Mars2020 Entry, Descent, and Landing Instrumentation (MEDLI2): Project Overview

Deepak Bose
MEDLI2 Principal Investigator
NASA Ames Research Center, Moffett Field, CA

Henry Wright
MEDLI2 Project Manager
NASA Langley Research Center, Hampton, VA

NASA EDL Instrumentation

Year	Mission	Planet	Forebody TPS	Afterbody TPS	TCs	Pressure	Heat Flux	Calorimeter	Radiometer/ Spectrometer	Recession/ Isotherm
1965	FIRE II	Earth	Beryllium	Fiberglass	X	X	X	X	X	
1966	Apollo AS-201	Earth	Avcoat	Avcoat	X	X	X	X		
1966	Apollo AS-202	Earth	Avcoat	Avcoat	X	X	X	X		
1967	Apollo 4	Earth	Avcoat	Avcoat	X	X		X	X	
1968	REENTRY-F	Earth	Beryllium	Glass-Phenolic	X	X	X			
1968	Apollo 6	Earth	Avcoat	Avcoat	X	X		X	X	
1971	PAET	Earth	Beryllium & Silicon Ealstomer	Silicon Elastomer	X	X	X		X	
1975	Viking	Mars	SLA-561	None	X	X				
1978	Pioneer Venus Large	Venus	Carbon-Phenolic		X					
1978	Pioneer Venus Small	Venus	Carbon-Phenolic		X					
1981	Shuttle	Earth	Reuseable	Reuseable	X	X	X			
1995	Galileo	Jupiter	Carbon-Phenolic	Phenolic-nylon	X			X		X
1997	Mars Pathfinder	Mars	SLA-561V	SLA-561S/SIRCA	X					
2012	IRVE-3	Earth	Rigid nose & Flexible Insulator	None	X	X	X			
2012	MSL-MEDLI	Mars	PICA	SLA-561V	X	X				X
2014	Orion EFT-1	Earth	Avcoat	Tiles	X	X			X	X
2015	LDSD-SIAD	Earth	Kevlar Attached Torus	None	X	X				
2018	Orion EM-1	Earth	Avcoat	Tiles	X	X			X	
2020	Mars2020-MEDLI2	Mars	PICA	SLA-561V	X	X	X		X	

Synthesized from Woollard, Braun, and Bose

NASA EDL Instrumentation

Year	Mission	Planet	Forebody TPS	Afterbody TPS	TCs	Pressure	Heat Flux	Calorimeter	Radiometer/ Spectrometer	Recession/ Isotherm
1965	FIRE II	Earth	Beryllium	Fiberglass	X	X	X	X	X	
1966	Apollo AS-201	Earth	Avcoat	Avcoat	X	X	X	X		
1966	Apollo AS-202	Earth	Avcoat	Avcoat	X	X	X	X		
1967	Apollo 4	Earth	Avcoat	Avcoat	X	X		X	X	
1968	REENTRY-F	Earth	Beryllium	Glass-Phenolic	X	X	X			
1968	Apollo 6	Earth	Avcoat	Avcoat	X	X		X	X	
1971	PAET	Earth	Beryllium & Silicon Ealstomer	Silicon Elastomer	X	X	X		X	
1975	Viking	Mars	SLA-561	None	X	X				
1978	Pioneer Venus Large	Venus	Carbon-Phenolic		X					
1978	Pioneer Venus Small	Venus	Carbon-Phenolic		X					
1981	Shuttle	Earth	Reuseable	Reuseable	X	X	X			
1995	Galileo	Jupiter	Carbon-Phenolic	Phenolic-nylon	X			X		X
1997	Mars Pathfinder	Mars	SLA-561V	SLA-561S/SIRCA	X					
2012	IRVE-3	Earth	Rigid nose & Flexible Insulator	None	X	X	X			
2012	MSL-MEDLI	Mars	PICA	SLA-561V	X	X				X
2014	Orion EFT-1	Earth	Avcoat	Tiles	X	X			X	X
2015	LDSD-SIAD	Earth	Kevlar Attached Torus	None	X	X				
2018	Orion EM-1	Earth	Avcoat	Tiles	X	X			X	
2020	Mars2020-MEDLI2	Mars	PICA	SLA-561V	X	X	X		X	

Instrumentation of a variety of TPS martials

TCs and Pressure Transducers are most desired

Heat flux gages and calorimeters are preferred for moderate non-ablative environments

Radiometers and recession sensors have been used with limited success

MEDLI2 Science Objectives

Aerothermal & TPS

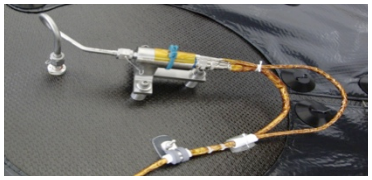
- Determine Forebody Aerothermal Heating
- Determine In-depth TPS Temperature
- Determine Backshell Aerothermal Environment

Aerodynamics and Atmosphere

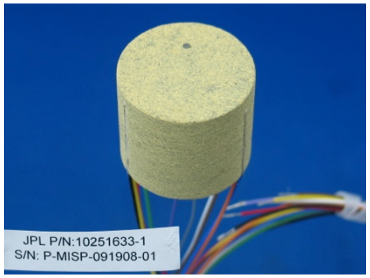
- Reconstruct Atmospheric Density, Winds, and Wind-Relative Attitude
- Determine Hypersonic & Supersonic Aerodynamics Forces
- Base Pressure Contribution to Drag

MEDLI and MEDLI2: Payload Differences

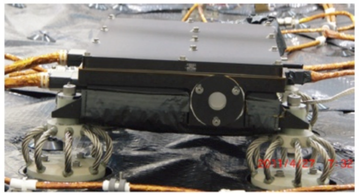
MEDLI on MSL(2012)



