MEDLI Aerothermal Environment Reconstruction Efforts

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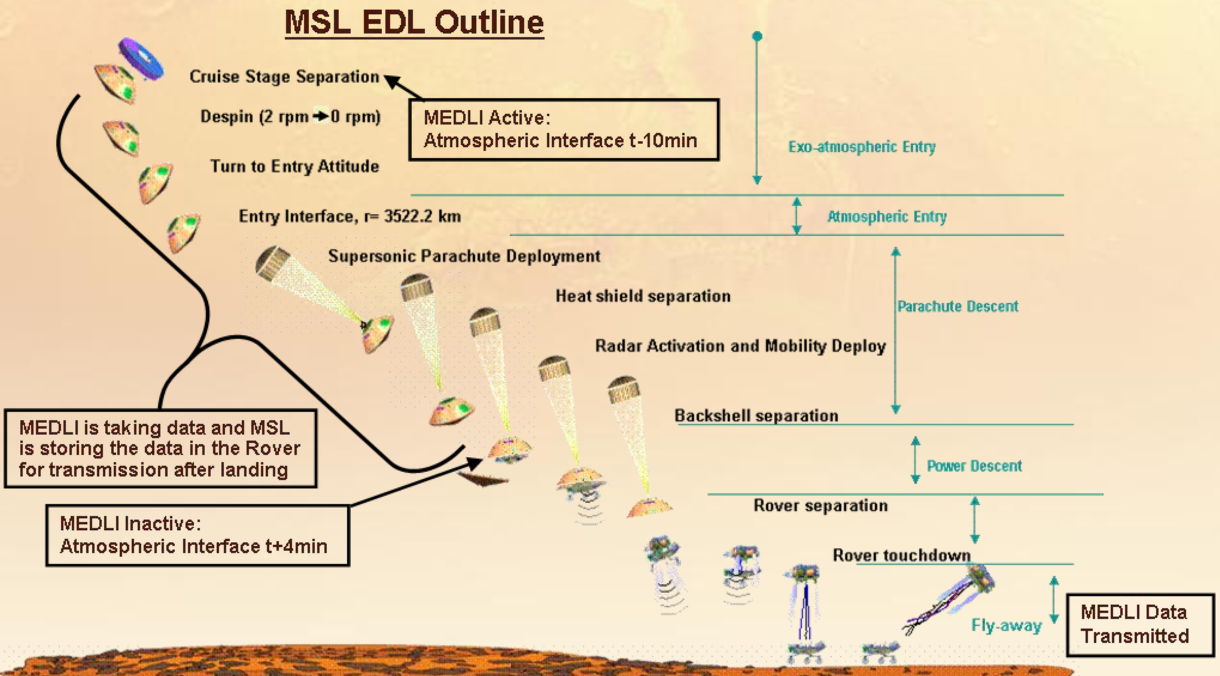
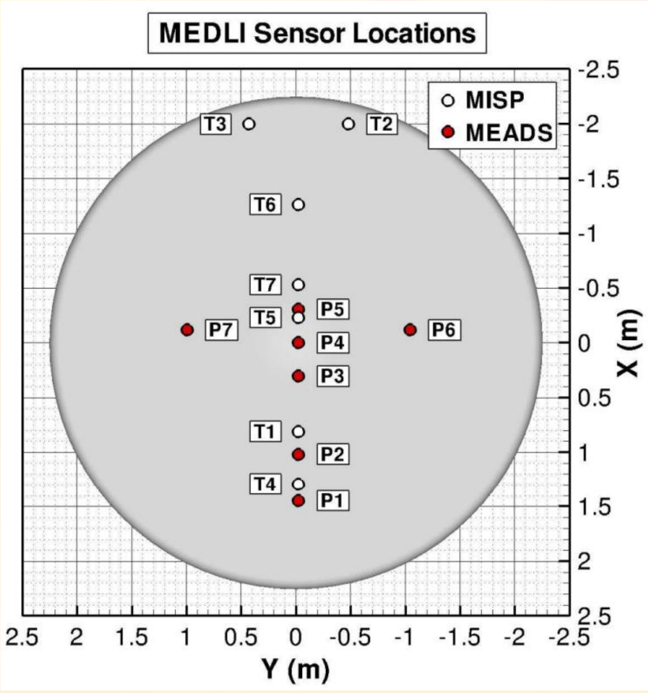
Overview

- Description of MEDLI & MISP
- MISP Science Goals
- Aerothermal Reconstruction
- Material Properties and Modeling
- Sensor Modeling
- Predictor-Correctors
- Conclusions & Forward Work
- Acknowledgements

MSL Entry Descent and Landing Instrumentation (MEDLI)

- Mars Science Laboratory (MSL) has a 4.5m diameter PICA tiled heatshield. It launches November 2011, and will enter Mars in the summer of 2012
- The heatshield is instrumented via MEDLI, with two main components
  - MEADS (Mars Entry Atmospheric Data System) Pressure ports and transducers, at 7 locations
  - **MISP (Mars Integrated Sensor Plug)**
    In-depth sensors at 7 locations, embedded in TPS.

