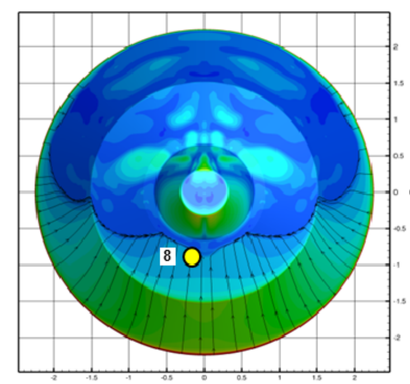
Backshell

Pressure Instrumentation



- Supersonic Pressure
- Hypersonic Pressure

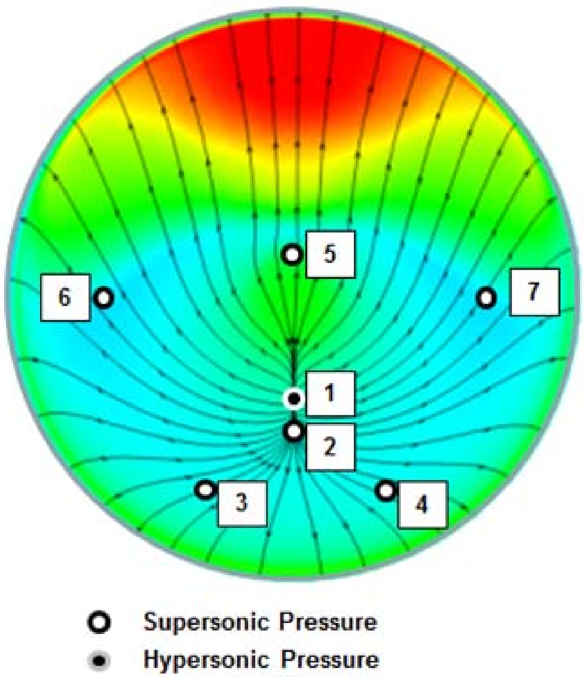
Heatshield



- Backshell Pressure

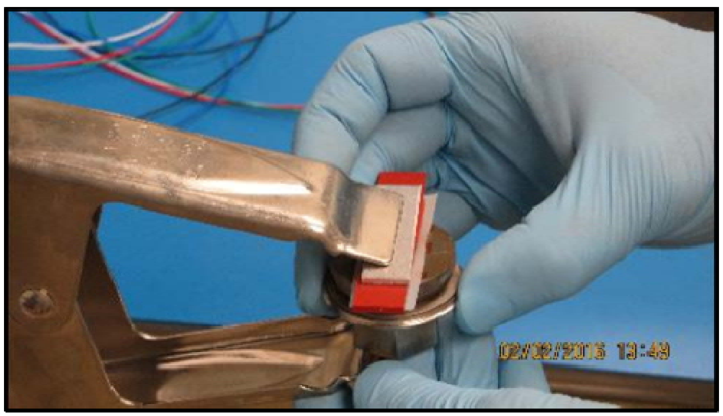
Backshell

MEDLI2 Forebody Pressure Measurement

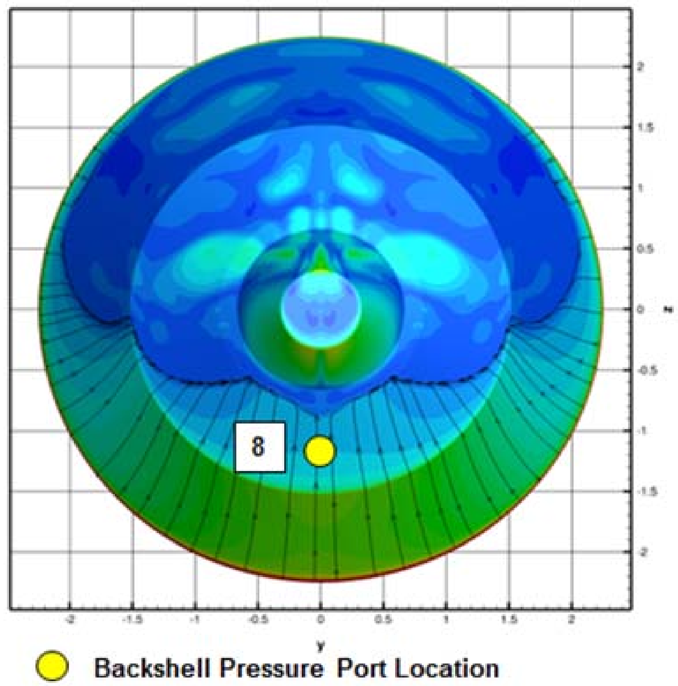


- **One pressure transducer to measure stagnation point pressure during hypersonic flight for reconstruction of atmospheric density, and C_A**
  - MEDLI flight spare
  - Target range: 1650 Pa – 35 kPa