7 HYP Pressure Transducers

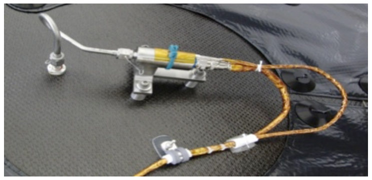


7 Instrumented Plugs
- **4 TCs**
- **1 HEAT sensor**

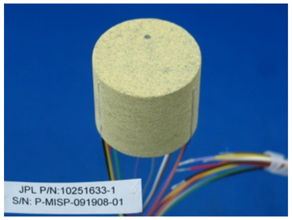


1 Sensor Support Electronics Box

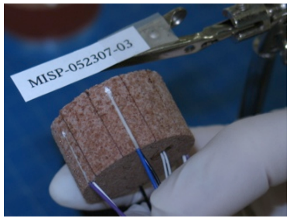
MEDLI2 on Mars 2020



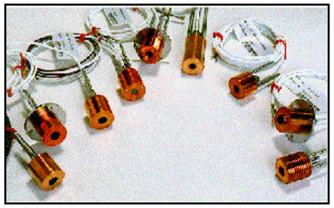
1 HYP, 6 SUP, and 1 Backshell Pressure Transducers



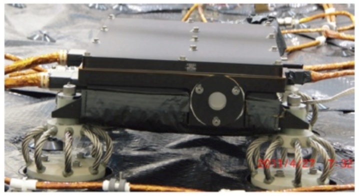
11 Instrumented PICA Plugs



6 Instrumented SLA Plugs



3 Heat Flux Gages

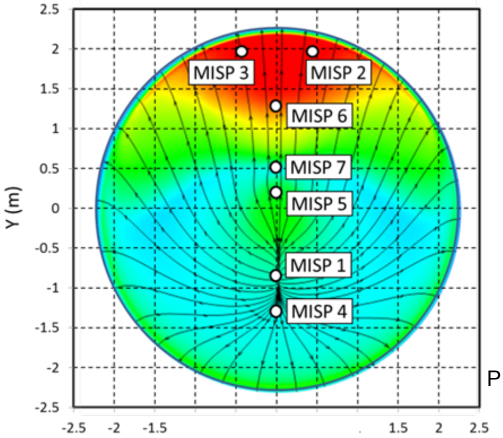


1 Sensor Support Electronics Box

MEDLI vs. MEDLI-2 Instrumentation Layout

MEDLI (2012)

Thermal Instrumentation (MISP)

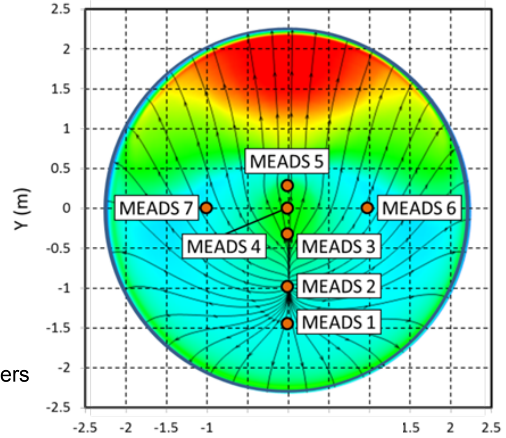


PICA Thermal Response Plugs

Heatshield

Pressure Instrumentation (MEADS)

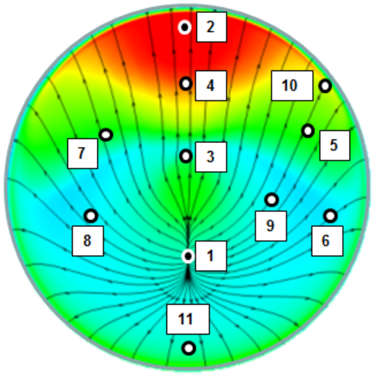
HYP Pressure Transducers



Heatshield

MEDLI2 (2020)

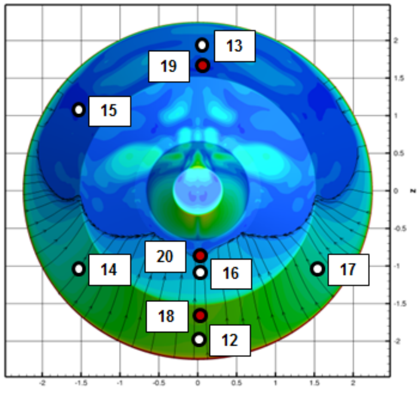
Thermal Instrumentation (MISP)



○ PICA Aerothermal Plug

◉ PICA Thermal Response Plug

Heatshield

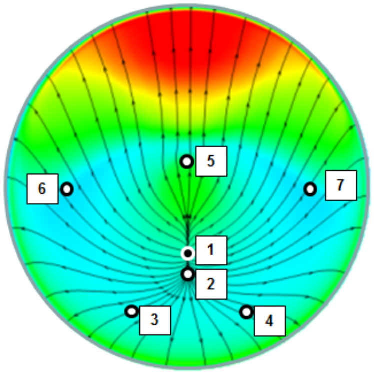


○ SLA Aerothermal Plug

● SLA Heat Flux Gage

Backshell

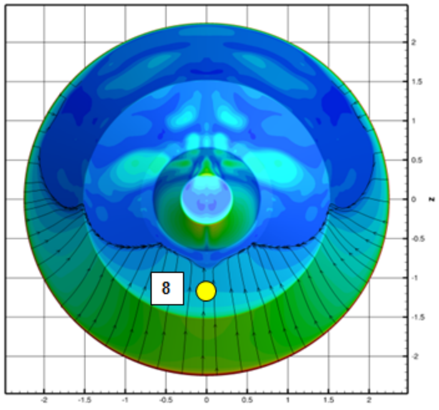
Pressure Instrumentation (MEADS)