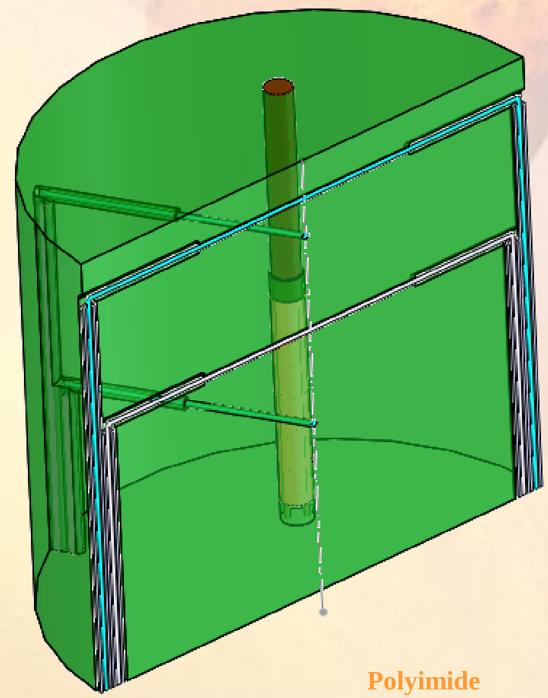


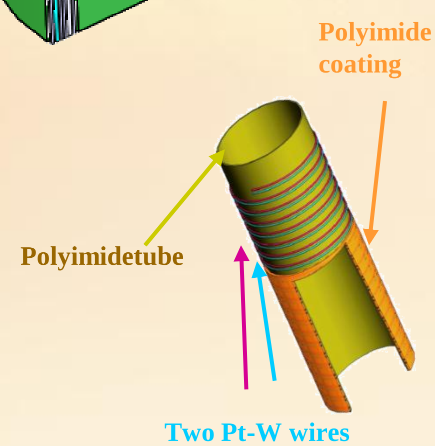


MISP (MEDLI Instrumented Sensor Plug)

- Each MISP consists of four thermocouples in 1.1” diameter by 1.25” deep PICA cylinder, with
- **Four type-K thermocouples (TCs)** with range to 1300K:
  - Two near surface thermocouples (0.1” and 0.2”) are sampled at 8 Hz,
  - Two deeper TCs (0.45” and 0.7”) are sampled at 1 Hhz.
- **One HEAT** (Hollow aErothermal Ablation and Temperature) sensor:
  - Wound Tungsten wires in Kapton tubing that is electrically conductive when charred, and changes resistivity (sampled at 8 Hz),
  - Often called a “Recession Sensor”, it does not measure recession, but tracks an iso-therm (720 deg C) through the material. For constant developed steady-state ablation, corresponds to recession rate.

Cross section of single MISP





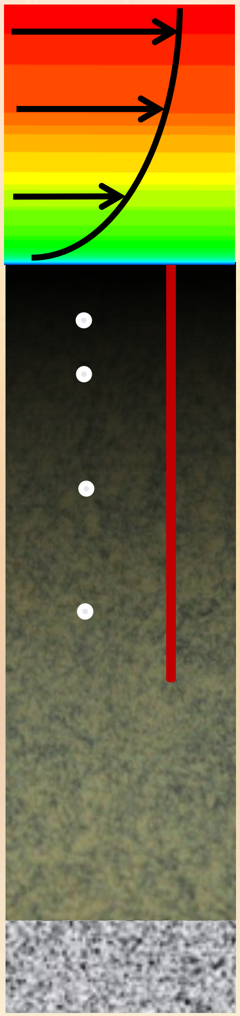
MISP Science Goals

- MISP Requirements specifically call for:
  - Measure subsurface temperature within ± 12%
  - Track 720C iso-therm progression through TPS within 0.03”
  - **Determine total TPS recession within ± 0.25”**
  - **Reconstruct Basic distribution of heating and stagnation point heating within ± 30 W/cm^2**
  - **Determine time of turbulent transition, within 2 seconds**
  - **Assess turbulent leeside heating within ± 30 W/cm^2**
  - **Identify windside heating augmentation within ± 30 W/cm^2**

- Only the first two are directly measured with instrumentation.
- All others require **analysis** in-the-loop (Hypersonic Computational Fluid Dynamics, and Ablator material modeling)

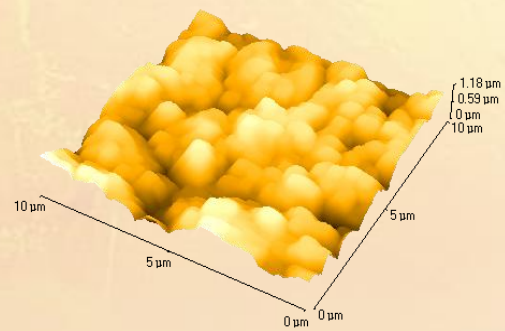
Aerothermal Reconstruction

Aerothermal reconstruction requires modeling and ground-based testing for three broad categories:

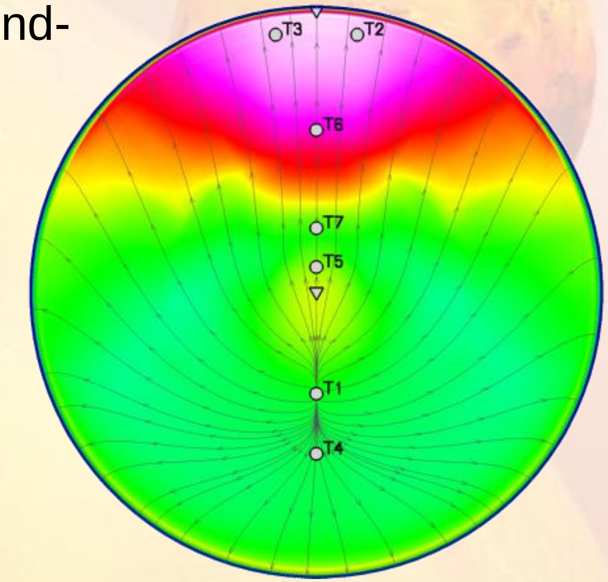


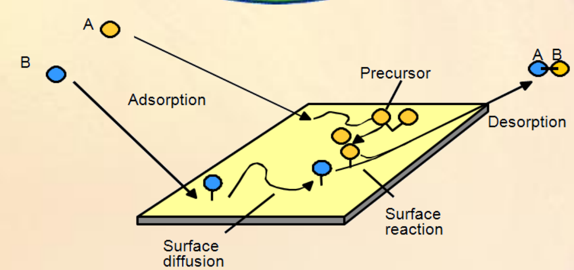
Aerothermal environments:
Gas-surface interaction
Turbulent onset and augmentation
Trajectory and atmospheric models
Gas-phase chemistry
Blowing and roughness
…

Material Response
Virgin properties
Char properties
Pyrolysis gas chemistry
Recession uncertainty
…



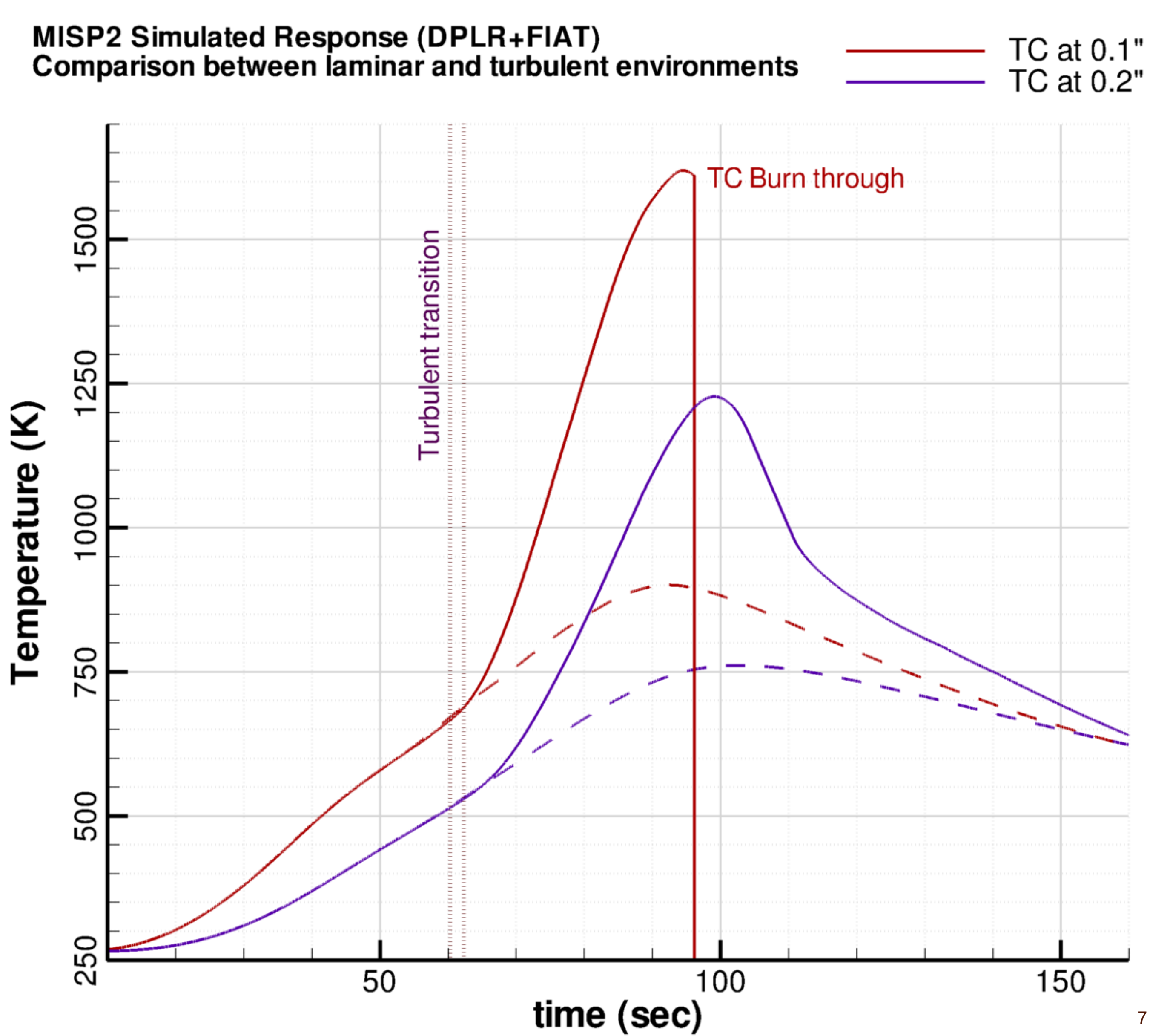
Sensor Response
TC Thermal lag
HEAT Calibration
Noise Filtering
Response to transient environment
…



