Mars Entry, Descent, and Landing Instrumentation (MEDLI): Return on Investment

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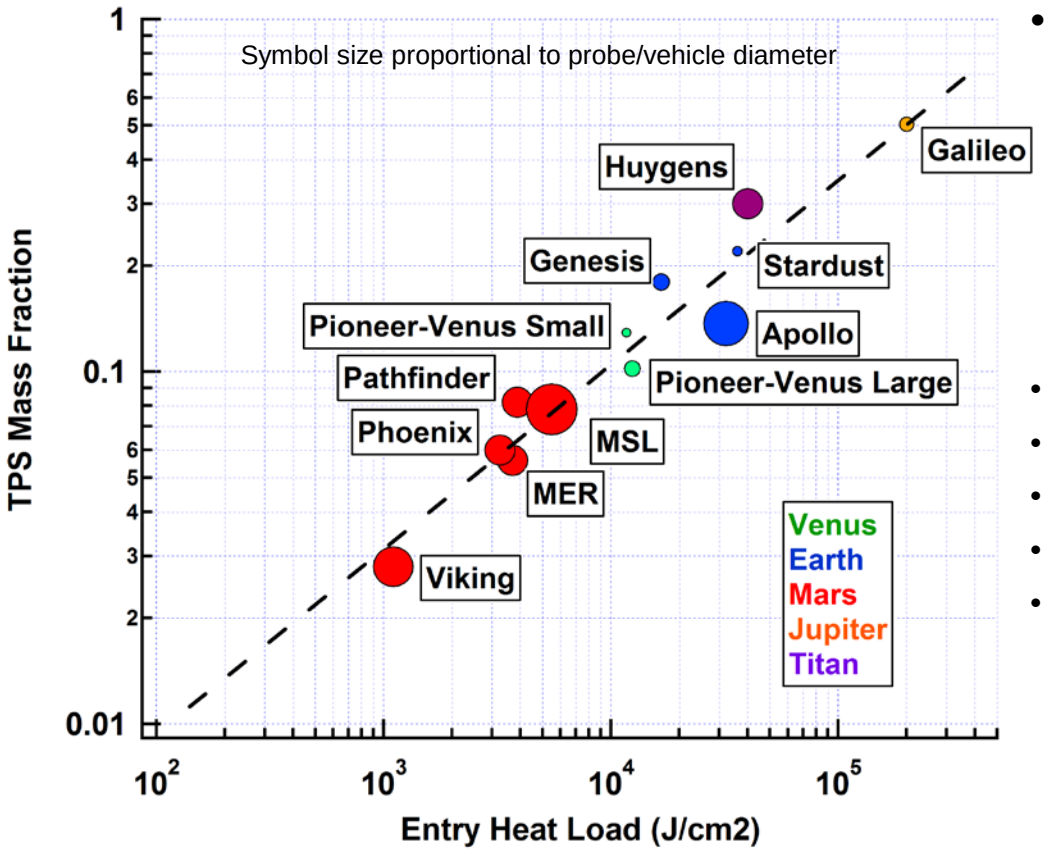
Planetary Entry Systems



