The Entry Descent and Landing Instrumentation (MEDLI2) Suite for the Mars 2020 Mission

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Science Instrumentation, Experiments, and In-Situ Measurements

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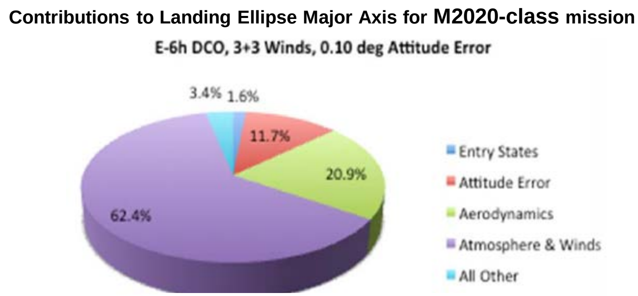
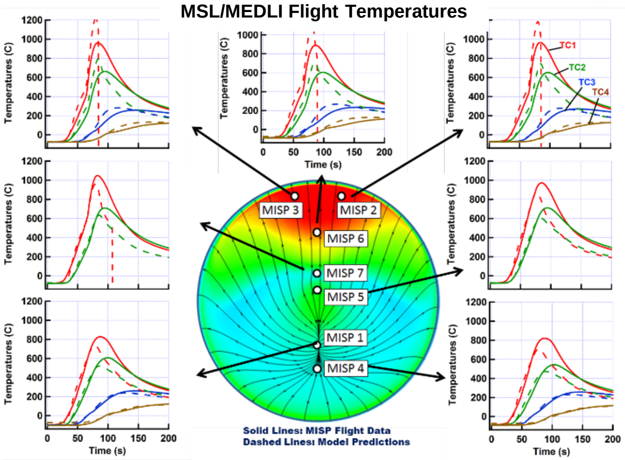
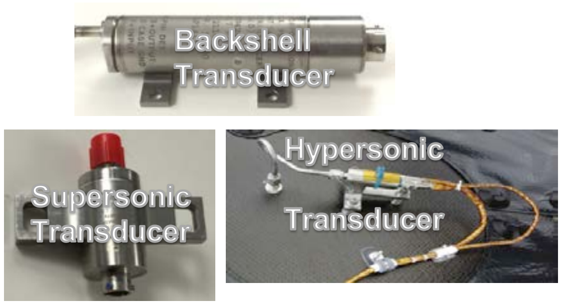
EDL Instrumentation

- Planetary entry probe missions are complex, costly, and infrequent
- It is important to the EDL and planetary exploration community to understand the entry environments, performance of the entry vehicle, and atmosphere density and winds
- Flight Instrumentation provides a valuable dataset to understand:
  - The as-flown environment, beyond the binary “it worked” or “it failed”
  - Areas of design conservatism
  - Accuracy and limitations of our state-of-the-art predictive simulations and experiments
- This data can be used for improved reliability, TPS mass reductions, and decreased landing ellipse sizes for future vehicles
  - Past instrumented EDL missions (Galileo, Space Shuttle/BLTFE, Orion EFT-1 DFI, MSL/MEDLI, Schiaparelli/AMELIA & COMARS+) always surprise us
- Mars 2020 includes MEDLI2 instrumentation suite focused on entry atmospheric, aerodynamic, aerothermal, and heatshield measurements



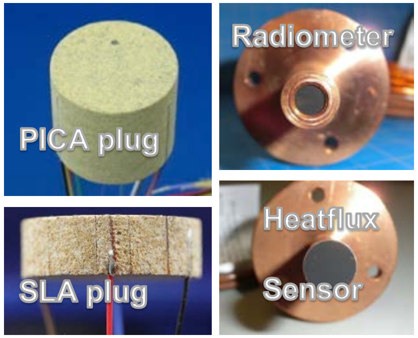


Instrumentation on M2020 Aeroshell



- Like MEDLI, MEDLI2 has three major hardware components for sensing and processing the entry environment:

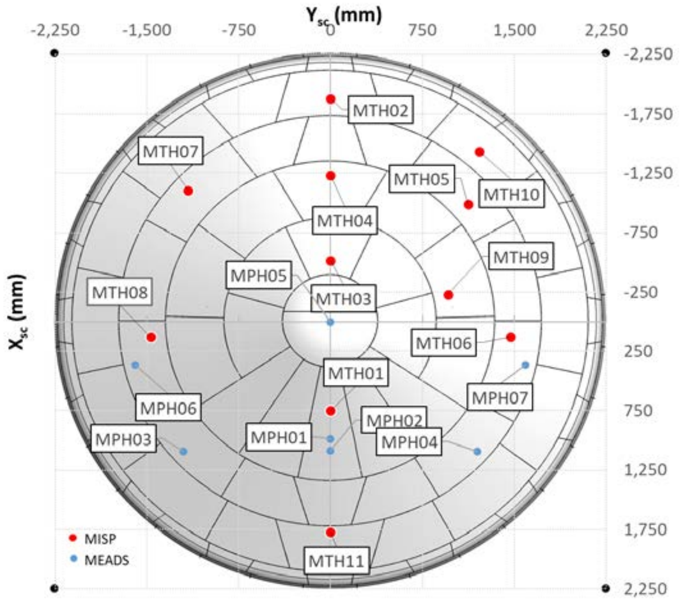
- MEADS (Mars Entry Atmospheric Data System)
  - Network of pressure transducers on the heatshield and backshell
  - These are a combination of Hypersonic, Supersonic, and low-pressure sensors

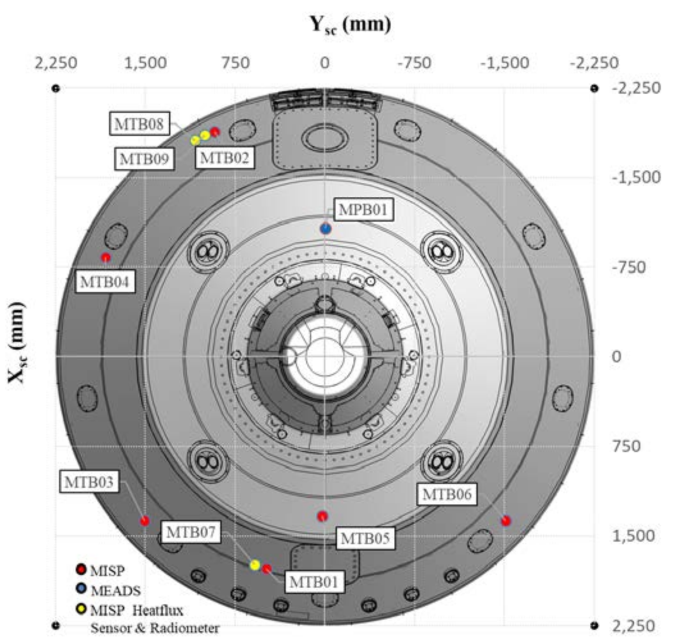


- MISP (Mars Instrumented Sensor Plugs)
  - Network of high-temperature thermocouples (TCs) embedded in thermal protection system plugs, installed across the PICA heatshield and SLA-561V backshell.
  - Two types of sensors for directly measuring incident heating on the backshell (total heating and radiative only)

- SSE (Sensor Support Electronics)
  - Multiplexing avionics for gathering, processing, and transferring MISP and MEADS sensor data to the Mars 2020 Descent Stage Power and Analog Module (DPAM)
  - Also includes harness between SSE and sensors, and from SSE to the DPAM

MEDLI2 Sensor Locations on M2020





- Measurement priorities and sensor locations were informed by MSL/MEDLI flight data
- MEDLI2 proudly continues MEDLI's nested-acronym naming convention to designate sensor locations, e.g.
  - **MPB**02: **M**EADS **P**ressure on **B**ackshell
  - **MTH**11: **M**ISP **T**hermal on **H**eatshield
- MEADS heatshield sensors were placed to optimize reconstructed vehicle angle of attack (α), sideslip (β), and atmospheric density
- MISP sensors on the heatshield were placed to capture acreage turbulent flowfield transition
  - Most plugs include on single TC
  - Some include multiple TCs to evaluate in-depth ablator performance
- Backshell MEADS port location was informed by earlier instrumented ballistic range testing
- Backshell MISP were placed to capture different types aeroheating in regions of attached and detached flow

Design and Expected Sensor Environments

- MEDLI2 sensors are designed and tested to withstand the M2020 worst-case entry (full margined) environments
  - For reconstruction, MEDLI2 also keeps track of the range of likely environments that the sensors may experience or measure.