○ Supersonic Pressure

◉ Hypersonic Pressure

Heatshield

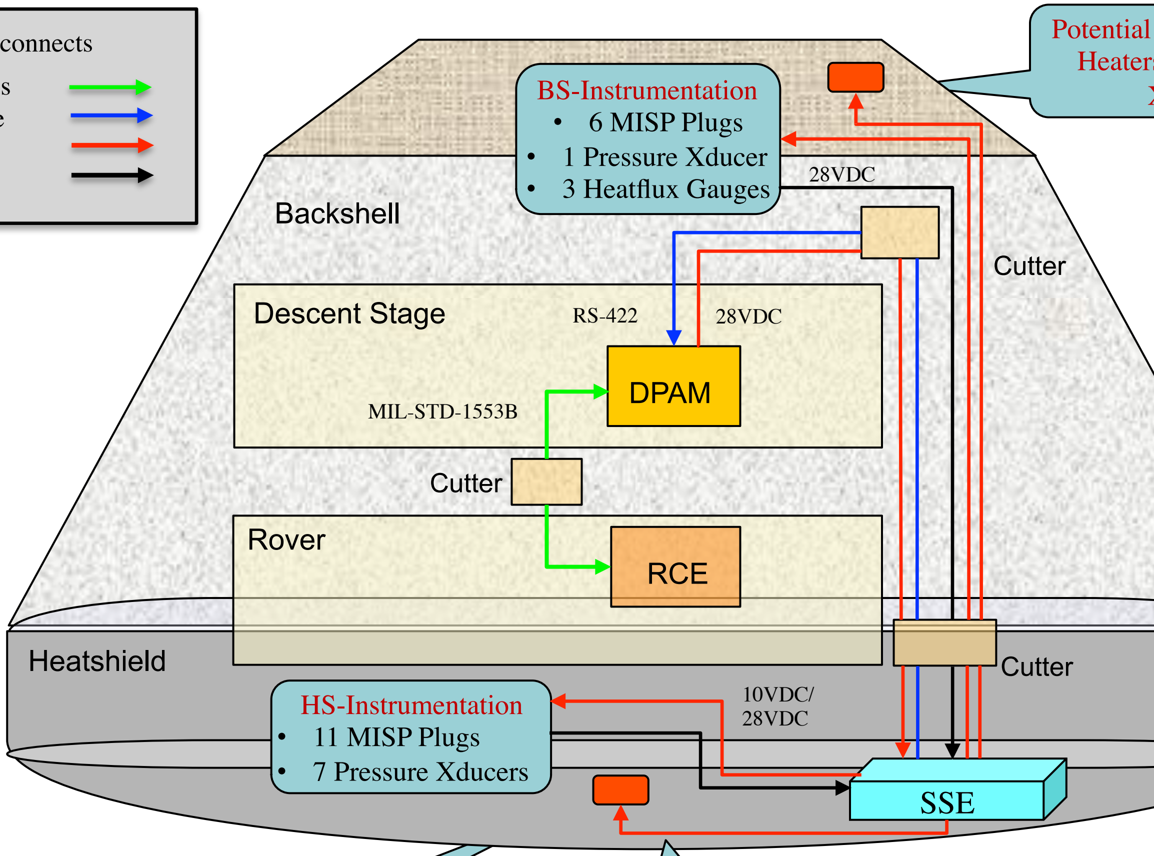


● Backshell Pressure Port Location

Backshell

MEDLI2 Electrical Implementation

Interconnects
- 1553 Data Bus →
- 422 Data Line →
- Power →
- Signal →

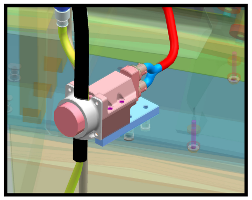


BS-Instrumentation
- 6 MISP Plugs
- 1 Pressure Xducer
- 3 Heatflux Gauges

HS-Instrumentation
- 11 MISP Plugs
- 7 Pressure Xducers

Potential Pre-Operational Heaters for Pressure Xducers

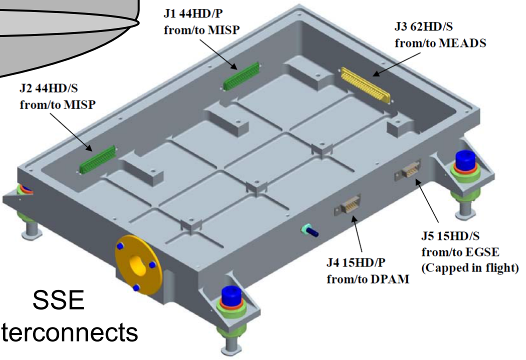
BS-HS Cutter Conductor: 50 Includes SSE redundant power, RS422 Output to Cable Cutter and all Backshell Power, Signal, Signal Returns. Note: does not include wires for potential heaters



BS-HS Cutter

Potential Pre-Operational Heaters for Pressure Xducers

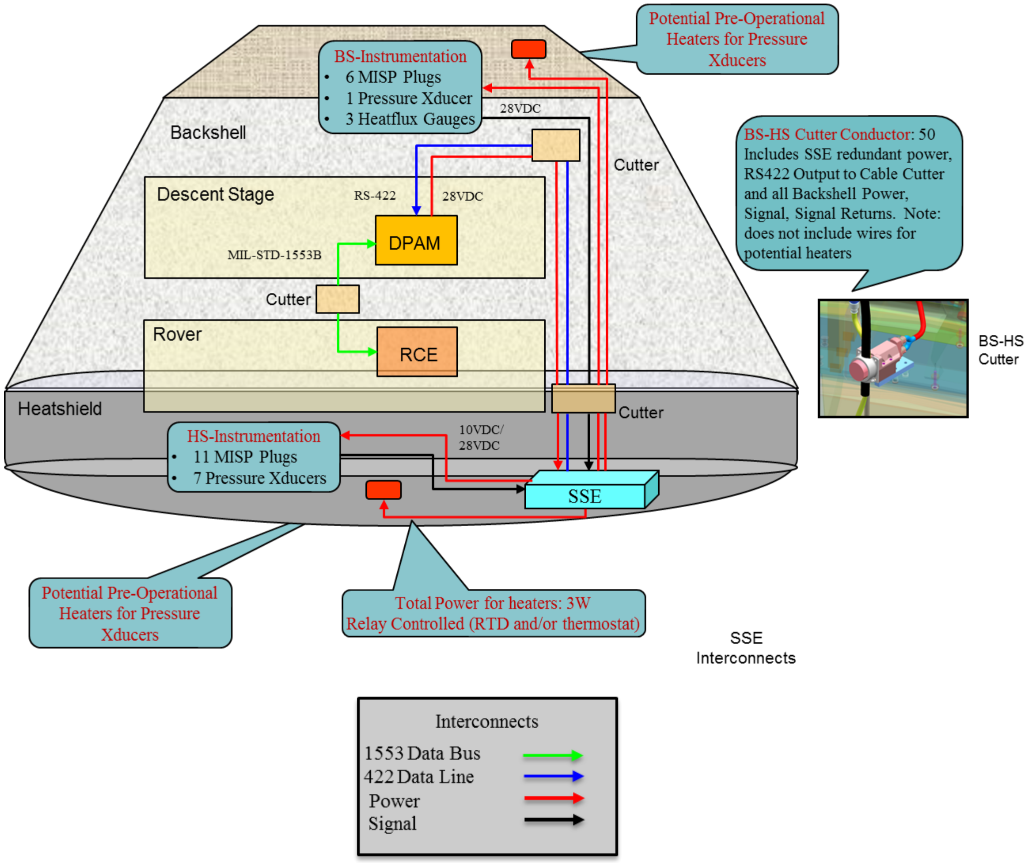
Total Power for heaters: 3W
Relay Controlled (RTD and/or thermostat)