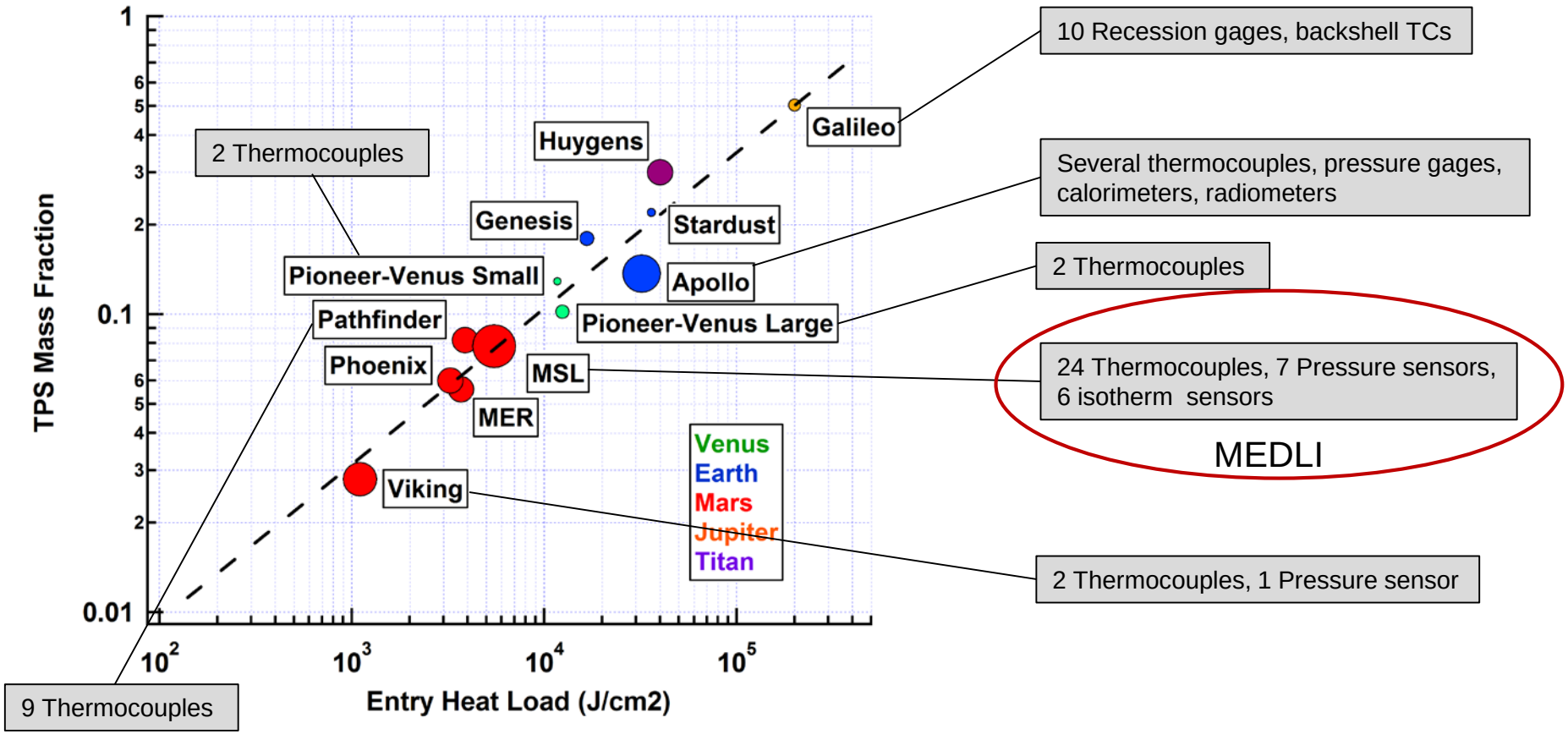
- To meet a diverse set of requirements, planetary entry systems vary significantly in size, TPS mass fraction, materials, aerodynamics, and flight profile

- Size: 0.8-4.5 m
- Aerodynamics: Ballistic to Lifting & Guided
- Aeroheating: few 10s W/cm^2 to a few kW/cm^2
- Atmosphere: Air, CO_2/N_2, H/He, N_2/CH_4
- Forebody TPS: SLA, PICA, AVCOAT, Carbon-Phenolic, etc.

Mission opportunities are limited, and most are unique

Flight instrumentation is key to maximizing learning from each opportunity

Entry Flight Aero/TPS Instrumentation

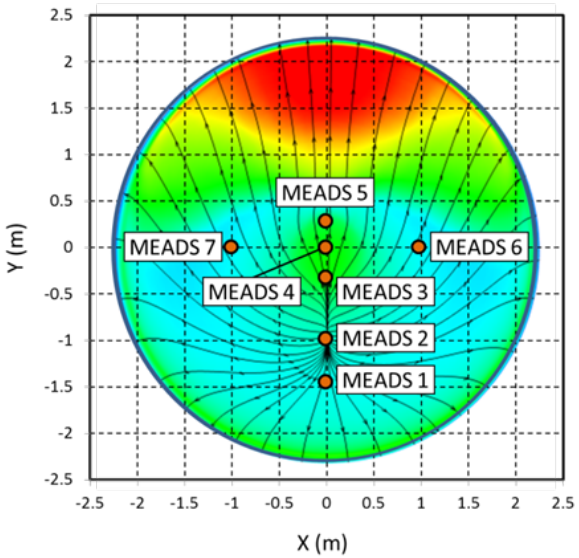


- Except Apollo missions, past flight instrumentation has been scant
- Several past instrumentation efforts have also suffered from malfunction or data analysis challenges
- MEDLI instrumentation has performed reliably and demonstrated robust flight instrumentation technologies