Subsystem	Range of Design Environments	Range of Anticipated Environments
MISP, Heatshield	0-180 W/cm^2 0-5100 J/cm^2 0-0.35 atm 0-0.3" recession	0-120 W/cm2 0-3200 J/cm^2 0-0.30 atm <<0.1" recession
MISP Backshell	0-15 W/cm^2 0-400 J/cm^2 0-0.008 atm no recession	0-8 W/cm^2 0-250 J/cm^2 0-0.006 atm no recession
MEADS Backshell	0-0.0034 atm	0-0.0025 atm
MEADS Heatshield	0-0.35 atm	0-0.30 atm

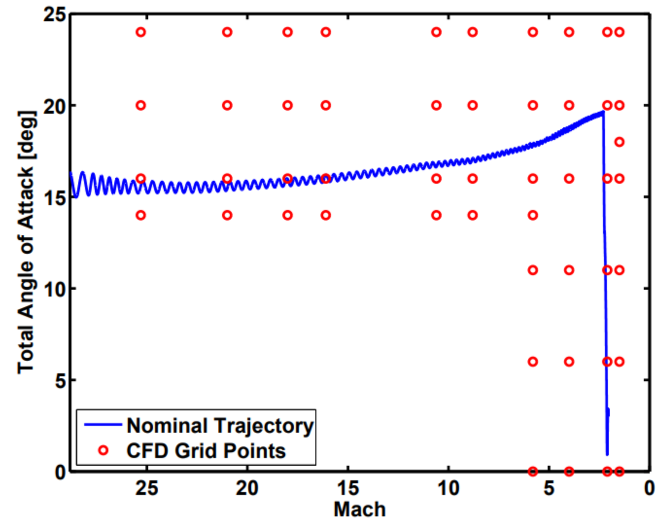
Data Rates and Live Channels

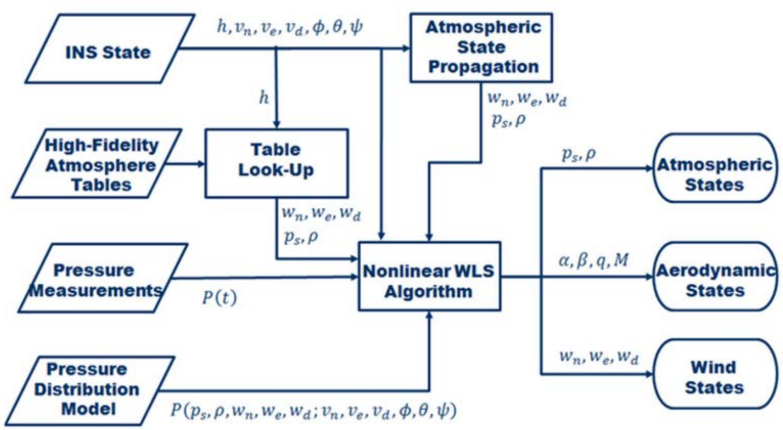
- Like MSL/MEDLI before, MEDLI2 will record ~10 minutes of EDL data up to heatshield separation
  - Most sensors data will be returned at 8Hz, with slower responding temperature measurements at 4-1Hz
  - Pressure transducers will be *filtered, and Heatflux sensors and Radiometers will be at 16Hz
  - MEDLI2 will also have a limited Real-time Data Product (**RTDP**) telemetered at 1Hz during entry:

RTDP Priorities	Name	Type	Data Rates (Hz)	Notes
Stagnation Pressure	**MPH01**	Hypersonic Pressure Transducer	8*, 1	MEDLI spare hypersonic transducer
	MPH02	Supersonic Pressure Transducer	8*, 1	Piezo Resistive Transducer with internal temperature sensor
	MPH03	Supersonic Pressure Transducer	8*, 1	Piezo Resistive Transducer with internal temperature sensor
	MPH04	Supersonic Pressure Transducer	8*, 1	Piezo Resistive Transducer with internal temperature sensor
	MPH05	Supersonic Pressure Transducer	8*, 1	Piezo Resistive Transducer with internal temperature sensor
	MPH06	Supersonic Pressure Transducer	8*, 1	Piezo Resistive Transducer with internal temperature sensor
	MPH07	Supersonic Pressure Transducer	8*, 1	Piezo Resistive Transducer with internal temperature sensor
Stagnation and Turbulent Heating	**MTH01**	3-TC PICA Plug	8, 4, 1	TCs at **1.905cm**, 5.08mm, 10.16mm
	MTH02	3-TC PICA Plug	8, 4, 1	TCs at **1.905cm**, 5.08mm, **10.16mm**
	MTH03	3-TC PICA Plug	8, 4, 1	TCs at **1.905cm**, 5.08mm, **10.16mm**
	MTH04	1-TC PICA Plug	8	TC at 2.54mm
Symmetric Acreage Heating	**MTH05**	1-TC PICA Plug	8	TC at **2.54mm**
	MTH06	1-TC PICA Plug	8	TC at 2.54mm
	MTH07	1-TC PICA Plug	8	TC at **2.54mm**
	MTH08	1-TC PICA Plug	8	TC at 2.54mm
	MTH09	1-TC PICA Plug	8	TC at 2.54mm
	MTH10	1-TC PICA Plug	8	TC at 2.54mm
	MTH11	1-TC PICA Plug	8	TC at 2.54mm
Backshell Pressure and heating	**MPB01**	Low Pressure Transducer	8*	Variable Reluctance Transducer, with external RTD
	MTB01	2-TC SLA-561V Plug	8, 4	TCs at 2.54mm, 6.35mm
	MTB02	1-TC SLA-561V Plug	8	TC at **2.54mm**
	MTB03	1-TC SLA-561V Plug	8	TC at 2.54mm
	MTB04	1-TC SLA-561V Plug	8	TC at 2.54mm
	MTB05	1-TC SLA-561V Plug	8	TC at 2.54mm
	MTB06	1-TC SLA-561V Plug	8	TC at 2.54mm
Backshell Radiation	**MTB07**	Heatflux Sensor	16, 1	Schmidt-Boelter with surface TC
	MTB08	Heatflux Sensor	16, 1	Schmidt-Boelter with surface TC
	MTB09	Radiometer	16, 1	Saphire window over Schmidt-Boelter with surface TC

Planned Reconstruction with MEADS data

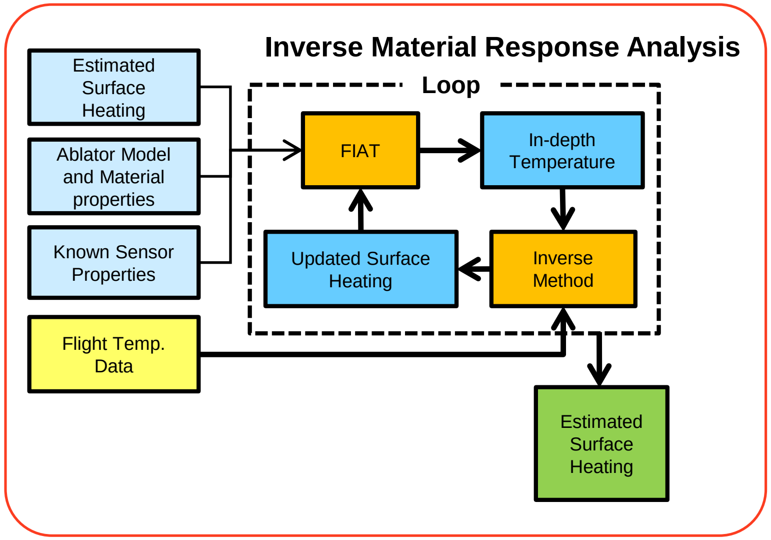
- MEADS reconstruction builds on MEDLI methods for vehicle and atmospheric reconstruction,
  - Trajectory reconstruction is performed using NewSTEP (New Statistical Trajectory Estimation Program) Extended Kalman Filter
  - NewSTEP obtains vehicle state time histories that best fit all available measurement data (accelerometer, pressure transducers, …) and pre-computed surface pressure database for the heatshield
- Linear covariance with NewSTEP has been used for generating reconstruction uncertainties
- The ongoing development is the nonlinear Monte Carlo method
- Also, reconstruction tools will handle flight-like data (format) and with sensor error models derived from actual calibration

