Sensitivity Analysis of PICA and PICA-N Using PATO and DAKOTA

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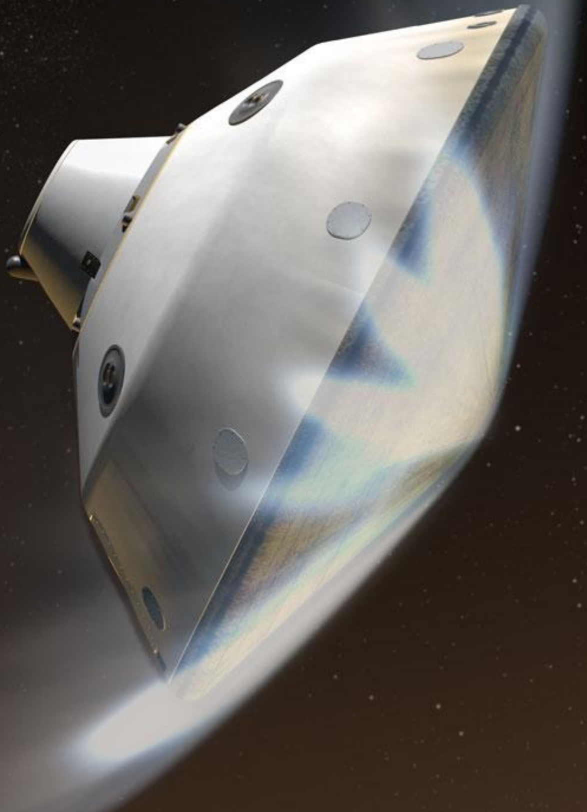
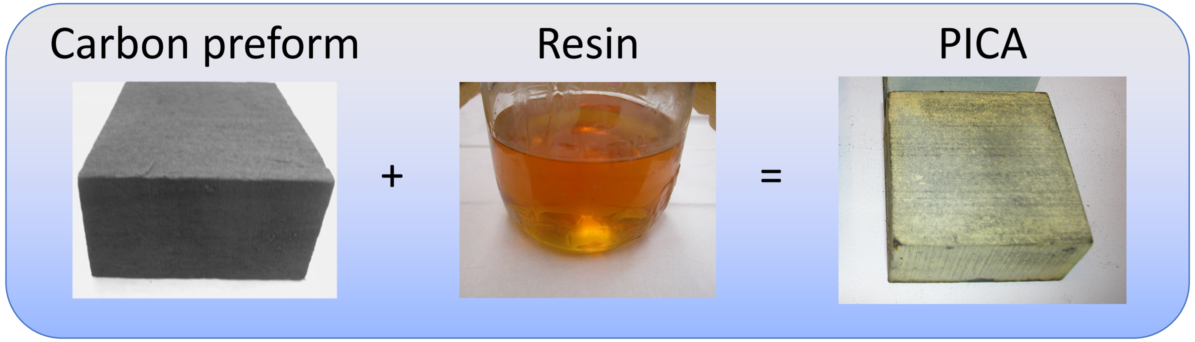
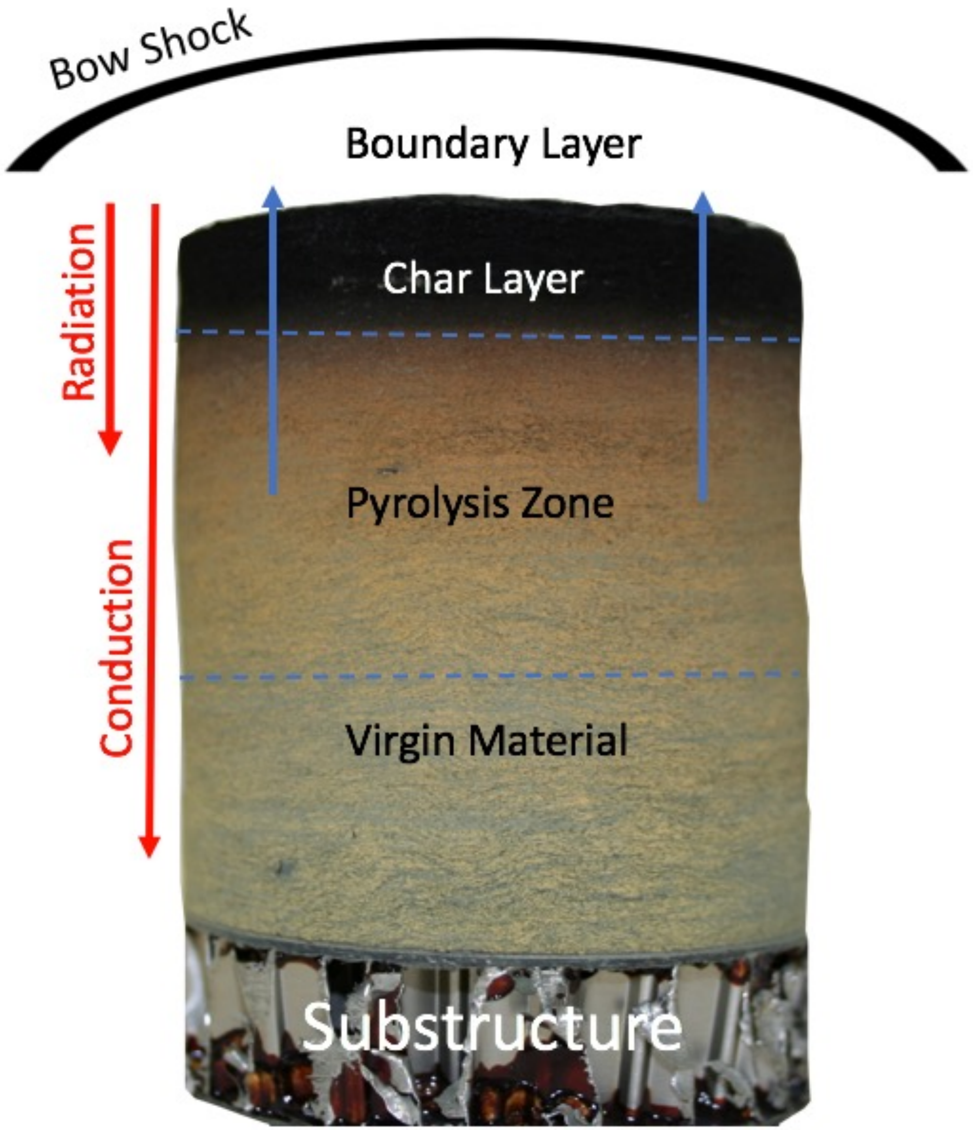