  - Target accuracy: 1% of reading
- **Six pressure transducers measure surface pressure in the range 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



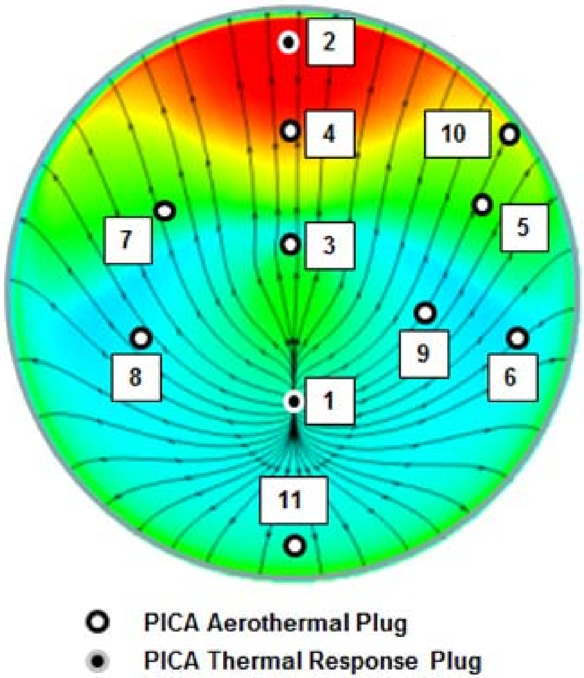
- **Driving requirement:**
  - Heatshield during cruise phase estimated to be as low as −130 °C
  - No commercially availably sensor can withstand the temperature range required
- **Proof of concept sensor constructed**
  - Disassemble and remove foil-backed strain gauge
  - Replace with COTS semiconductor 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**