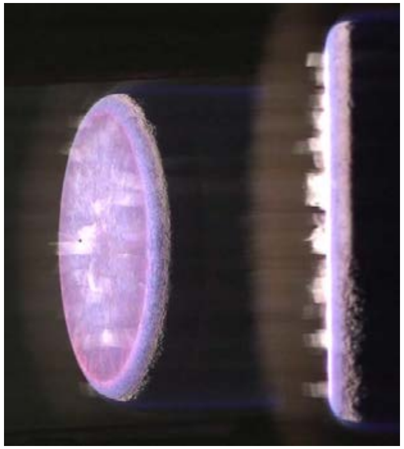




Heating Estimation with MISP data

- Similarly, MISP analysis builds on MEDLI methods for TPS and aerothermal estimation using in-depth measurements
  - Inverse methods will be used to reconstruct surface heating from in-depth temperature data collected by MISP plug TCs in PICA & SLA-561V
  - The surface heating is estimated by minimizing the difference between ablator temperature predictions and flight measurements (iterative process)
- Sensitivity and Monte Carlo analysis is used to quantify the effect of uncertainties in the input parameters on reconstructed surface heating
- Estimated heating will then be compared with backshell heatflux and radiometer measurements
- Ongoing efforts:
  - Reconstruction-specific ablator response models are being constructed based on MISP plug ablator material with dedicated experiments: $\kappa(T)$, $C_p(T)$, ε, α, etc.
  - MEDLI2 needs an analytical model for thin PICA-NuSil in ablator modeling (see Thursday's Presentation by B. Bessire)

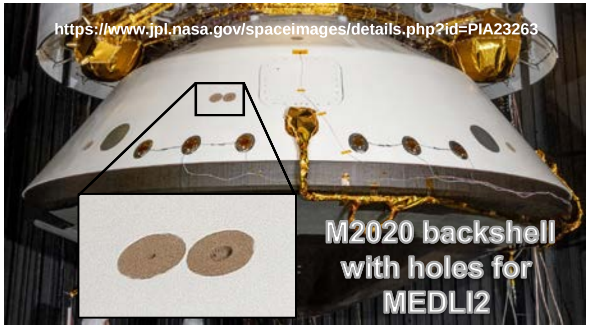




MSL and M2020 PICA heatshields included a clear NuSil spray coat on PICA, including all MEDLI/MEDLI2. This coating represses recession and lowers the surface temperature.

Status of MEDLI2 Hardware

- The backshell MEADS, and heatshield and backshell MISP flight sensors have been selected, shipped, and accepted by M2020:
  - Calibration of backshell flight and flight spare pressure transducers completed
  - Property testing competed on PICA surrounding flight plugs
  - Radiant calibration of heatflux sensor and radiometers completed
- Coming soon: Heatshield and backshell sensor integration!
  - Lockheed Martin has already drilled holes for backshell MISP and MEADS