August 12th, 2021

PICA Overview

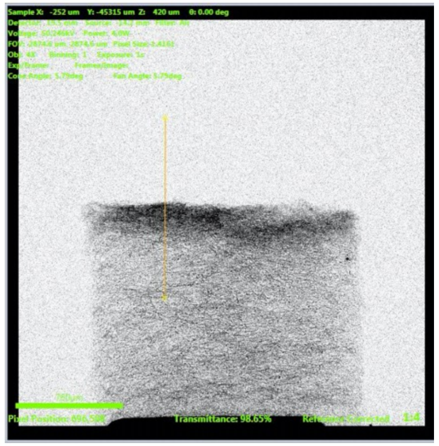


- PICA, or Phenolic Impregnated Carbon Ablator, consists of a carbon fiber preform with an infused phenolic resin
- PICA is a popular lightweight heat shield, and was the material used on the Mars Science Laboratory. It has also been used by SpaceX on the Dragon capsule
- During the extreme conditions of atmospheric entry, the resin and carbon fibers decompose at different rates, creating distinct zones in the material.
    - The virgin material, which does not show any decomposition
    - The char layer, in which the resin has fully decomposed. As the carbon fibers decompose, it leads to recession of the heat shield
    - The pyrolysis zone, which is a result of interpolating between the virgin and char layers

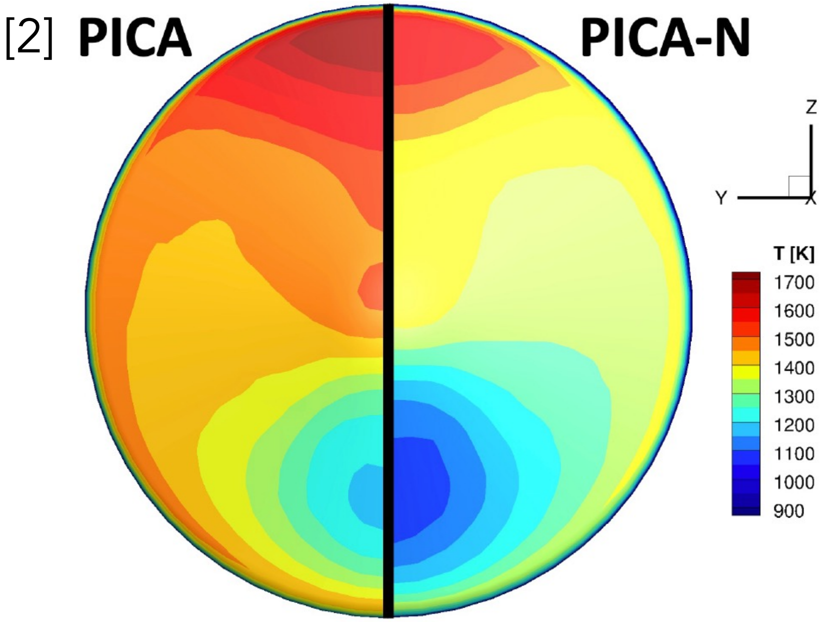


PICA NuSil

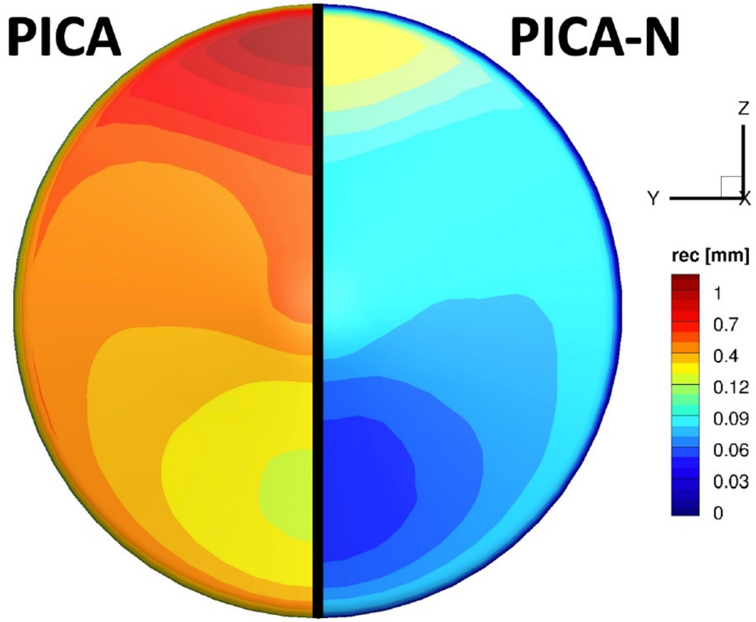
- PICA-NuSil, commonly known as PICA-N, is an adaptation of traditional PICA that features a vulcanized silica-based coating that covers the heat shield entirely.
- Adding NuSil mitigates the spread of phenolic dust found in PICA, which also improves the integrity of the heat shield by making it more resistant to humidity and erosion.
- The application of NuSil has been shown to cause no negative effects on PICA's performance. [1]
- Using arc-jet testing, it has been determined that the addition of a NuSil coating does modify the thermal response of PICA at high temperatures.



