

INVERSE DETERMINATION OF AEROHEATING AND CHARRING ABLATOR RESPONSE



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Introduction

The Mars Science Laboratory (MSL) was protected during its Mars atmospheric entry by an instrumented heatshield that used NASA's Phenolic Impregnated Carbon Ablator (PICA) [1]. PICA is a lightweight carbon fiber/polymeric resin material that offers excellent performances for protecting probes during planetary entry. The Mars Entry Descent and Landing Instrument (MEDLI) suite on MSL offers unique in-flight validation data for models of atmospheric entry and material response. MEDLI recorded, among others, time-resolved in-depth temperature data of PICA using thermocouple sensors assembled in the MEDLI Integrated Sensor Plugs (MISP). These measurements have been widely used in the literature as a validation benchmark for state-of-the-art ablation codes [2,3,4]. The objective of this work is to perform an inverse estimate of the MSL heatshield material properties and aerothermal environment during Mars entry from the MISP flight data.

Porous material Analysis Toolbox based on OpenFOAM (PATO)

The computational model is a generic mass and heat transfer model for porous reactive materials containing several solid phases and a single gas phase. The detailed chemical interactions occurring between the solid phases and the gas phase are modeled at the pore scale assuming Local Thermal Equilibrium (LTE). This model is implemented in the Porous material Analysis Toolbox based on OpenFOAM (PATO) [5,6,7], a C++ top level module of the open source computational fluid dynamics software program **OpenFOAM**. The open source third party library **Mutation++**, produced by the von Karman Institute for Fluid Dynamics, is dynamically linked to compute equilibrium chemistry compositions and thermodynamic and transport properties [8]. For this study, the Theoretical Ablative Composite for Open Testing (TACOT) database developed by the TPS community was used to define the porous material properties. TACOT is a fictitious material that was inspired from low density carbon/phenolic ablators.

NASA Release

DPLR: <https://software.nasa.gov/software/ARC-16021-1A>
PATO: <https://software.nasa.gov/software/ARC-16680-1>