MEDLI: An Instrumentation Suite on MSL Heatshield

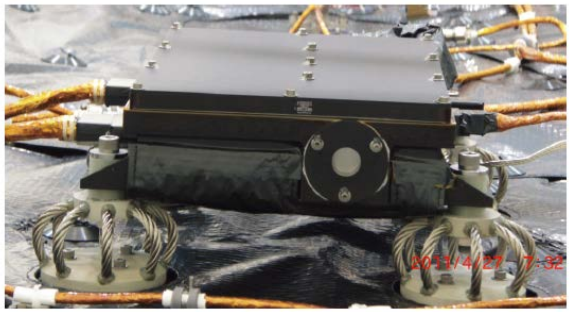
MEADS: Pressure Sensors

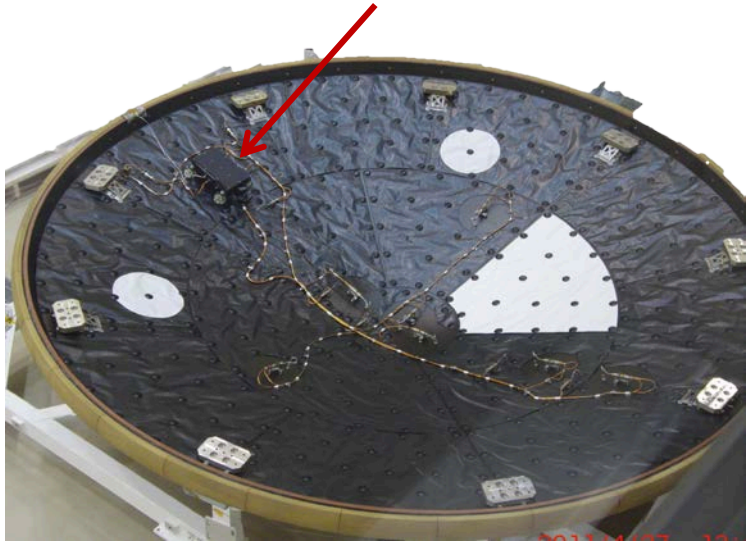
7 Pressure Ports in the PICA TPS



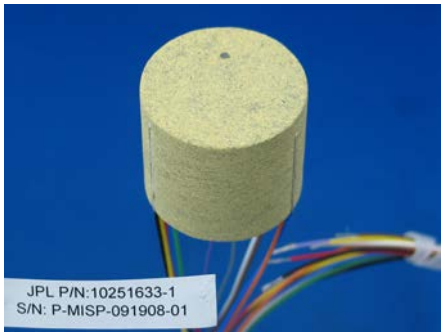
SSE: Sensor Support Electronics

For signal conditioning and sensor excitation

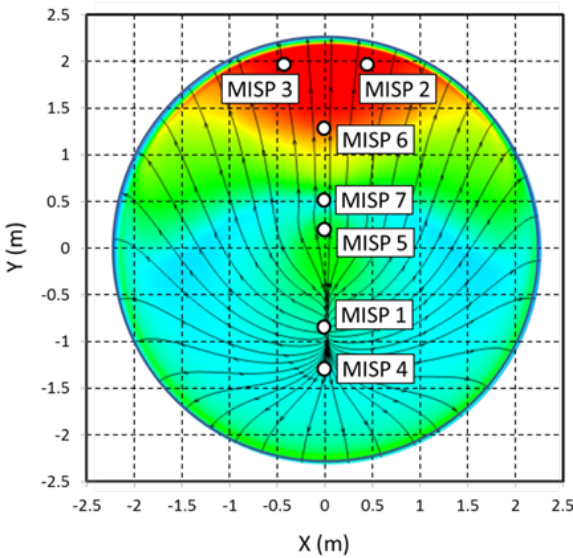




MISP: Thermal Plug

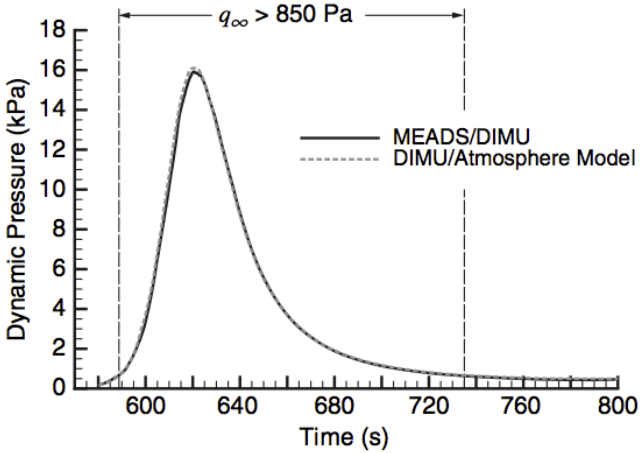


7 Plugs in the PICA TPS

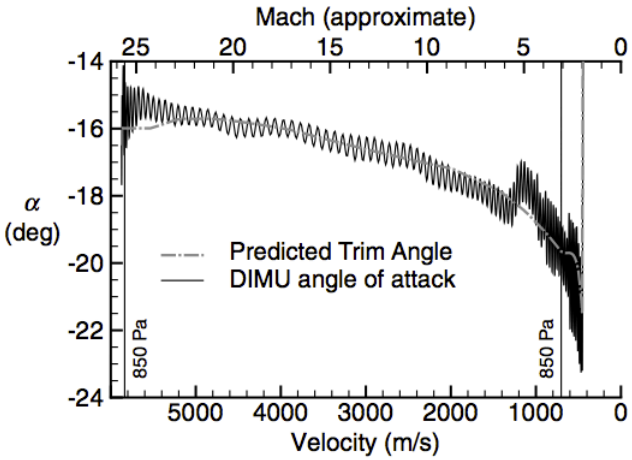