Micro tomography of PICA-N



Computed surface temperature of MSL at 80 seconds after EI

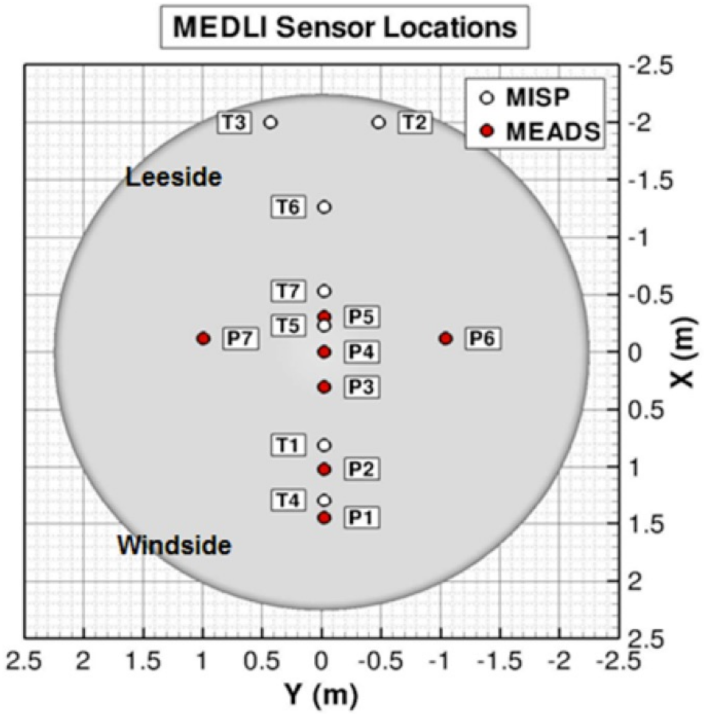


Computed surface recession of MSL at 80 seconds after EI

[1] B. Bessire et. al Progress Towards Modeling the Mars Science Laboratory PICA-NuSil Heatshield, IPPW (2019)
[2] J. Meurisse et al. 3D Material Response of the MSL Heatshield Using NuSil-Coated PICA, IPPW (2021)

Thermocouple Measurements from Mars Science Laboratory (MSL)

- Mars Science Laboratory (MSL) included heat, temperature, and pressure sensors within the