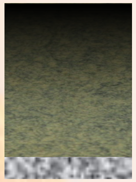


Aerothermal Analysis

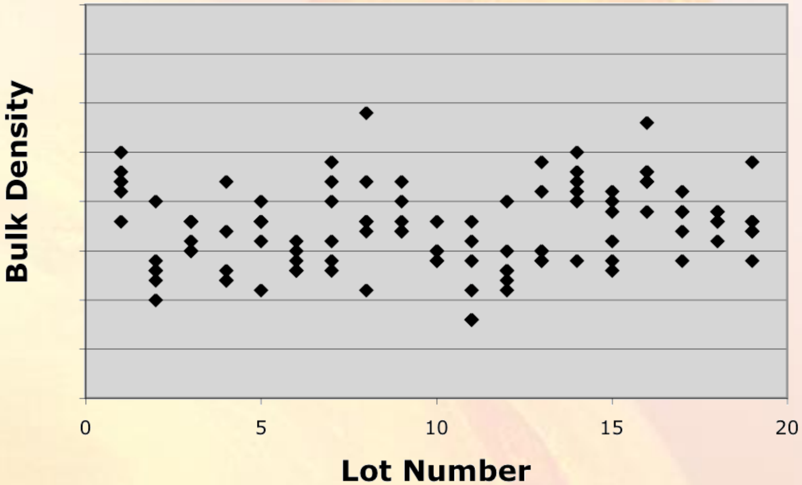
- What is the expected MISP response to turbulent transition and augmentation?
- For a single plug location, the response of top two TCs is shown, for simulated laminar and turbulent environments.
- Turbulent heating leads to a noticeable slope change in TCs particularly close to surface.