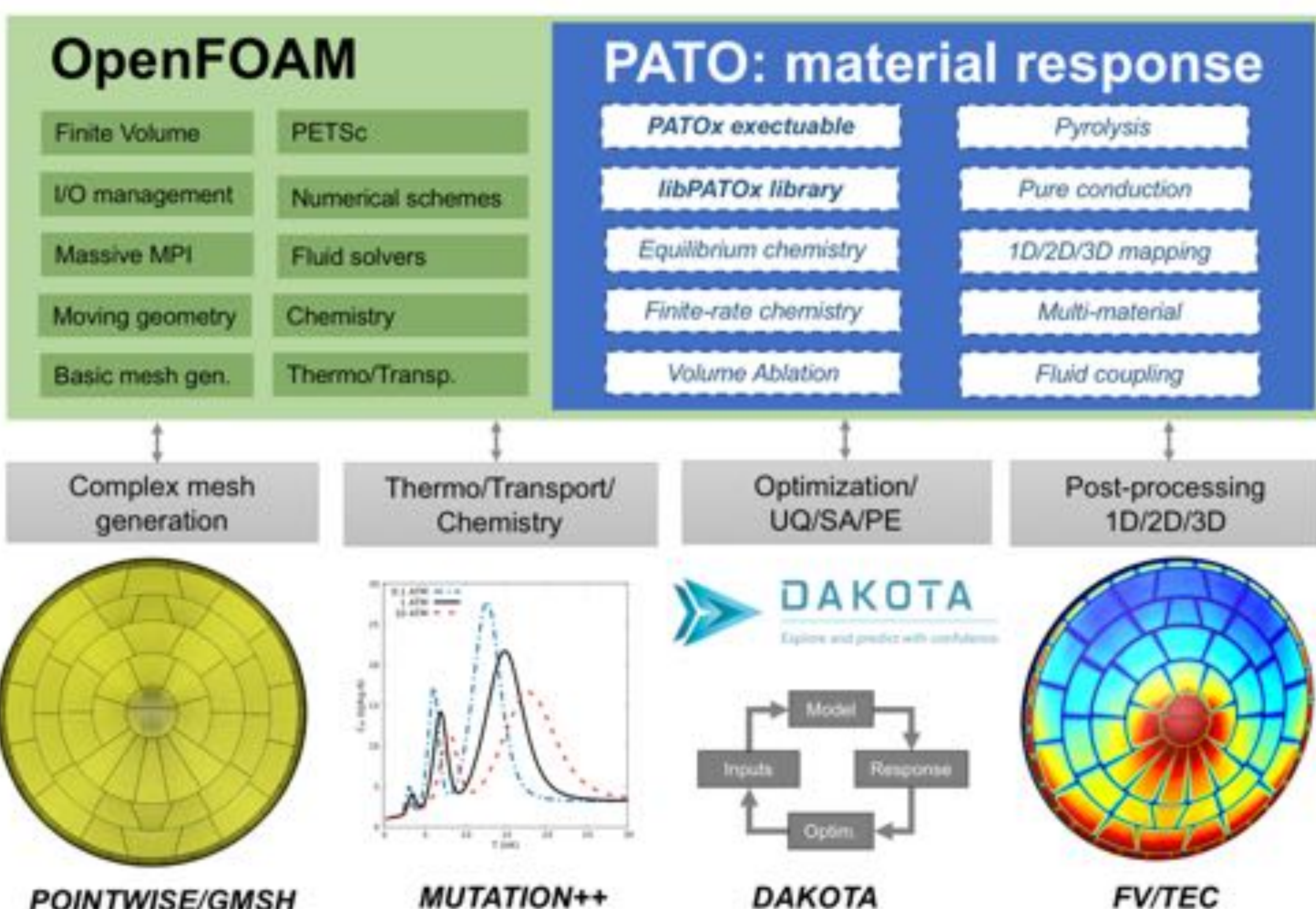


Fig. 1 Software architecture of the Porous material Analysis Toolbox based on OpenFOAM (PATO) version 3