Summary

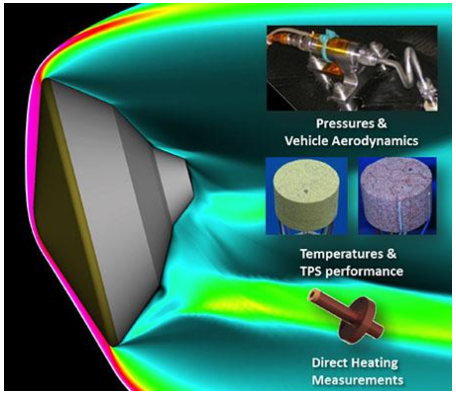
- MEDLI2 sensors will expand understanding of entry vehicle aerodynamics, atmosphere, aerothermal environments, and TPS performance
  - This time, there is increased focus on backshell pressure and heating
  - MEDLI2 Science team is extending the flight data analysis tools beyond MEDLI
- Half of MEDLI2 sensor sensors have been delivered
  - Integration with the heatshield and backshell will start soon
- M2020 Launch window opens July 17, 2020
- MEDLI2 will record EDL data on February 18, 2021
  - MEDLI2 sensor data and subsequent analysis will be shared with the broader vehicle design and EDL modelling communities

Backup

Introduction: Because entry descent and landing (EDL) missions are infrequent and involve complex physics, space agencies and spacecraft designers are increasingly instrumenting in-situ sensor suites on spacecrafts so the EDL modelling community and future mission designers can validate their models with flight data. Over the last decade, NASA [1].[2], ESA [3], and JAXA [4] have seen a resurgence in the gathering of in-situ entry aerothermal and aerodynamic data using accurate temperature and pressure sensing systems. The availability of high-quality flight data coupled with increasingly more powerful computer systems has enabled the EDL community to refine their aerothermal, aerodynamic, and thermal protection system models for various planetary missions.

Mars 2020 & MEDLI2: The Mars 2020 mission will launch in July, 2020 and will enter the Martian atmosphere on February 18th, 2021. Like the Mars Science Laboratory (MSL) mission before it, Mars 2020 includes an aeroshell instrumentation suite to accurately measure the atmospheric conditions and vehicle entry state during EDL. The Mars 2020 instrumentation suite is shown in Figure 1, and is called the Mars Entry Descent and Landing Instrumentation Suite 2, or MEDLI2 [5]. MEDLI2 is a combined effort of NASA Langley and Ames; the Jet Propulsion Laboratories; and Lockheed Martin, which is responsible for the sensors, support electronics, and integration of MEDLI2 onto the aeroshell and to the rover computer systems. Mars 2020 is a flagship-class mission, and the MEDLI2 suite includes an array of previously demonstrated instrument types flown on MSL as well as new instruments to better characterize entry phenomena at Mars. MEDLI2 will gather approximately 10 minutes of data from these sensors, starting prior to atmospheric entry and down through heatshield separation. This dataset will allow aerospace engineers to reconstruct the aerodynamic and aerothermal environment with great accuracy.

Scope of the Presentation: This presentation will discuss the current state of each of the main measurements systems for MEDLI2. The first system is a network of pressure transducers, the Mars Entry Atmospheric Data System (MEADS). Improving upon MEDLI, separate MEDLI2 pressure transducers span the measurement range suitable for both hypersonic and supersonic flows. The MEADS will also measure pressure on the backshell of the vehicle to better characterize the contribution of backshell pressure on the overall forces and moments on the entry probe. The second system is the thermal instrumentation, or Mars Instrumented Sensor Plugs. This system includes a network of high-temperature thermocouples embedded in the thermal protection system across the heatshield and backshell. The MISP also includes two types of sensors for directly measuring incident heatflux on the backshell of the vehicle. In addition, a radiometer is instrumented on the backshell to measure radiative heating. The presentation will also cover the current state of the MEDLI2 hardware, expected environments that will be measured, and data analysis techniques being developed to infer vehicle entry performance from both the MISP and MEADS sensor systems.



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[3] A. Gülhan. et al. “Aerothermal Measurements from the ExoMars Schiaparelli Capsule Entry” Journal of Spacecraft and Rockets, 2018.

[4] T. Yamada, K. Yoshihara, K. Yamada, “Hayabusa-2 Reentry Capsule and its Verification Tests”, IPPW11 (2014).

[5] H. Hwang, D. Bose, H. Wright, T. White, M. Schoenenberger, J. Santos, C. Karlgaard, C. Kuhl, T. Oishi, D. Trombetta, "Mars 2020 Entry, Descent, and Landing Instrumentation (MEDLI2)", AIAA 2016-3536.