Findings: Atmosphere and Aerodynamics

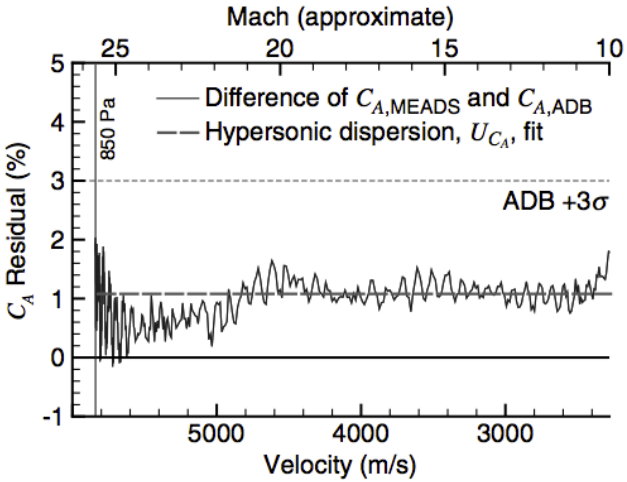
- Vehicle dynamics pressure reconstructed: agrees within ±2% with purely IMU based reconstruction
- Vehicle angle of attack and side-slip angle reconstructed (within 0.5˚)
- Vehicle drag coefficient validated (within 1%)
- In-situ atmospheric density reconstructed



Dynamic Pressure

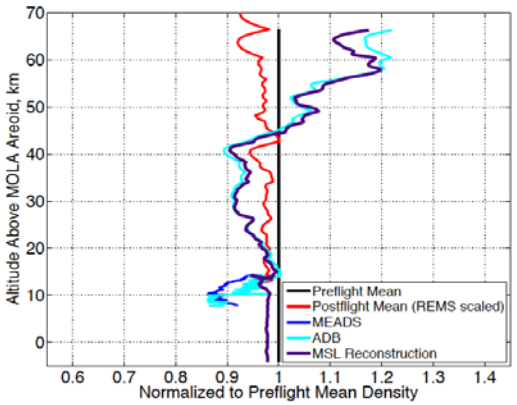


Angle of Attack



Aerodynamic Drag

From Chen et al.