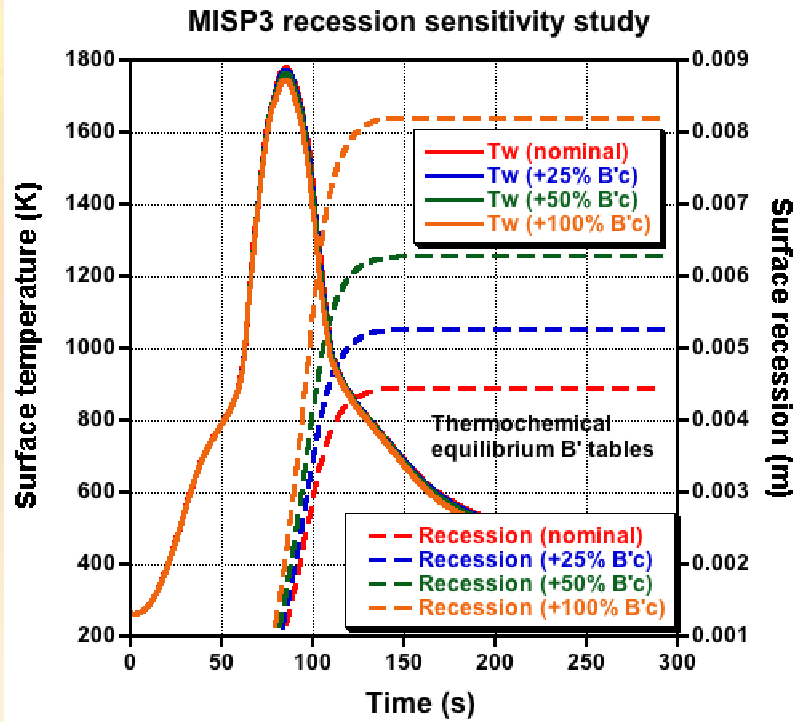


Ablator Modeling and Material properties testing



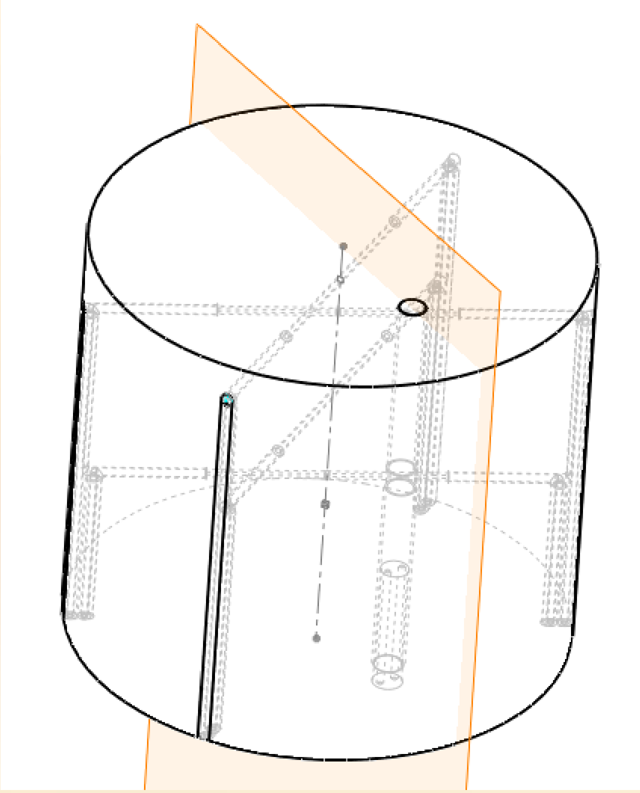
- Existing material models for PICA are intended to cover variability in PICA billets, and in arc-jet tests.
- We are tailoring the PICA model to the material in the sensor plugs, with an emphasis on parameters relating to thermal conduction model (virgin and char ρ, C_P, and k)