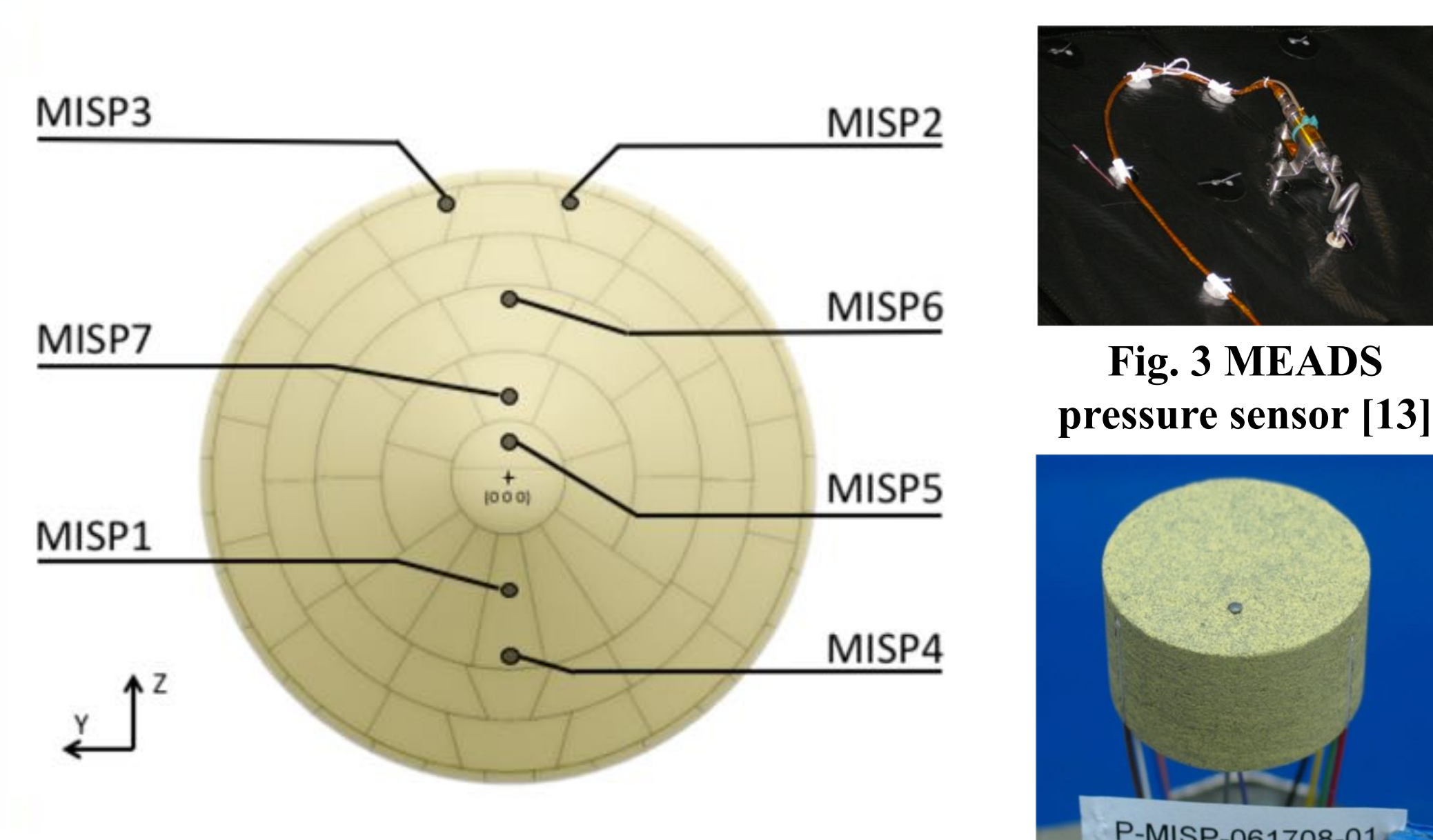


Fig. 2 MEDLI Integrated Sensor Plug (MISP) [7]

Fig. 4 MISP [13]