heatshield. These sensors make up what is known as the Mars Entry Descent and Landing Instrument (MEDLI) suite.
- MEDLI contained:
  - Pressure sensors in the Mars Entry Atmospheric Data System (MEADS) at 7 locations on the heat shield
  - Thermocouple and Heat sensors in MEDLI Integrated Sensor Plugs (MISP's) at 7 locations (Different from MEADS locations)
- Each MISP contained 4 thermocouples at depths of 0.10", 0.20", 0.45", and 0.70" from the surface of the heat shield



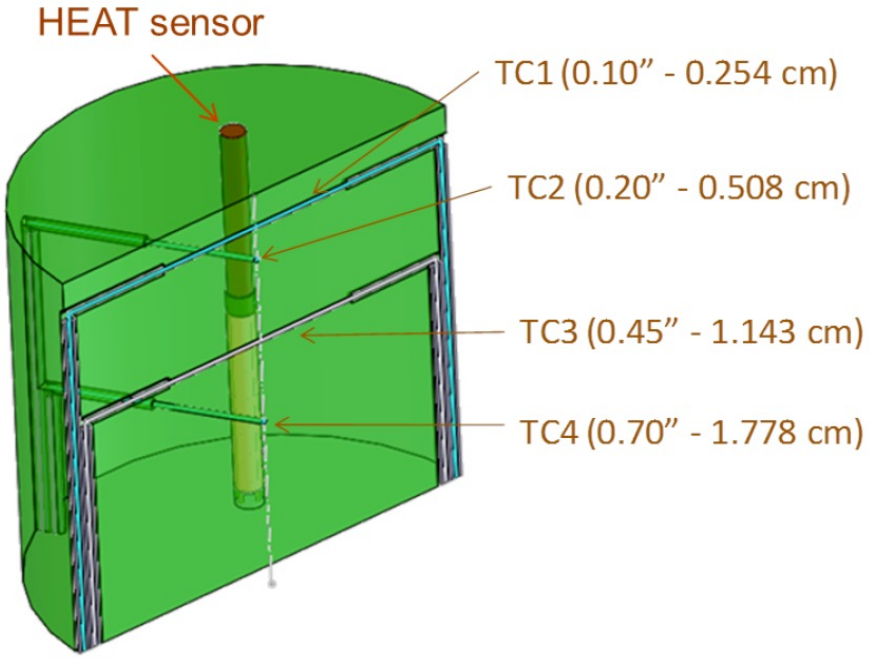
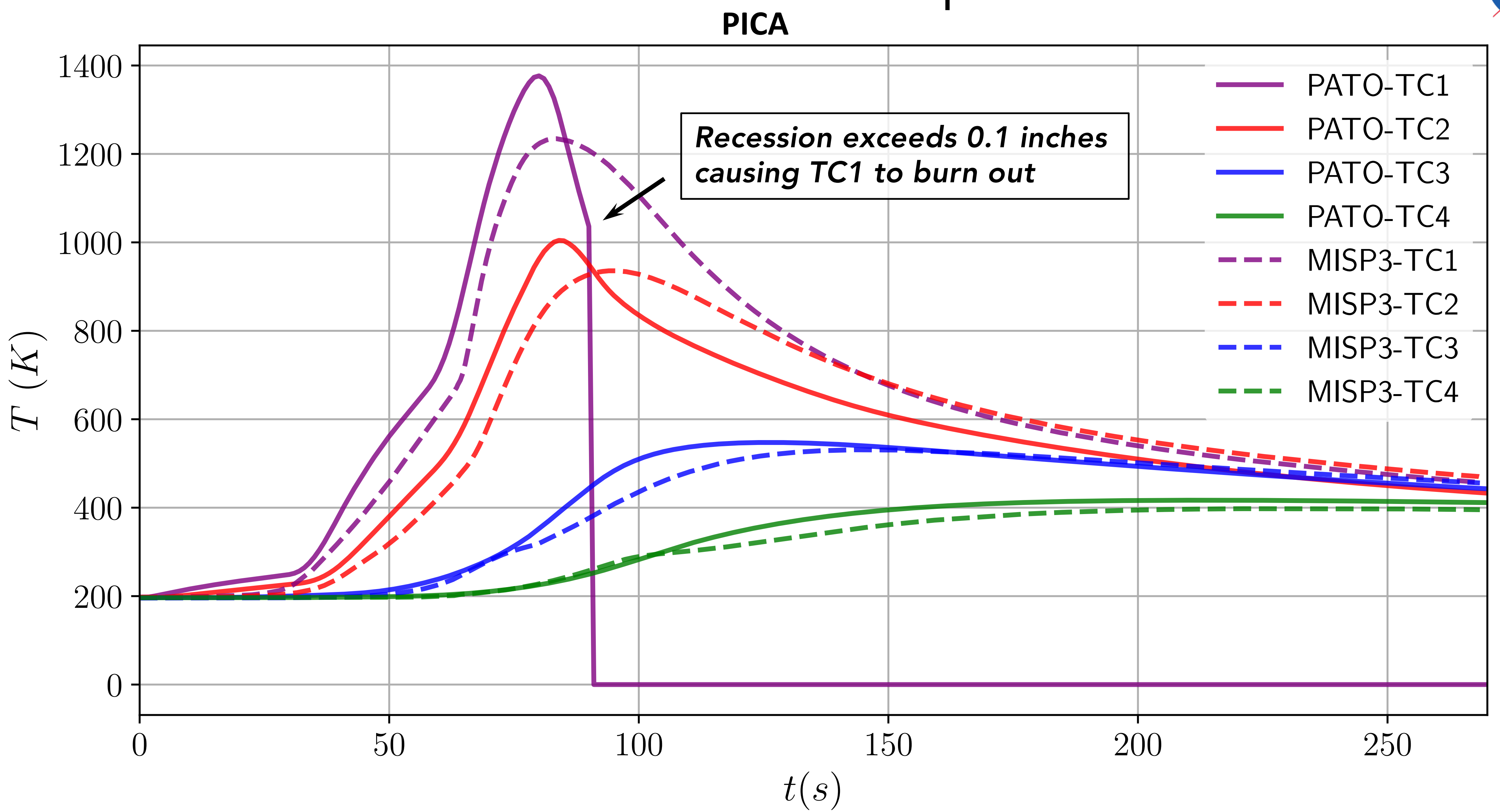