- **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**

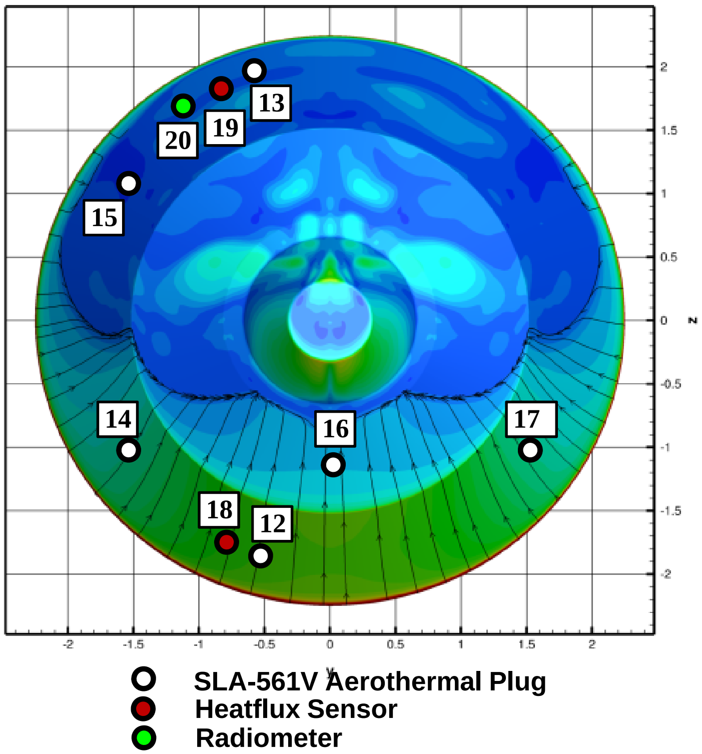
From: John Van Norman

MEDLI2 Forebody Thermal Instrumentation



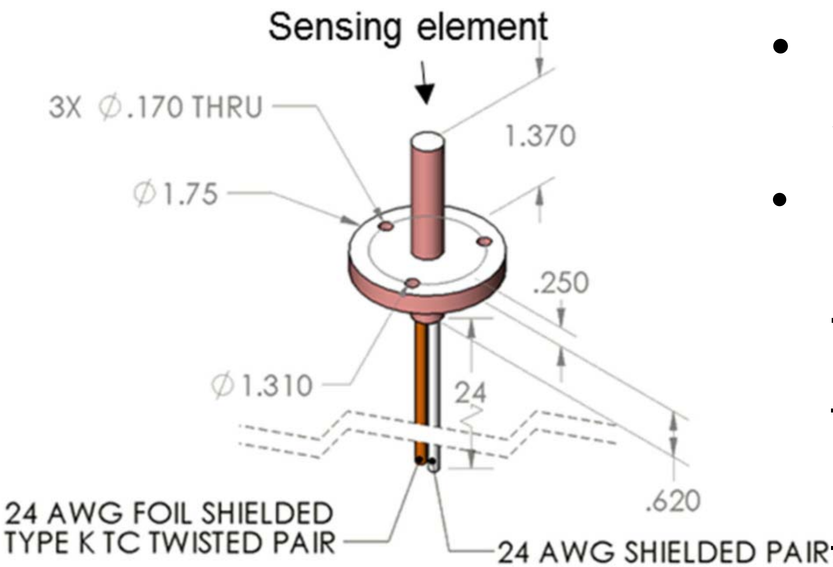
- **Science objectives: Measure baseline heating, transition to turbulence, and turbulent heating footprint**
- **Forebody thermal instrumentation includes 11 PICA plugs with embedded thermocouples**
  - Three plugs (1-3) with three thermocouples each to measure in-depth thermal response
  - Eight plugs (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/cm^2
  - ***In-depth:***
    - Type K: -270 to 1260 °C, for depths ≥ 0.1 inches
    - Target Accuracy: ±50 °C

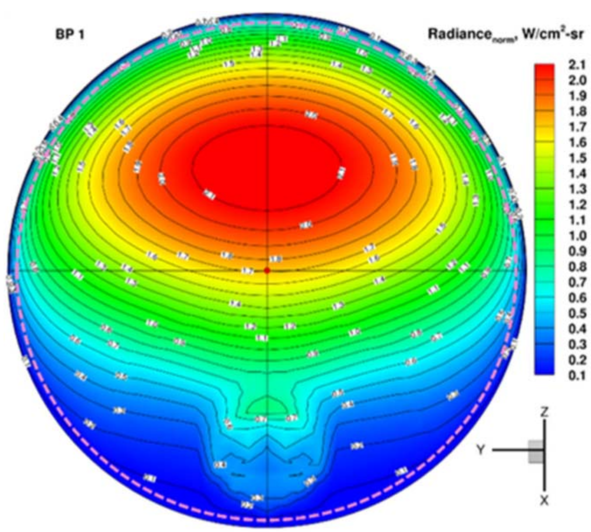
MEDLI2 Aftbody Thermal Instrumentation



- **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/cm^2
- **Heat flux gauges will directly measure total heating**
  - Target Range: 0 – 15 W/cm^2
  - Target Accuracy: ±1 W/cm^2
- **Radiometer will measure radiative heating at location predicted to be have peak radiative component**
  - Target Range: 0 – 15 W/cm^2
  - Target Accuracy: ±1 W/cm^2