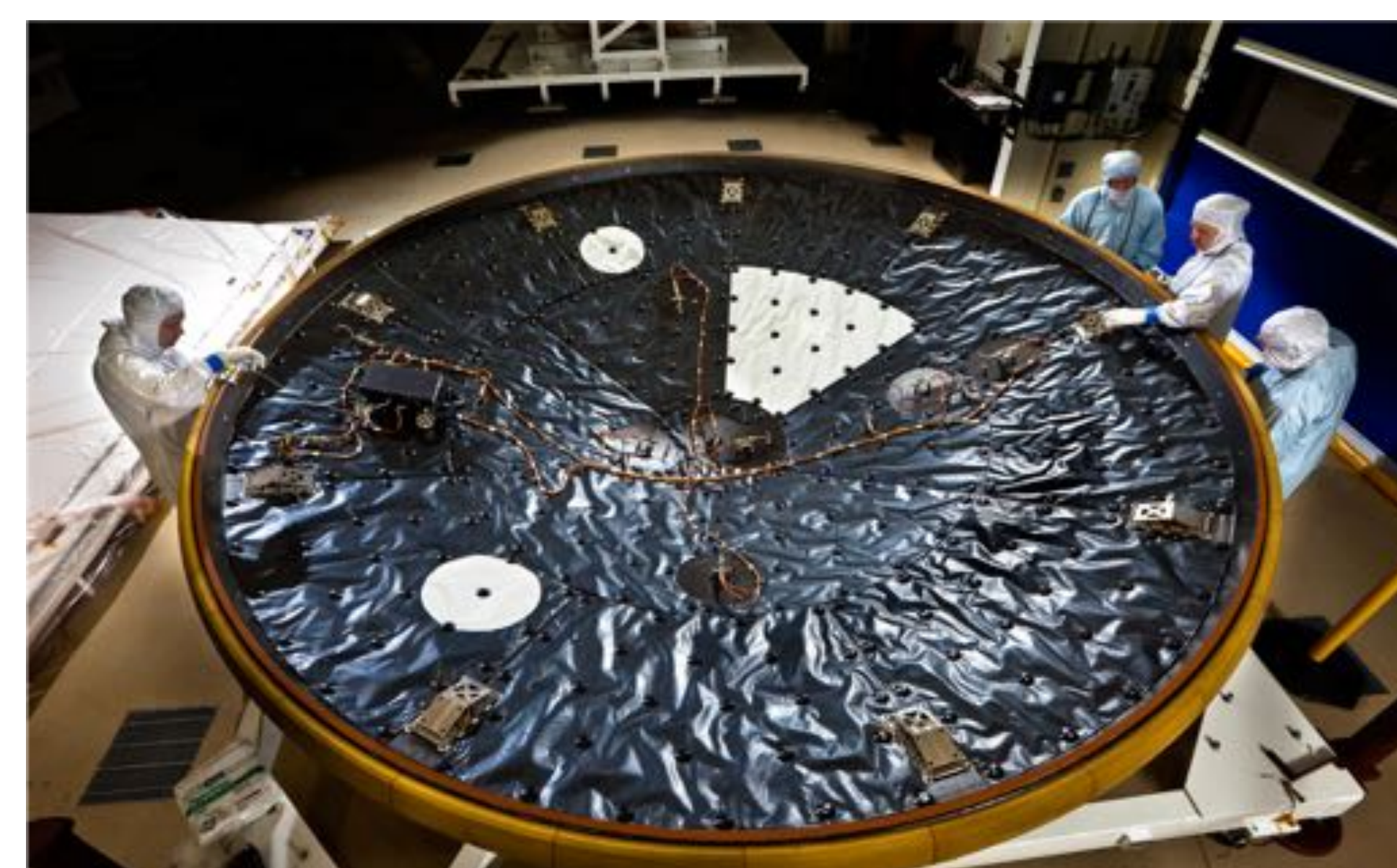


Fig. 5 MSL EDL Instrument (MEDLI) Suite assembling [13]