Diagram of a MEDLI Integrated Sensor Plug (MISP)

T. White et. al, Proposed Analysis Process for Mars Science Laboratory Heat Shield Sensor Plug Flight Data, AIAA. (2011)

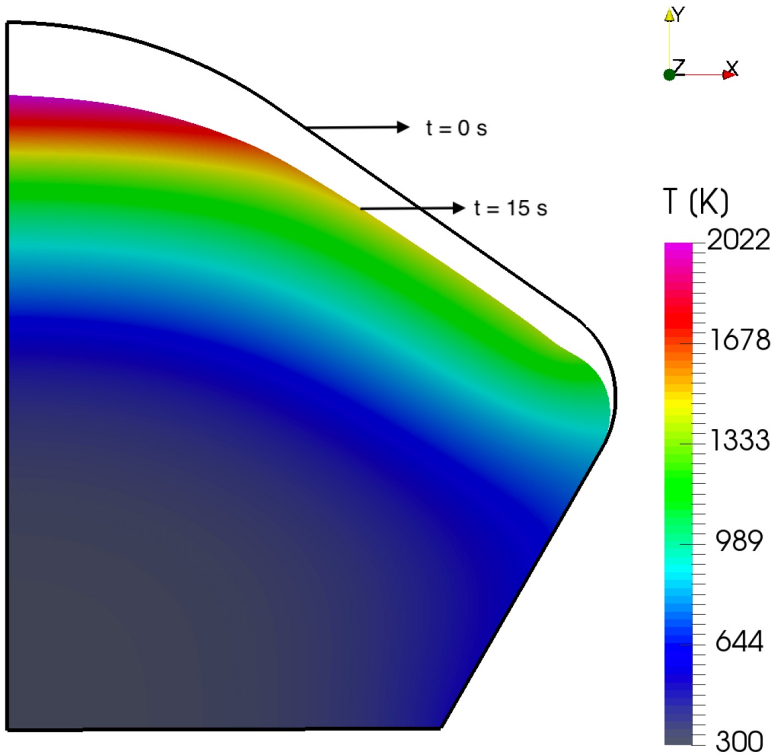
Simulated MISP3 Material Response with PATO