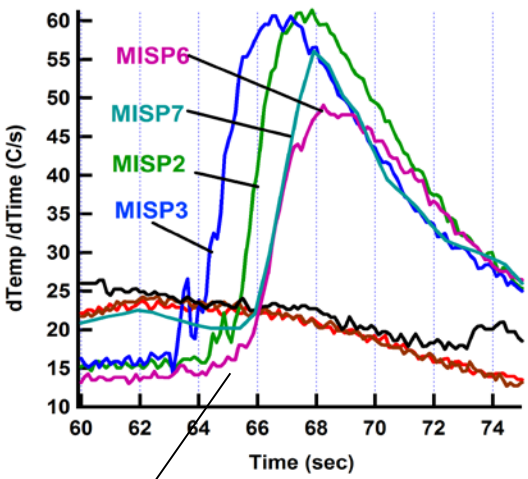


Atmospheric Density

Findings: Aerothermal Environment

- Boundary layer transition occurred on the leeside and moved rapidly upstream, suggesting a roughness induced transition
  - Development/Validation of transition criteria in flight environment
- Leeside turbulent aeroheating on forebody explained well by RANS model
  - No roughness augmentation needed, except at the trip location (trip overshoot)
- Windside laminar aeroheating under predicted
  - Additional heating mechanism, such as radiation maybe explain the difference

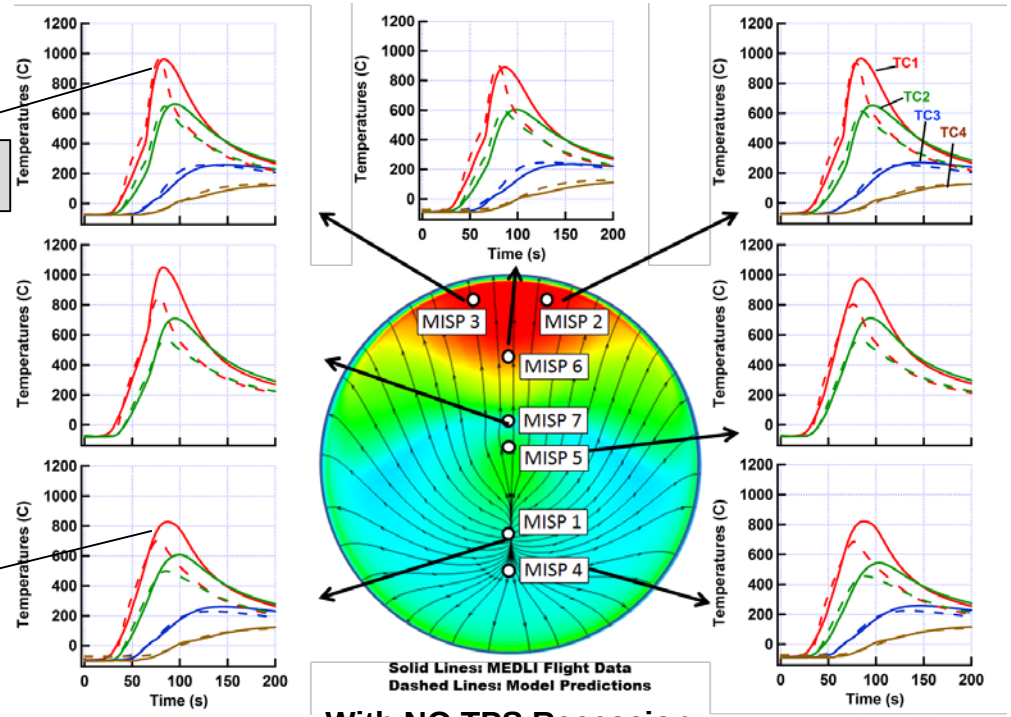
TC	Depths
TC1	0.1 in
TC2	0.2 in
TC3	0.45 in
TC4	0.7 in