SSE Interconnects

MEDLI2 Constraints

- Minimize changes to SSE
- No. of data channels must be similar to MEDLI
- Data bandwidth: 6 Addresses (up from 4)
- Cable cutter constraint
- Mass, Power, and Volume constraints
- Physical interference and keep-out zones
- Limited sensor installation and mounting options
- Sensor heaters



Potential Pre-Operational Heaters for Pressure Xducers

BS-Instrumentation
- 6 MISP Plugs
- 1 Pressure Xducer
- 3 Heatflux Gauges

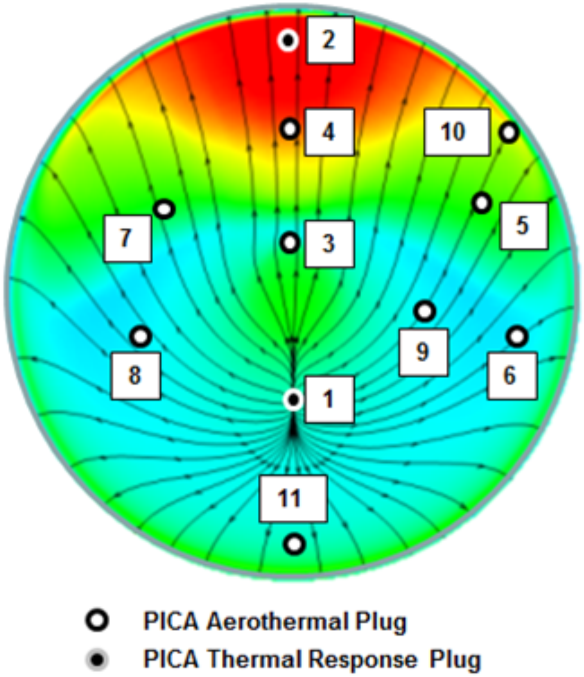
BS-HS Cutter Conductor: 50 Includes SSE redundant power, RS422 Output to Cable Cutter and all Backshell Power, Signal, Signal Returns. Note: does not include wires for potential heaters

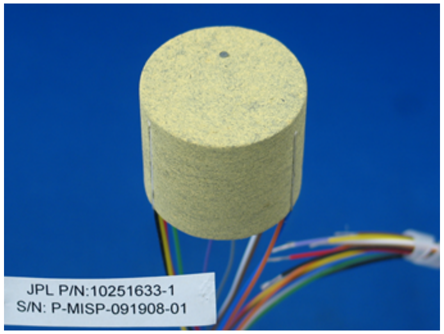
HS-Instrumentation
- 11 MISP Plugs
- 7 Pressure Xducers

Potential Pre-Operational Heaters for Pressure Xducers

Total Power for heaters: 3W Relay Controlled (RTD and/or thermostat)

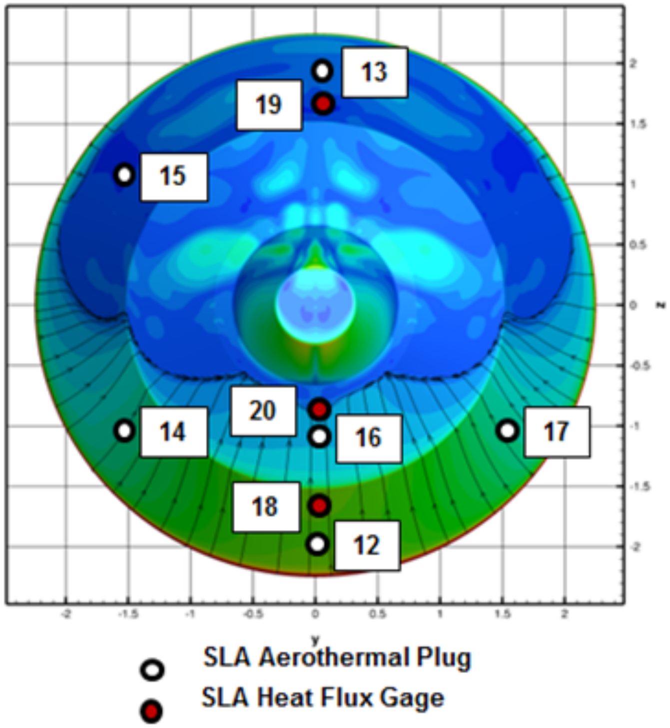
MEDLI2 Forebody Thermal Instrumentation

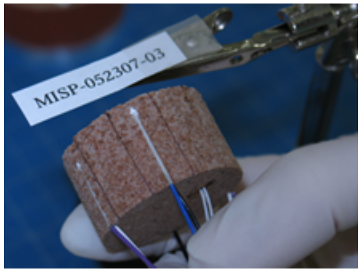


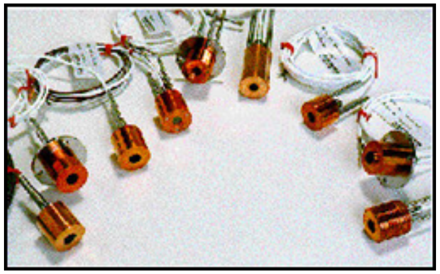


- **Science objectives**: Measure baseline heating, transition to turbulence, turbulent heating footprint, heating augmentation due to fencing at tile gaps
- Forebody thermal instrumentation includes **11 PICA plugs** with embedded thermocouples
  - Three plugs (1-3) with three thermocouples each to measure in-depth thermal response
  - Eight plugs (4-11) with one thermocouple for aerothermal reconstruction
- A combination of Type-S and Type-K TCs
  - Range: -155 to 1372 C (Type-K), TBD-1768 C (Type-S)
  - Data Rate: 2-8 Hz
- **Post-flight reconstruction target**:
  - Heat flux: ±15 W/cm2
  - Transition to turbulence: 1 sec