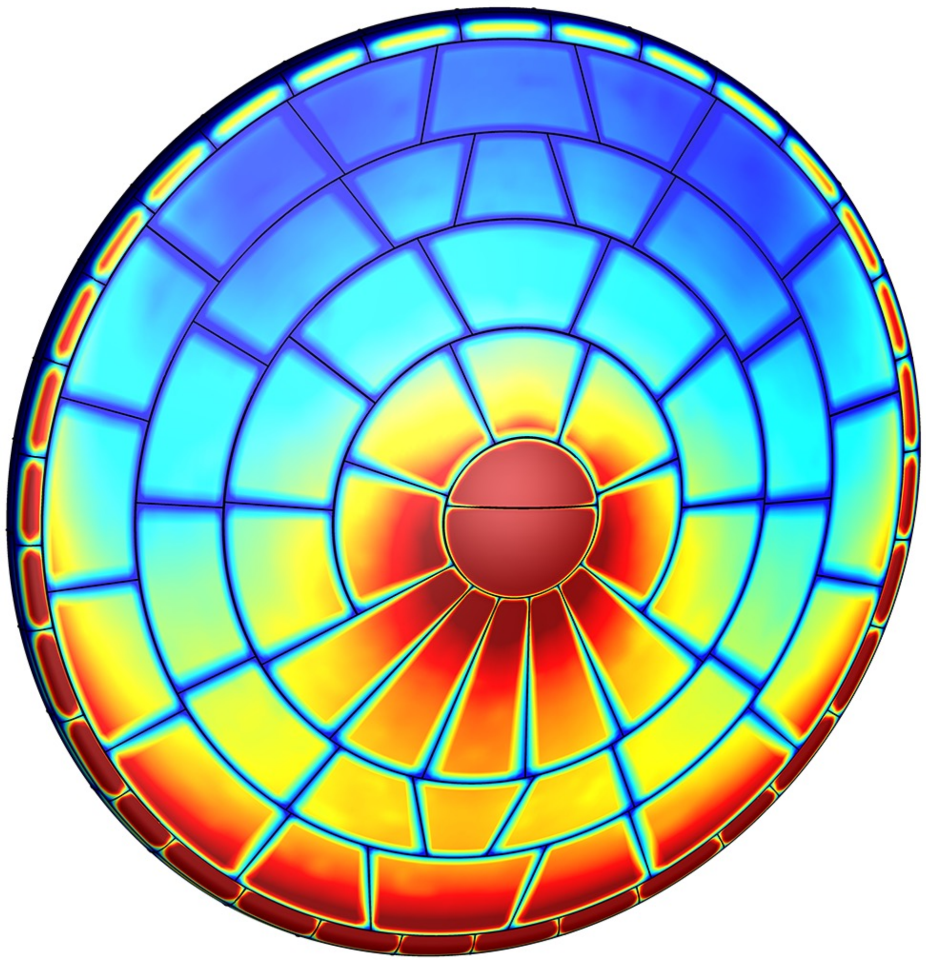
Analysis Methods

PATO Overview

- Porous-material Analysis Toolbox
- Ames ESM Predictive Materials Modeling (PMM)
- New generation code based on macro-scale formulation of ablation models
- Allows for significant advancement of modeling high-fidelity TPS material response models

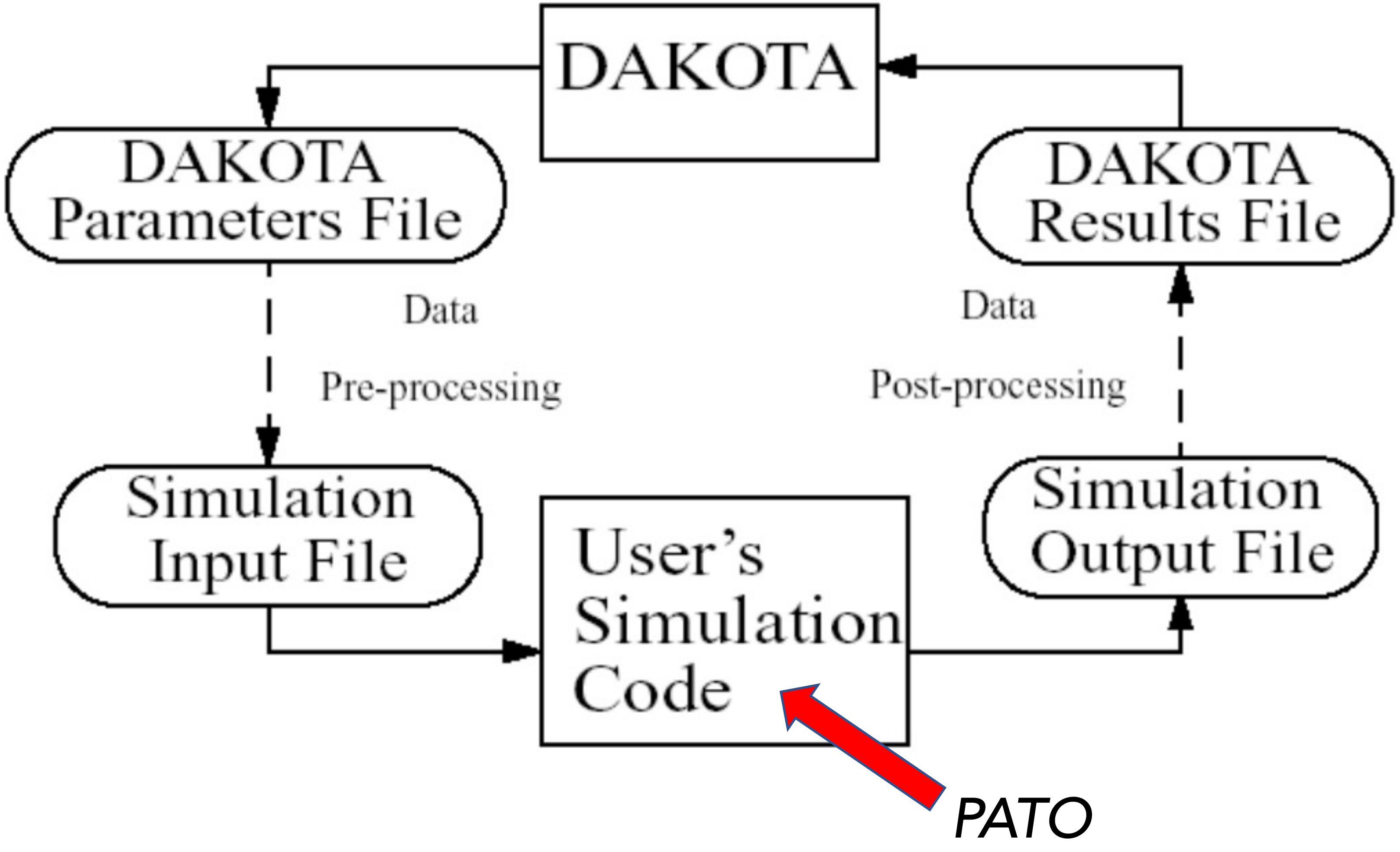


Temperature and recession of sphere cone sample in arc-jet testing



Computed recession of MSL Heat Shield from PATO

DAKOTA Overview



- PATO integrated into DAKOTA
- Morris One-At-A-Time Method (MOAT): a method of sensitivity analysis in which one variable is varied at a time while all others are held constant