Boundary Layer Transition

Turbulent Heating Prediction

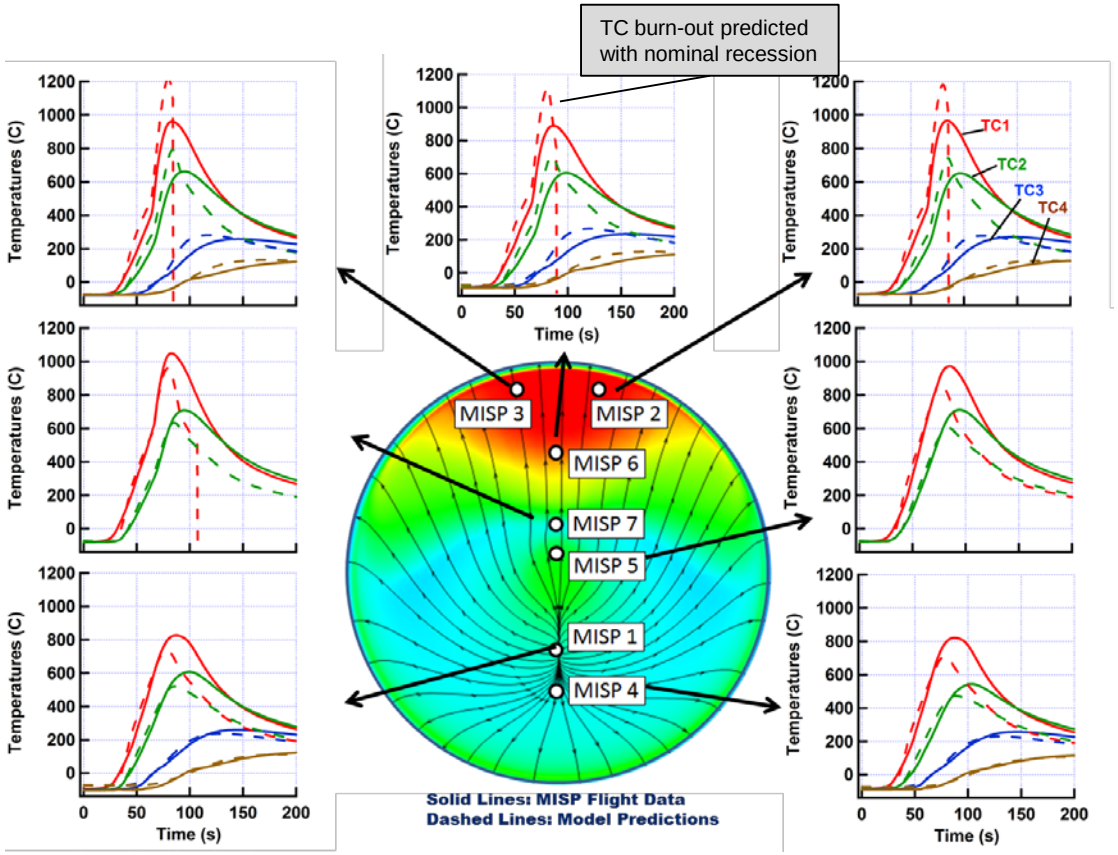
Winside Laminar Heating Underprediction



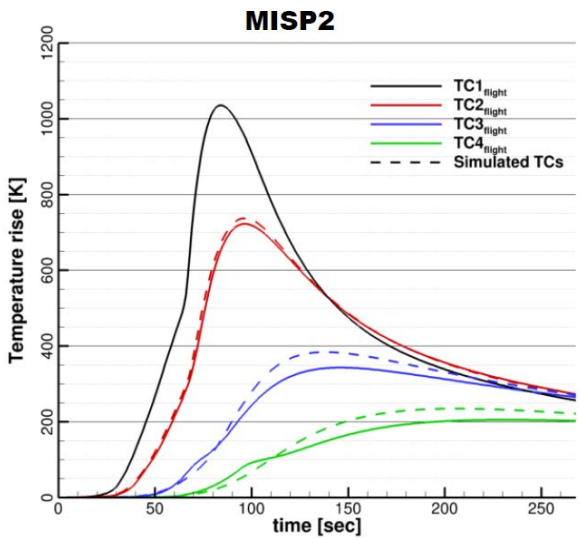
With NO TPS Recession

Findings: Thermal Protection System

- TPS recession lower than predicted
  - All TCs 0.1-in deep survived the heat pulse; predicted recession 0.16-in
- In-depth thermal response predicted within ± 50 C