MEDLI2 Afterbody Thermal Instrumentation

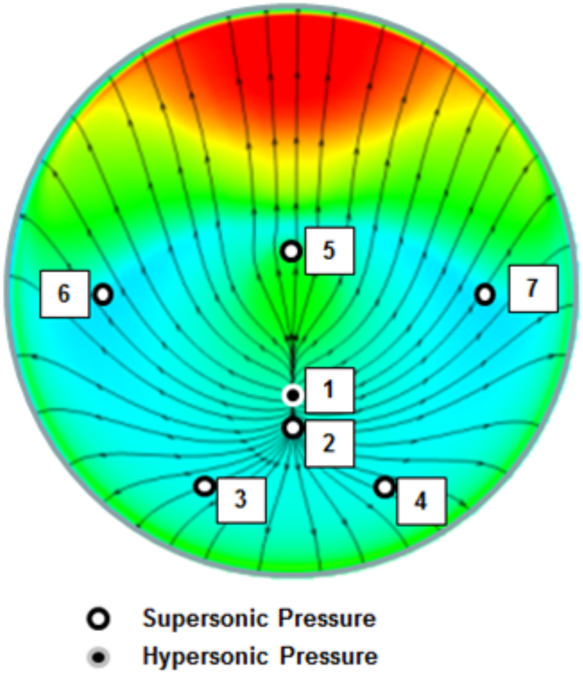


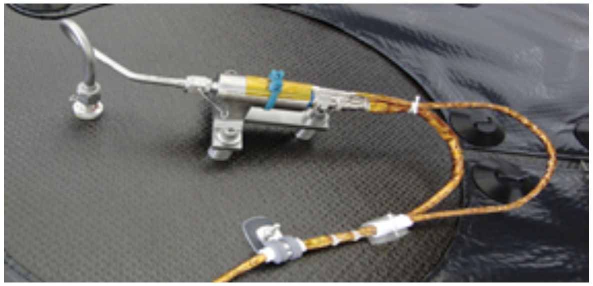




- **Science objectives:** Measure/reconstruct
  - Aeroheating (reconstructed and direct measurement)
  - RCS interaction (if any)
  - Radiative heating (under consideration)
- Afterbody instrumentation includes **6 SLA-561V thermal plugs, heat flux gages, & a radiometer**
- Each plug will have 1 or 2 Type-K thermocouple for aerothermal reconstruction
  - Range: -100 to 1372 C
  - Data Rate: 2-8 Hz
- **3 Heat flux gages** will also be used for fast-response direct heat flux measurements
  - Range: 0-25 W/cm2
  - Data Rate: 16 Hz
- **Post-flight reconstruction target**:
  - Heat flux reconstruction: ±3 W/cm^2 at 8 Hz
  - Direct heat flux measurement: ±1 W/cm^2 at 16 Hz

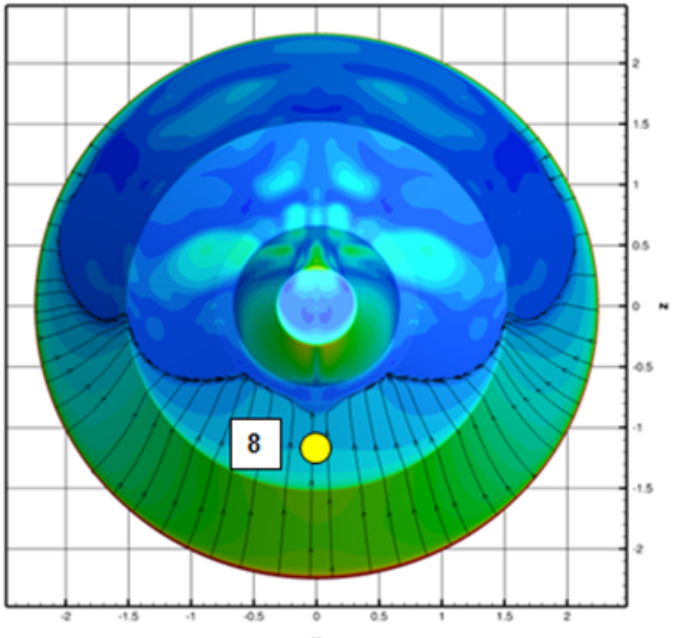
MEDLI2 Forebody Pressure Measurement



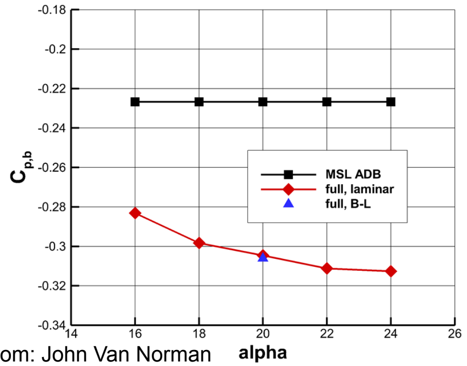


- **Science objectives**: Reconstruct
  - Winds & wind relative vehicle attitude (supersonic)
  - axial force coefficient (supersonic, hypersonic)
  - as-flown atmospheric density
- **Six pressure transducers** measure surface pressure in the range relevant for supersonic flight
  - Range: 0-1 psia
  - Data Rate: 8 Hz
- **One pressure transducer** to measure stagnation point pressure during hypersonic flight for reconstruction of atmospheric density, and CA
  - Range: 0-5 psia
  - Data Rate: 8 Hz
- The “supersonic” port locations are based on a constrained-optimization process to minimize error in the reconstruction of angles of attack and side-slip
- **Post-flight reconstruction target:**
  - Vehicle attitude: ±0.5 degrees
  - Axial force coefficient: ±2%
  - Atmospheric winds: ±10 m/s, Atmospheric density: ±5%

MEDLI2 Afterbody Pressure Measurement



● Backshell Pressure Port Location



From: John Van Norman

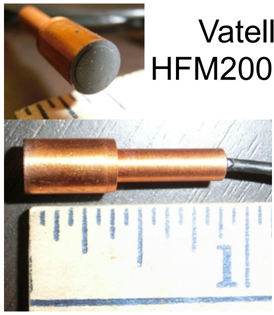
- **Science Objectives:**
  - Improve backshell pressure model
  - Estimate backshell contribution to drag
- **One pressure measurement** port in the afterbody
  - Range: 0-0.1 psia
  - Data Rate: 8 Hz
  - Engagement with suitable vendors ongoing based on responses from industry
- The current port location is defined based on available wind tunnel data and CFD analysis
- Further refinement of the location will occur based on the results of on-going ballistics range test
- **Post-flight reconstruction target:**
  - Measure backshell pressure within 4 Pa