Heat Flux Sensors and Radiometer





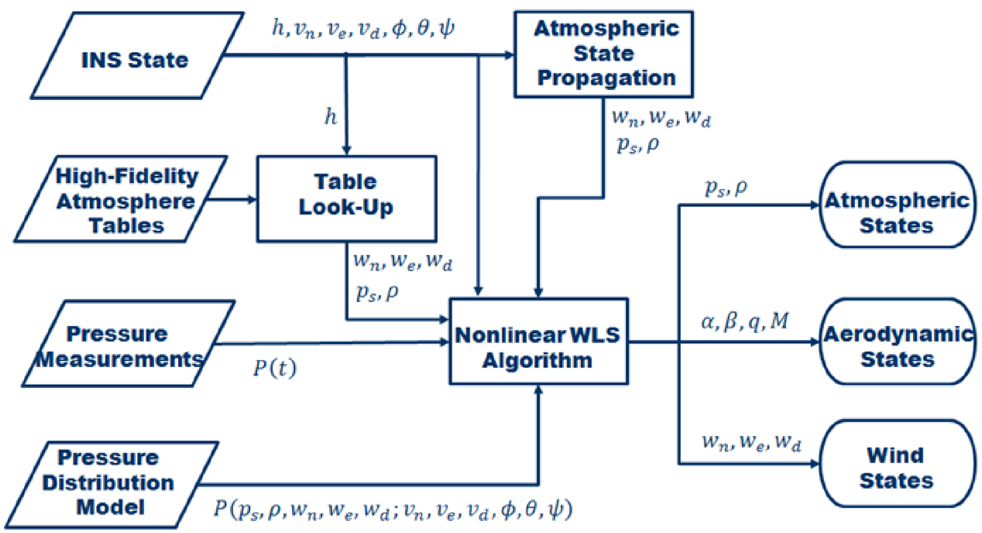
- **Heat flux sensors and radiometer are Schmidt-Boelter gauges**
- **Radiometer is a heat flux sensor with a sapphire window at the sensing element tip**
  - Sapphire blocks convective heating component
  - Wide view angle (−150°) combined with highly radiating aftbody flowfield will lead to substantial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

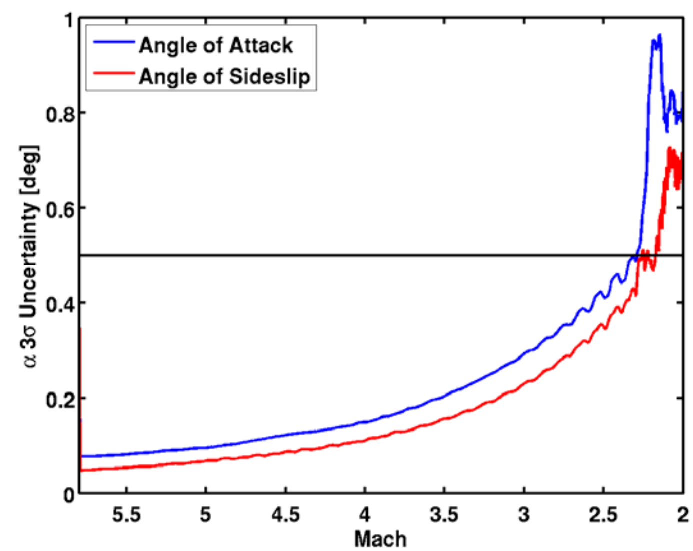
Reconstruction Targets

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

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.





Thermal Measurements Reconstruction Methodology

- **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?