- We also are assessing the impact of material modeling uncertainties within our analysis tools.

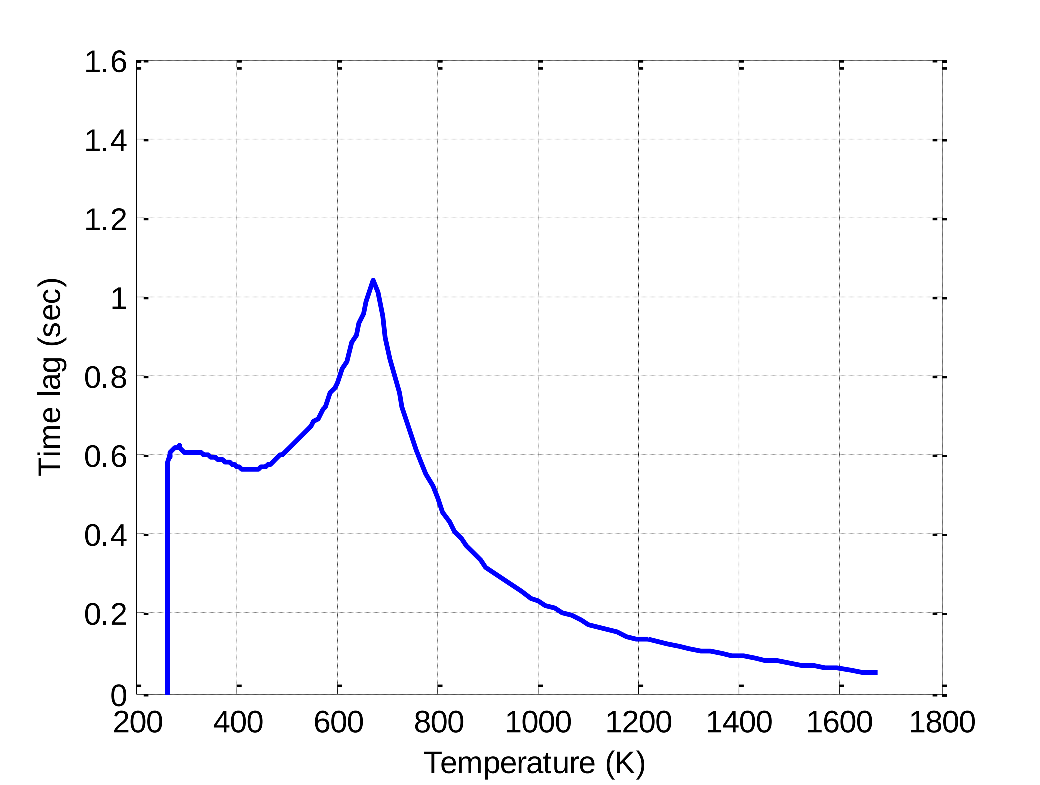




MISP Sensor Lag

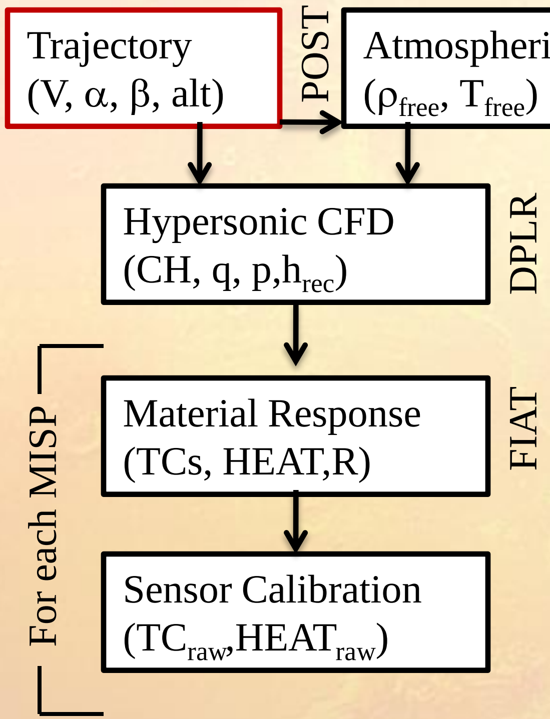
- Thermocouple accuracy is determined from manufacturer's ratings, and current lag has determined from simplified 2D finite element analysis of arc-jet tests.
- Ongoing 3D finite element analysis should provide better understanding of lag, and possible improvements in HEAT calibration.