B. A. Adams et. al, Dakota User's Manual, Version 6.10. (2019)

Sensitivity Studies

- Determining how variations of input variables influence response values
- Uncertainties in input variables create uncertainties in output variables
- Improves model prediction by increasing understanding of variable relationships

Sensitivity studies are useful for understanding how changing certain variables can impact a desired result.

Specific Heat	Max Temp (TC4)
1 (no change)	440.845
0.95 (5% decrease)	447.242
1.05 (5% increase)	434.852
1.10 (10% increase)	429.226

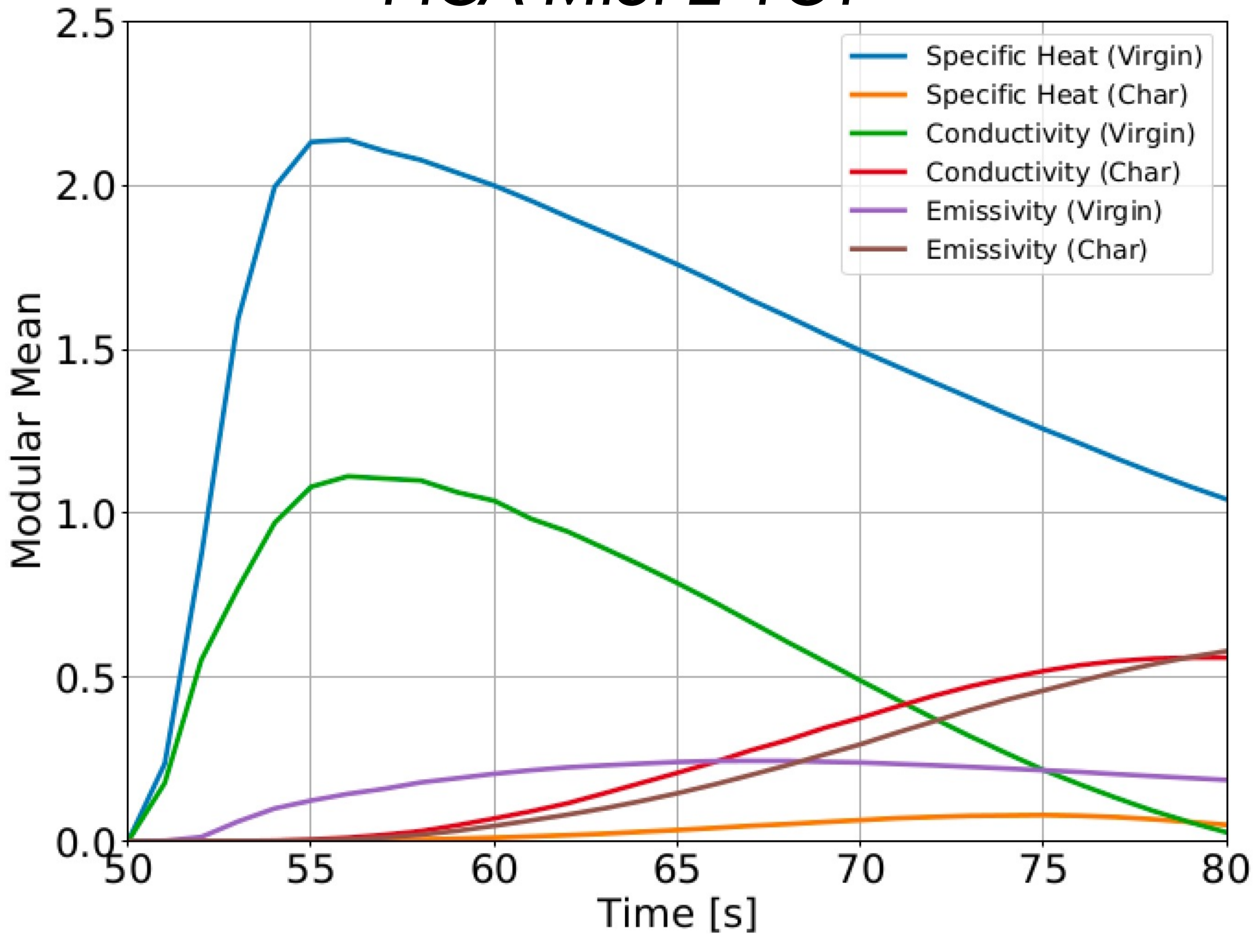
Sensitivity Study on MSL-MISP2 TC4

Sensitivity Analysis of MSL-MISP2

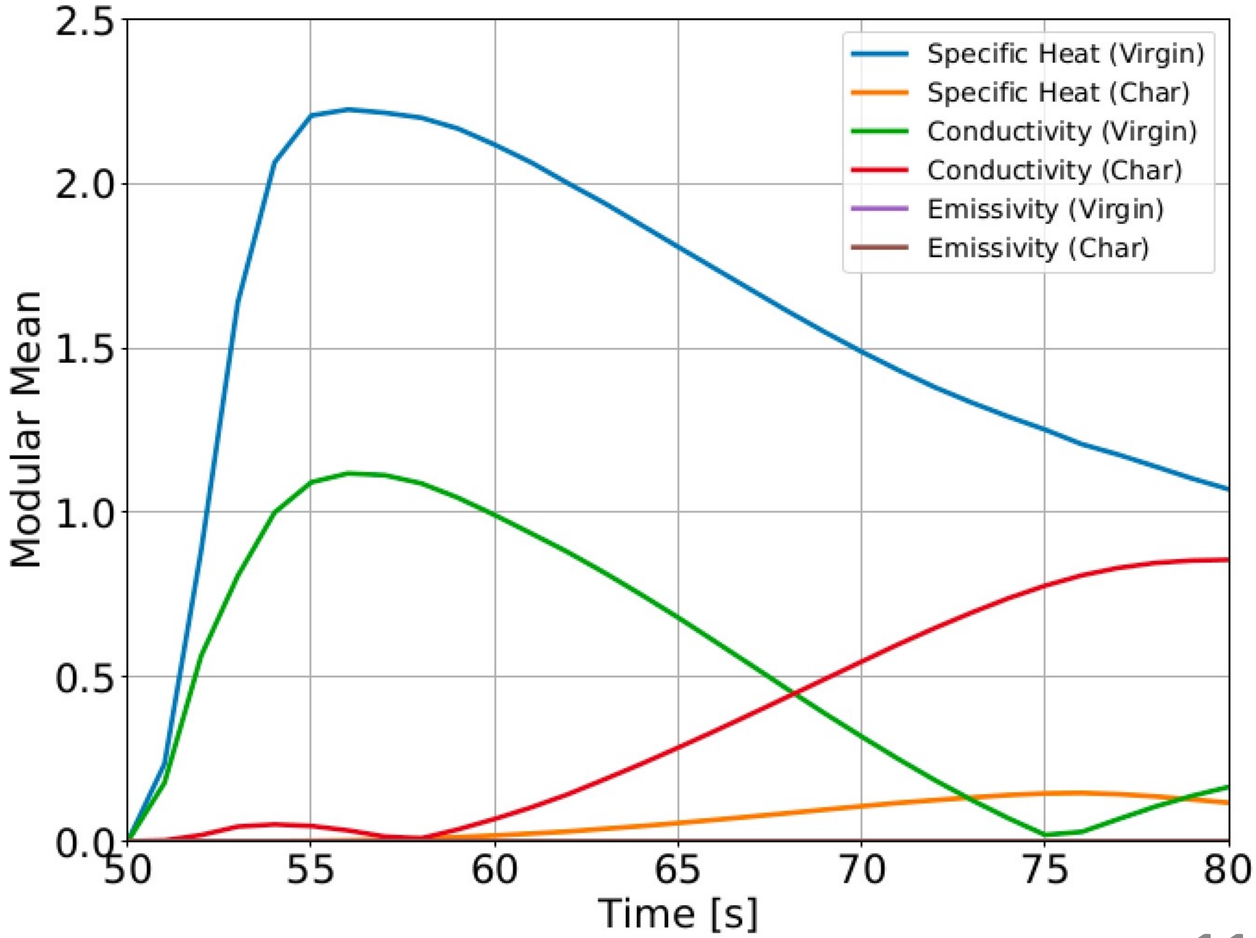
Material Properties of PICA vs. PICA-N

Description: Comparing material properties of PICA vs PICA-N. Perform a sensitivity analysis using material properties of both PICA and PICA-N, including specific heat, conductivity, and emissivity. A laminar environment was used in all cases.