Instrumentation Selection Strategy

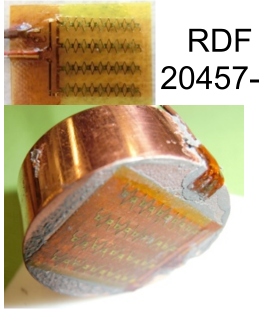
Instrument requirements flow down from Science Requirements and Error Budget Analysis

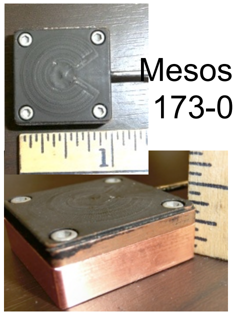
Sensor	Range	Status	Vendor
PICA Thermal Plugs	-155-1768 C	MEDLI heritage, minor modifications TC depths and types	NASA ARC
SLA Thermal Plugs	-100-1372 C	Limited MEDLI heritage, being desinged for thinner TPS	NASA ARC
Backshell Heat Flux Sensor	0-25 W/cm2	RFI survey ongoing, off-the shelf sensor tested	TBD
Backshell Radiometer (Under Consideration)	0-25 W/cm3	RFI survey ongoing, off-the shelf sensor tested	TBD
Hypersonic Pressure Transducer	0-7 psia	MEDLI heritage	Stellar
Supersonic Pressure Transducer	0-1 psia	RFI survey complete, RFQ relased; some development on cold temperature survivability	TBD
Backshell Pressure Transducer	0-0.1 psia	RFI survey complete, RFQ relased; some development on cold temperature survivability	TBD

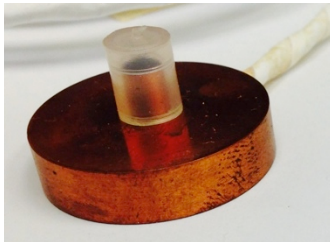
Characterization and Accommodation of Heat Flux Gage


Vatell
HFM2000-0


Vatell
TG2000-0

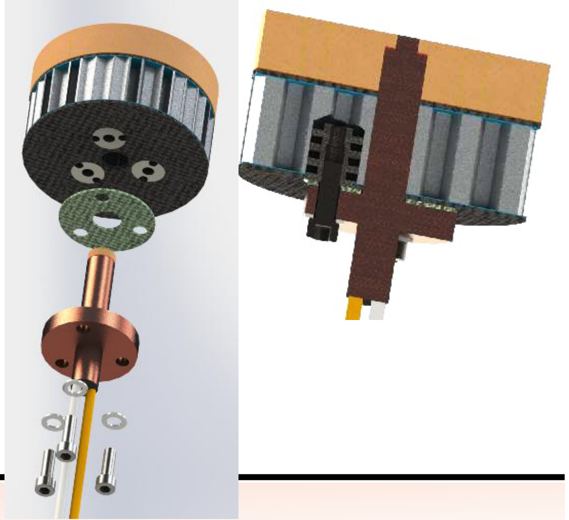

RDF
20457-1


Mesoscribe
173-0005


Medtherm
21497

- Completed Bench top testing of 5 candidate backshell heat flux sensors.
  - Time Response tests
  - Calibration
  - Heatload Survivability and heat sink design
- Developed mechanical mounting method – Mars 2020 concurred
- *Sensor selection enables start of Do No Harm efforts*


Testing Complete



MEDLI2 SSE Changes

- MEDLI2 leverages the existing MEDLI SSE design
- Changes due to sensors
    - One additional pressure measurement
    - Change existing seven temperature measurements (via externally mounted T/C) of pressure transducer shell to existing PRT measurement of internal temperature
    - Delete all HEAT sensor circuits
    - Change 3 of the MISP Type K T/C circuits to be Type S T/C circuits
    - Add three Heat Flux sensors (use the board area where the HEAT circuits were located)
    - Add three T/C measurements of the Heat Flux sensors
- Changes due to sampling
    - Sampling changes due to sensor changes result in need for six RS-422 addresses (vs. four from MEDLI)
    - Need to add/change MUX
- EEE Parts review has identified some potential parts changes

Do-No-Harm Environmental + Arc Jet Testing

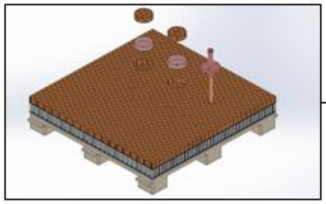
Do-No-Harm Testing (5 Panels)

Environmental

12" x 12" Models Testing
(3 Panels, 9 Plugs)

3 Plugs per panel; thermal plug, pressure plug, **updated** heat flux sensor. Vibration, Shock, Thermal Vacuum tests

Analyze/Validate



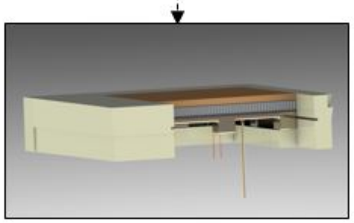
3 Complete PTF models Environmentally tested. Larger custom mount for shaker/PTF

3/5

Arc Jet (3 Test Days)

PTF TESTS
(5 Panels, 15 Plugs)