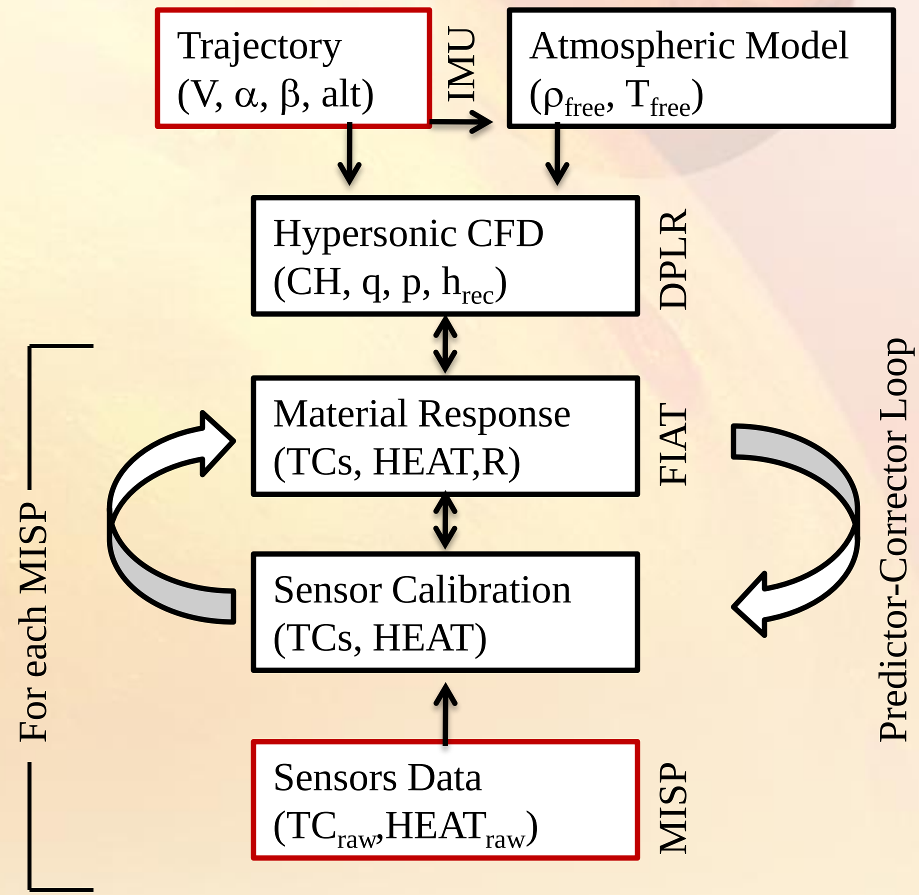


Putting it all together

Direct Process



Process for Flight Data

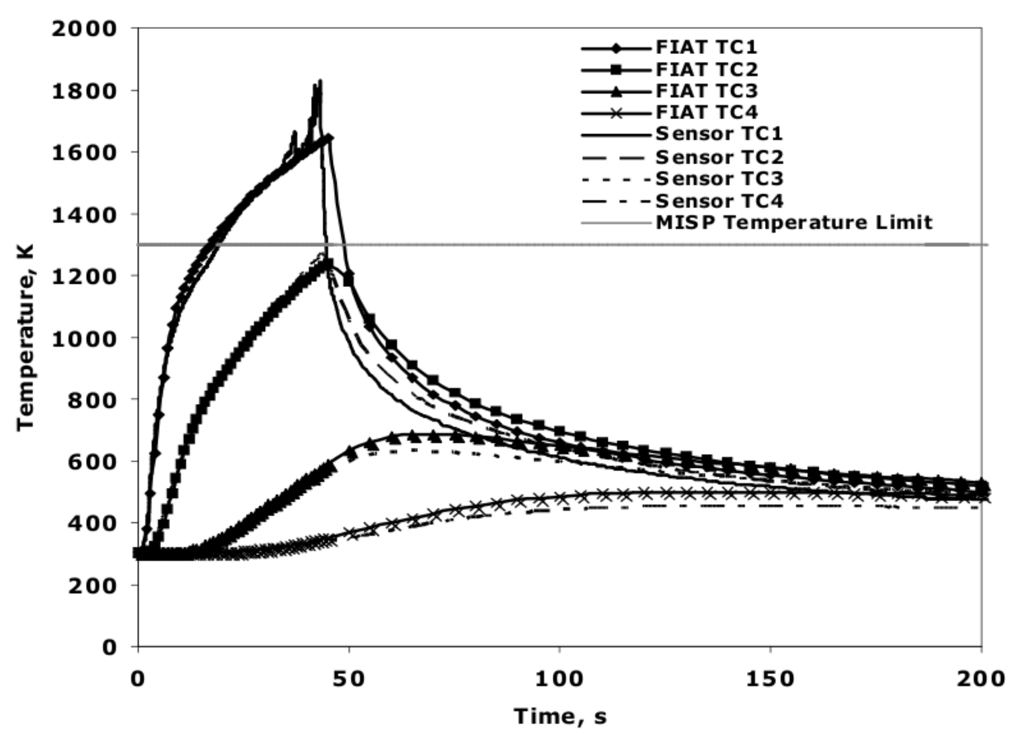


- Direct process akin to vehicle design
- Flight data process needs way to reconcile predicted environments and measured environments
- Analysis step must include model sensitivities.

Predictor-Corrector Development

- Given a **material model**, **four TCs**, and **an isotherm**, how do you recreate in time what happened at the TPS surface (film coefficient, and pressure)?

- Several methods in development:
  - JSC EG3 developing inverse routines for OFT-1 heat shield sensors that searches for CH.
  - Optimization routine wrapped around FIAT (FIAT_Opt), to iterate for CH, and also edge enthalpy, and/or pressure.



- Predictor-Corrector process is limited by:
  - Stability of reverse methodology
  - Quality of input data (susceptible to sensor noise)
  - Applicability of material model

Conclusions & Forward Work

- We need continued aerothermal CFD, material, and sensor analysis, as well as arc-jet and materials properties testing to understand MISP response and MSL environments.
- Imperative to apply analysis tools and methodologies on arc-jet test data.
- Data gathered will be greatly valuable to the aerothermal community, and available for future reconstruction, improvement of tools and methodology.