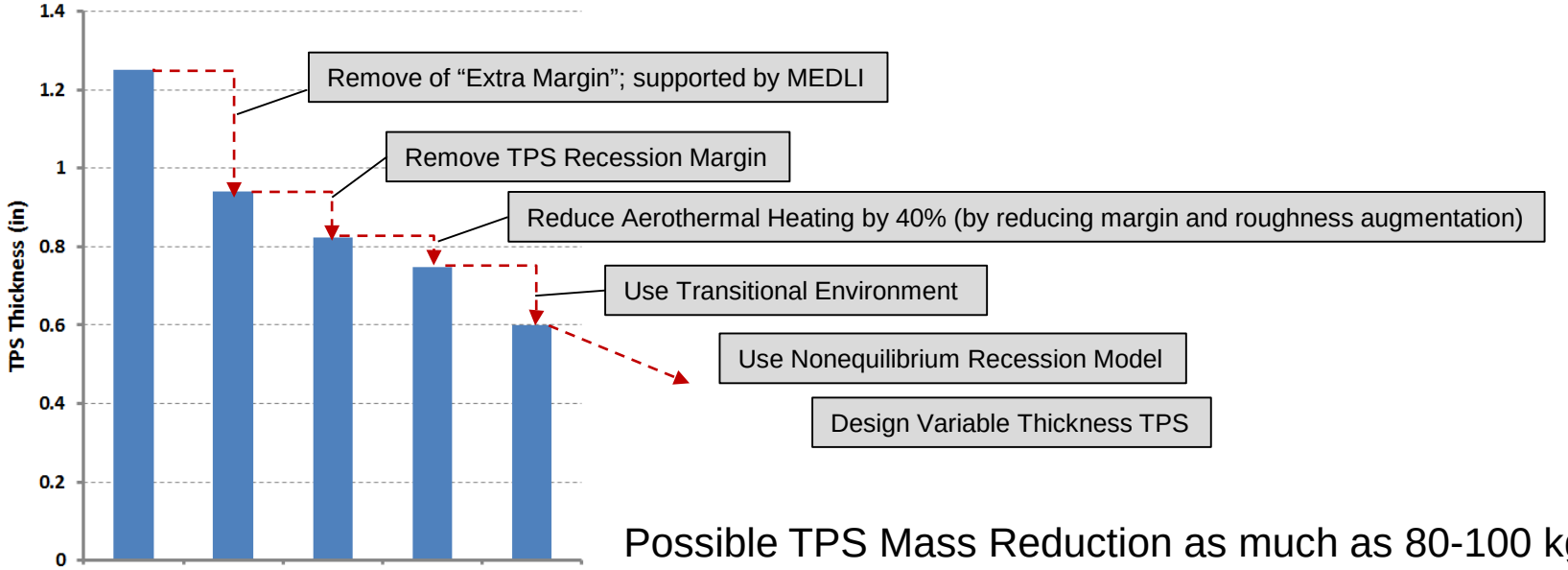
With Nominal TPS Recession



TC Driver Modeling: In-depth temps predicted with 50 C

Path to Reducing TPS Mass (MSL Example)

Impact of MEDLI on MSL TPS Design Margins		
	Pre-Flight	**Finding from MEDLI**
Turbulent Aeroheating Margin	35%	Excessive, not needed to explain data
Stagnation Point Heating	50%	Needed, radiative heating likely
Turbulent Roughness Augmentation	20%-30%	Not needed to explain data except at trip locations
Boundary Layer Transition	Fully Turbulent	Only on leeside forebody, roughness induced
Thermal Margin	45-60F	Margin needed
TPS Recession	150%	Not needed, even un-margined prediction too high



Possible TPS Mass Reduction as much as 80-100 kg!

Impact on EDL Missions

- **Mars InSight (2016)**
  - While InSight is a Phoenix build-to-print, it has a higher entry speed, higher ballistic coefficient, and is flying during dust storm season (i.e. extra recession)
  - MEDLI data assisted in defining aerothermal entry environment
    - MEDLI data provided guidance on transition to turbulence mechanism & criteria
    - MEDLI data was used to affirm the possibility of radiative heating at moderate Mars entry speeds
  - MEDLI data provided confidence, reduced risk, and likely avoided testing and analysis cost
- **Orion Exploration Flight Test -1 (2014)**
  - TPS Instrumentation suite based on MEDLI design
  - Reconstruction techniques heavily leveraged from MEDLI

Mars InSight (2016)