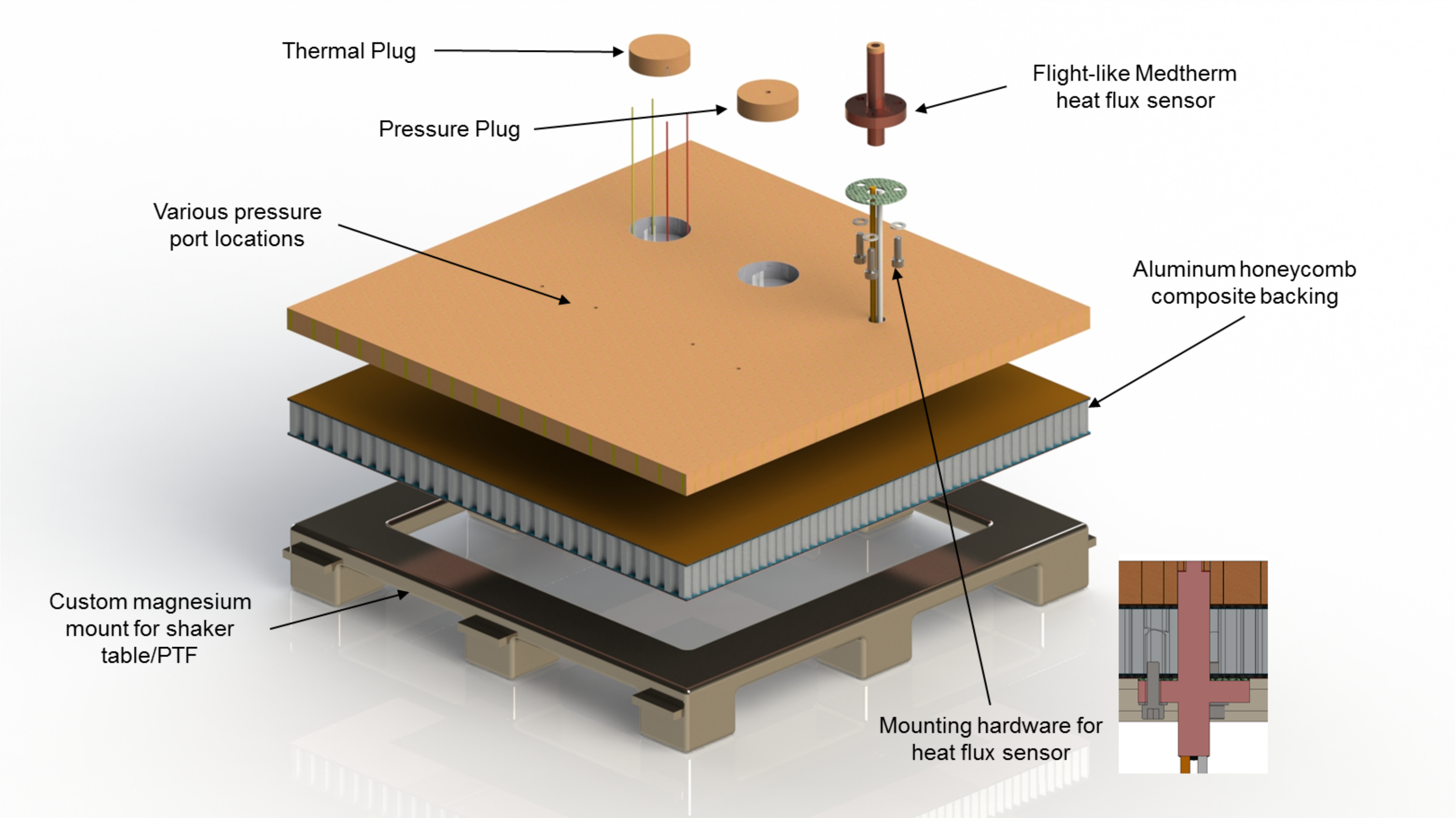
2 Control PTF Panels, 2 Environmentallly - tested PTF Panels, 1 Environmental & cold-soaked PTF Panel. 2 tests/day = 3 Days



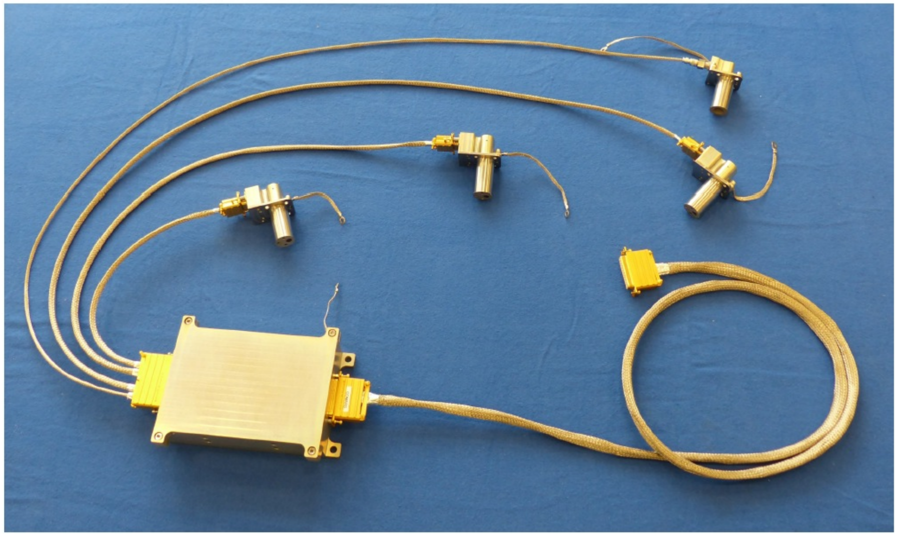
5 Models Tested in PTF with updated HF Sensor model and selected adhesive

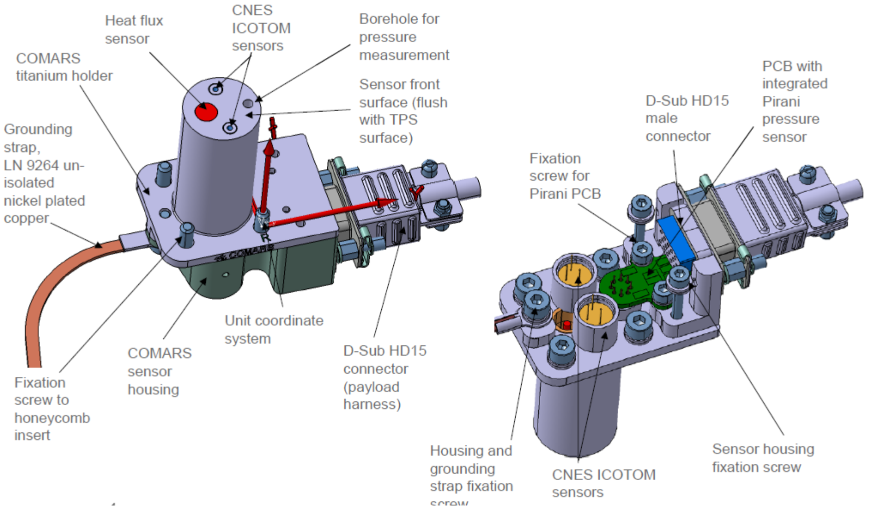
Instrumented Panel

- Due to low heat flux environment on the backshell, the Panel Test Facility will be used to test and demonstrate Do-No-Harm of TC Plugs, Pressure Ports, and Heat Flux Sensors
- MEDLI2 will claim MSL/MEDLI heritage for forebody sensors