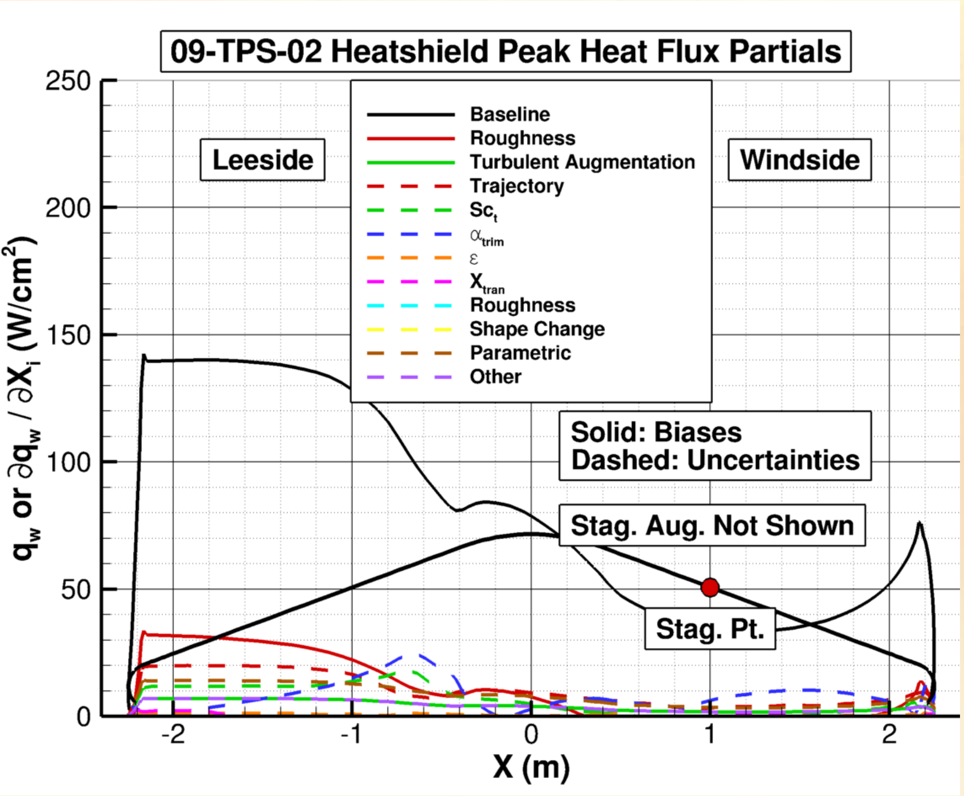
Acknowledgements

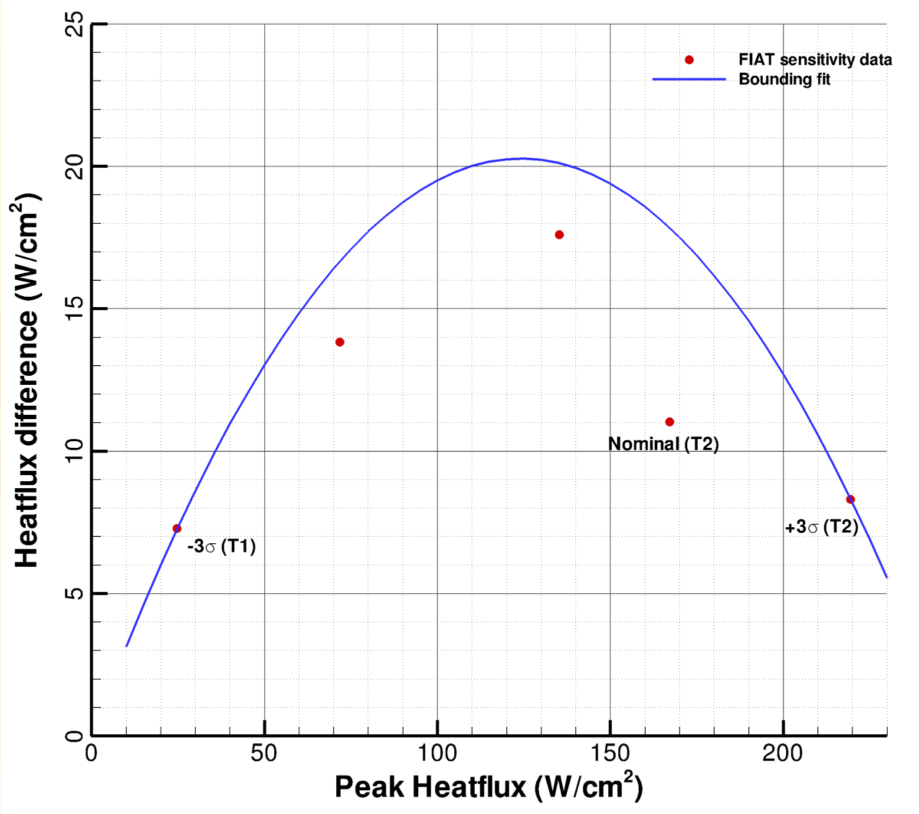
- Thanks to both MEDLI ESMD and MEDLI ARMD projects for their funding of hardware, testing, and reconstruction activities.
- Portions of this work done under contract NNA10DE12C to ERC, Inc and NNA09DB39C to Jacobs Engineering.

Backup

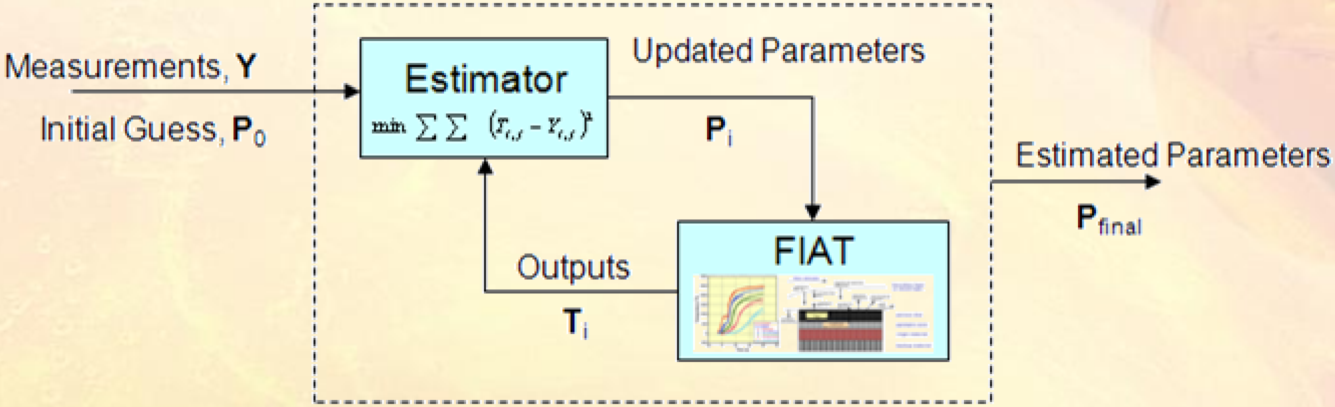
Aerothermal Sensitivities, cont.

- To assess the overall sensitivity of the sensors to a heating increase, the entire heating pulse is scaled linearly, from -3 sigma to +3 sigma.
- We then extract the miniumum change in the peak heatflux that will cause any of the TCs or HEAT to fall outside the known instrument uncertainty .
- This provides a rough sensitivity of the MISP sensors to aerothemal uncertainties, relative to the peak-heatflux.





Inverse Parameter Estimation approach



- The Inverse Parameter Estimation (IPE) code wraps around FIAT and estimates scaling factors of the <u>input parameters</u> to match measured data via an optimization procedure.
- Code verification
  - Recovers parameters back to the nominal values if starting at a random initial guess
  - Converges to the mathematical minimum of the sum of squares of errors with the experimental data
- Code validation: ArcJet MSL PICA test
- Challenges:
  - Solution existence, uniqueness and process stability
- Minimize errors: ε_{model}, ε_{random}, ε_{bias}

Sum of square of errors between measurements and FIAT predictions