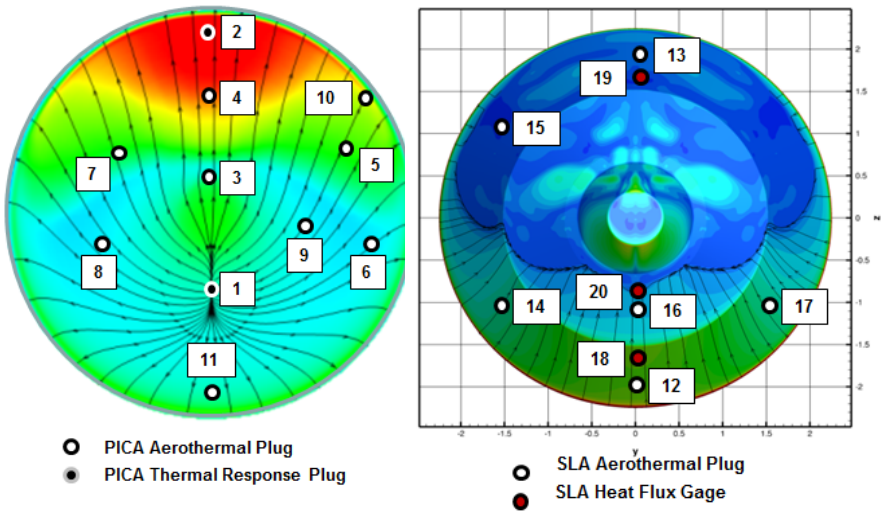
Orion Exploration Flight Test-1 Vehicle

Summary of MEDLI Impact

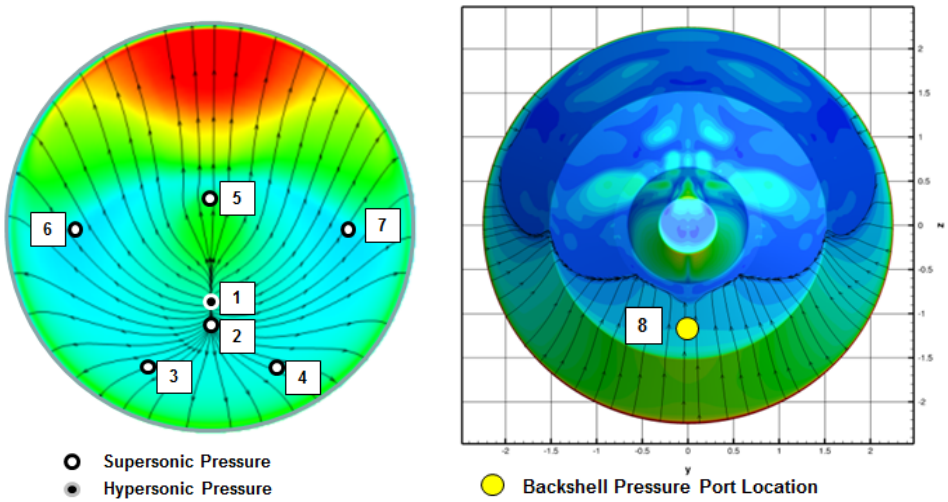
- **EDL Reconstruction (for host mission):**
  - Reconstruction of trajectory, atmosphere, aerodynamic, aerothermodynamic, and TPS response
  - Provide forensic data, if needed
- **Reduce Mission Risk:**
  - Better definition of Mars Insight entry aerothermodynamics
  - Mars-2020 aero, aerothermodynamics, TPS performance, now well understood
  - Low risk instrumentation suite for Orion EFT-1
- **Identify Capability Limits of Build-to-Print Systems:**
  - Build-to-print systems can be taken further than originally designed
- **Increase System Performance:**
  - Clear path to reducing significant TPS from MSL-class vehicles
  - Reduce aerodynamic uncertainties and isolate wind effects → increase landing accuracy
- **Reduce System Development Cost:**
  - MEDLI data will enable relaxed Mars entry Aerothermal & TPS requirements
  - MEDLI data can also be used to justify reduced test and analyses

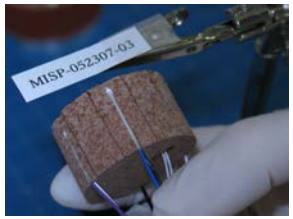
What’s Next?

MEDLI-2 Instrumentation for Mars 2020 Mission



Thermal Instrumentation



Pressure Instrumentation

- Forebody thermal instrumentation spread over larger area of the heatshield
- Pressure transducers relevant for supersonic range replace all but one hypersonic pressure transducer
- Backshell instrumentation includes SLA thermal plugs, heat flux gages, and a pressure transducer