DLR COMARS++ Assessment





- DLR COMARS++ installed on ExoMars 201 entry vehicle backshell
- The sensor package includes
  - three integrated sensors (heat flux gage, pressure sensors, and two radiometers)
  - One broadband radiometer
  - One supporting electronic box with signal amplifiers and multiplexers
- MEDLI2 currently assessing this sensor suite as a supplement to baseline MEDLI2 suite

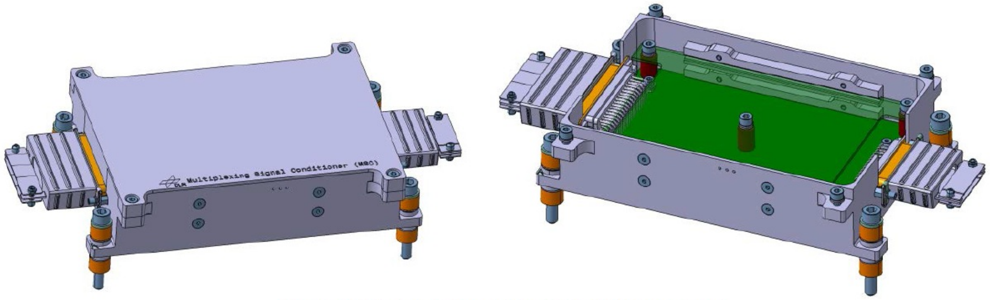
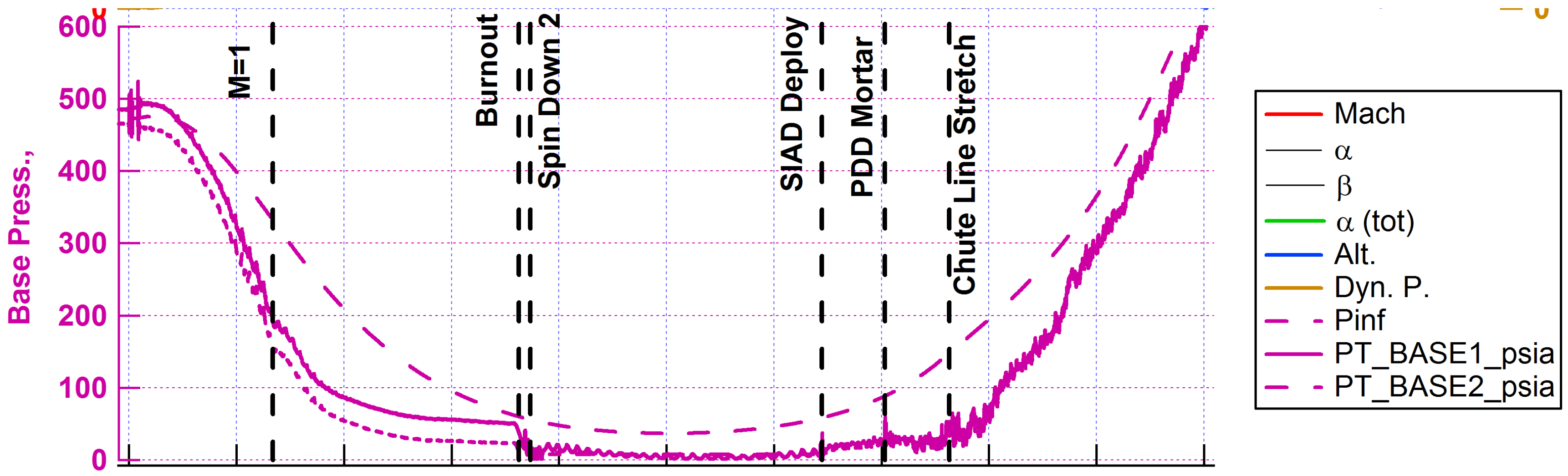
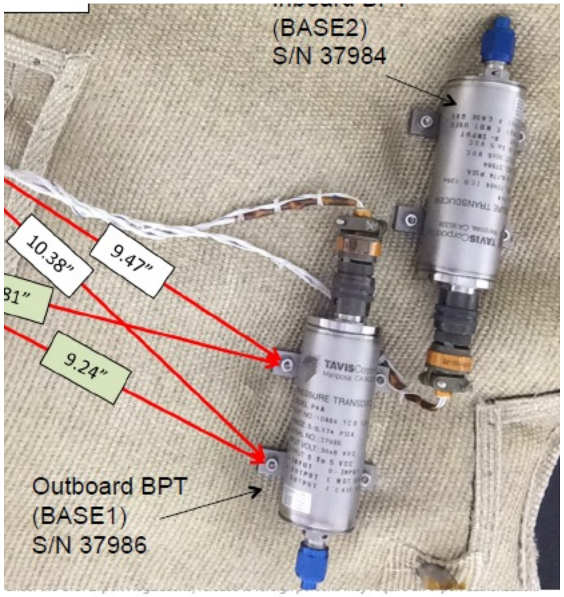


Figure 3: Electronic box of the COMARS+ payload

Low Pressure Transducer Demo. On LDSD Second Flight





- A low pressure transducer suitable for MEDLI2 backshell recently used by LDSD for afterbody pressure measurements
- The transducers returned useable data, and compared very well with CFD predictions

Thoughts on Commoditizing Flight Instrument

- A Product Development Task
- Define a small set of high priority measurements & instrument specs.
- Develop a small range of products :
  - Product A: Thermocouples (Type-K) + Pressure Transducers + Electronics
  - Product B: Thermocouples (Type-K) + Pressure Transducers + Radiometer + Electronics
  - Product C: Thermocouples (Type-K) + Pressure Transducers + Heat Flux Gage + Electronics
- Commonly used sensors are mostly agnostic to the TPS material:
  - TCs can be installed in a plug form in a variety of materials (some exceptions exist)
  - Pressure ports (FADS) have also be installed in a variety of materials
  - Heat flux gages and radiometers for backshell (non ablative environment) will be demonstrated by MEDLI2
- Formal environmental and do-no-harm tests will have to be performed by the customer, but representative testing can be performed during product development to minimize future test burden
- Provide some flexibility for mechanical mounting