PICA MISP2-TC1



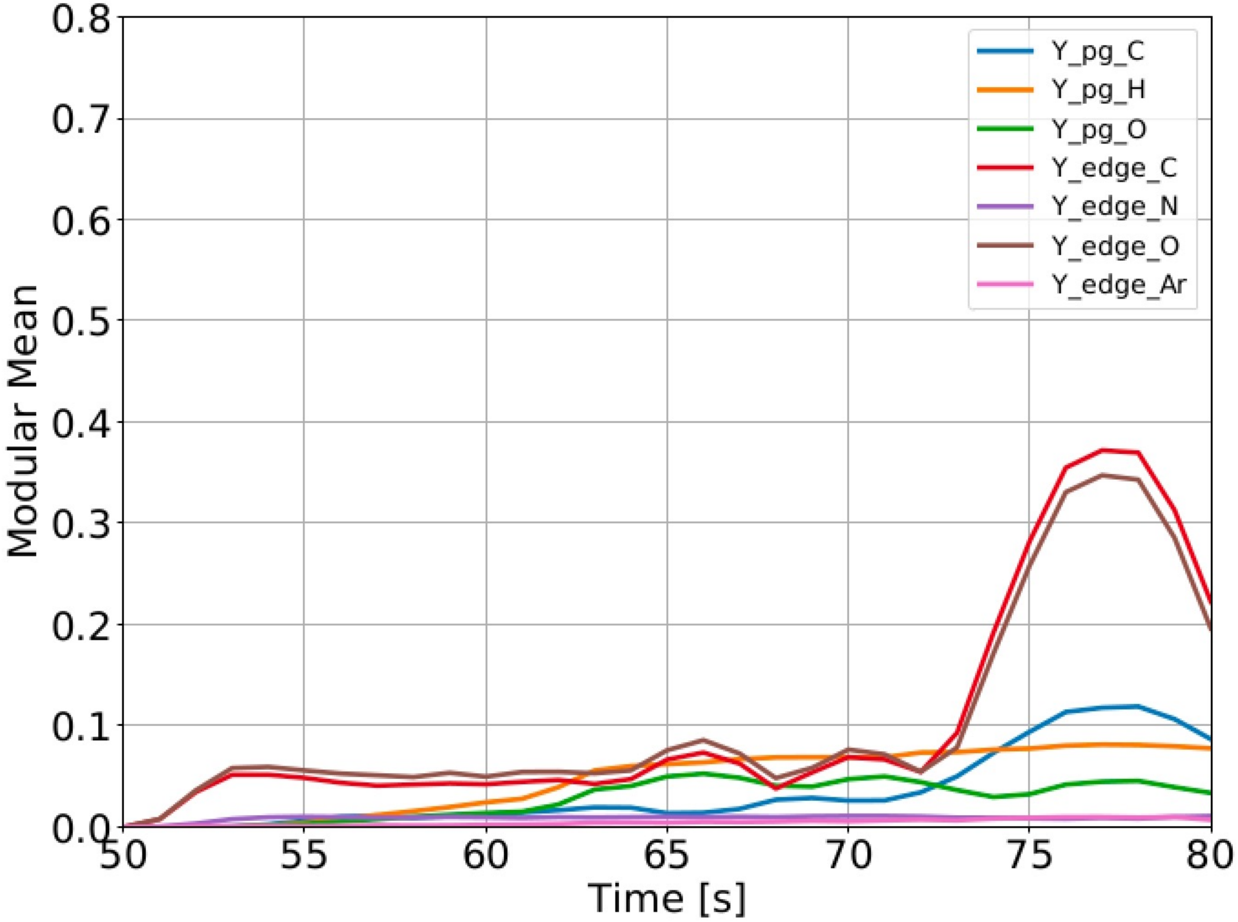
PICA-N MISP2-TC1



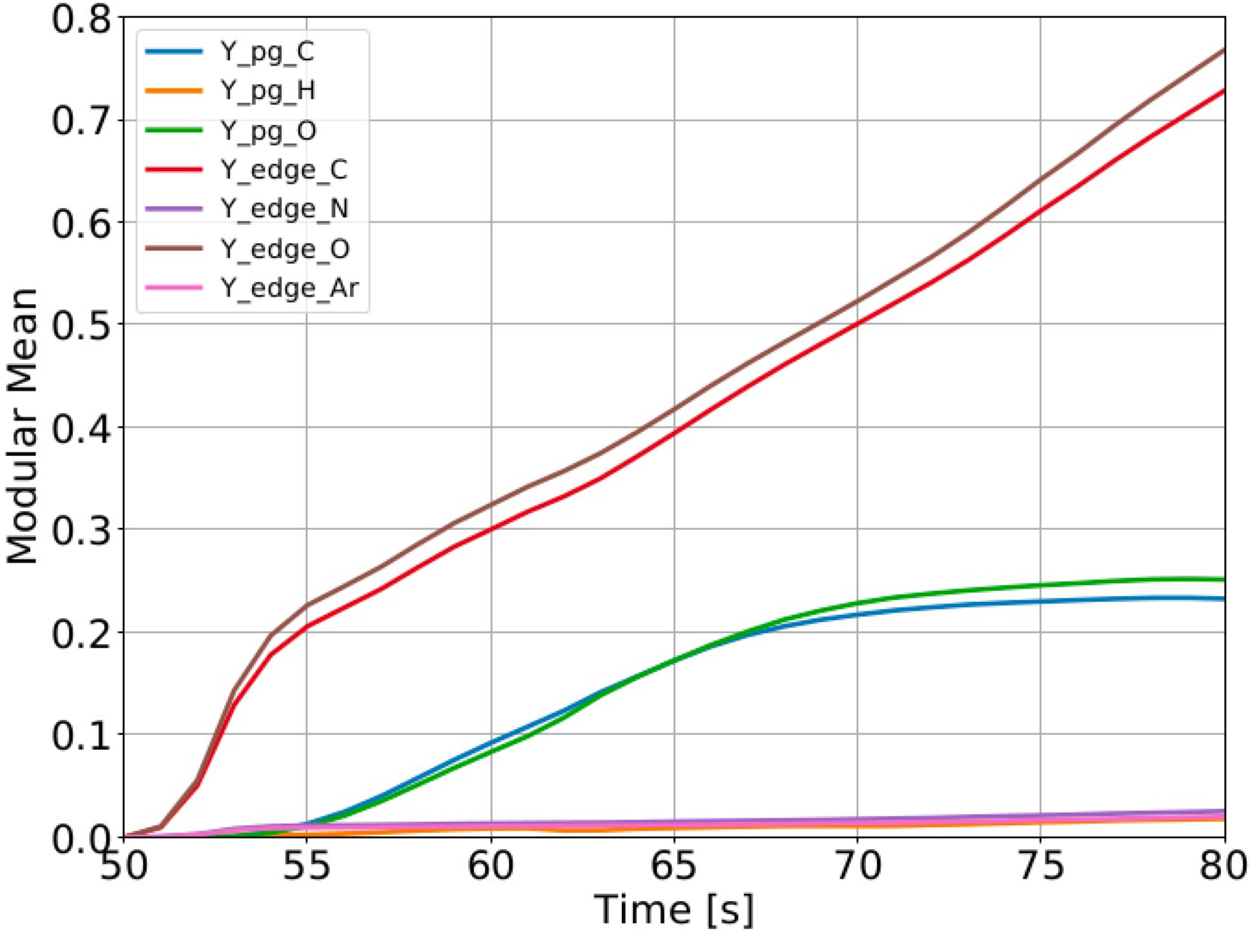
Gas Properties of PICA vs. PICA-N

Description: Comparing sensitivity to pyrolysis gas compositions and boundary layer edge compositions for both PICA and PICA-N. Use a python script to automatically vary pyrolysis gas and boundary layer edge compositions by a weighted mass fraction using the MOAT method.

PICA MISP2-TC1



PICA-N MISP2-TC1



Summary

- Completed numerous sensitivity studies
- Integrated PATO with DAKOTA
- Performed Sensitivity Analyses in a laminar environment of MSL-MISP2
    - Investigated impact of changes on overall sensitivity
    - Consideration: Rerunning SA with non-laminar conditions
- Compared properties of PICA vs. PICA NuSil
    - Material and Gas Properties
    - Future work: Compare PICA-N results with MEDLI flight data

THANK YOU