TC1 driver results

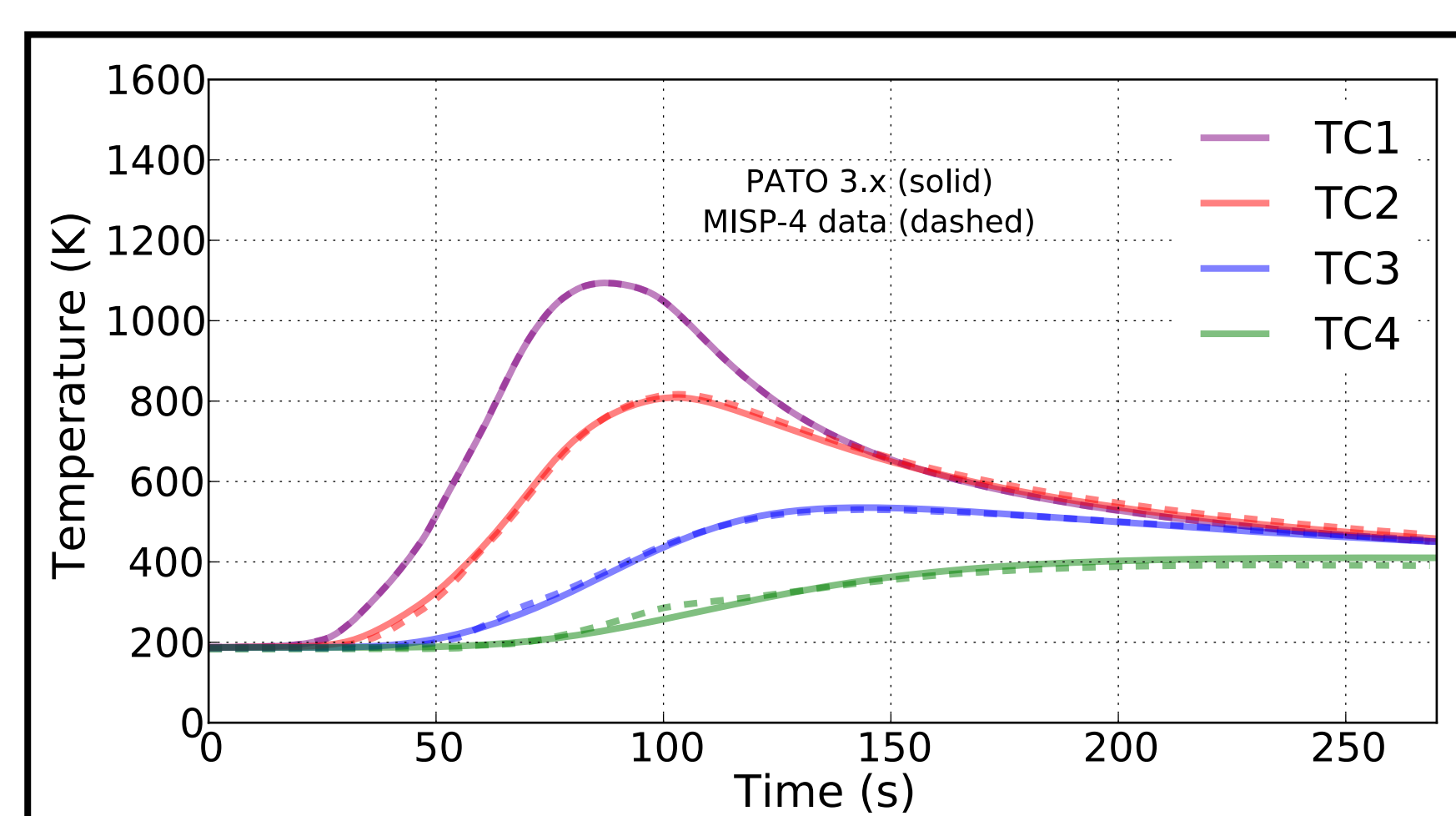


Fig. 6 Thermal response at MISP4 using TC1 driver

Inverse environment results

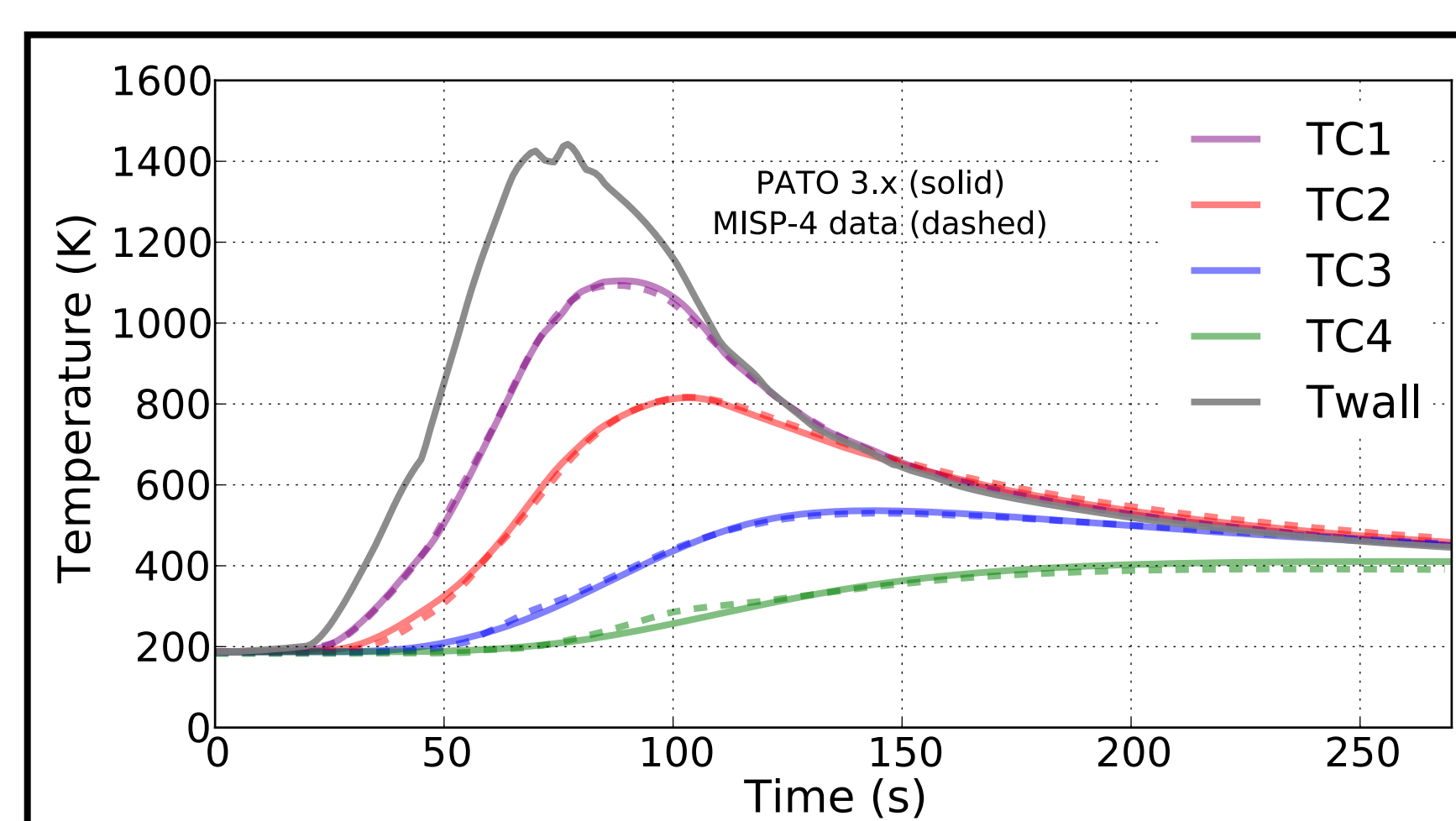


Fig. 7 Thermal response at MISP4 using the inverse environment

Comparison to DPLR results

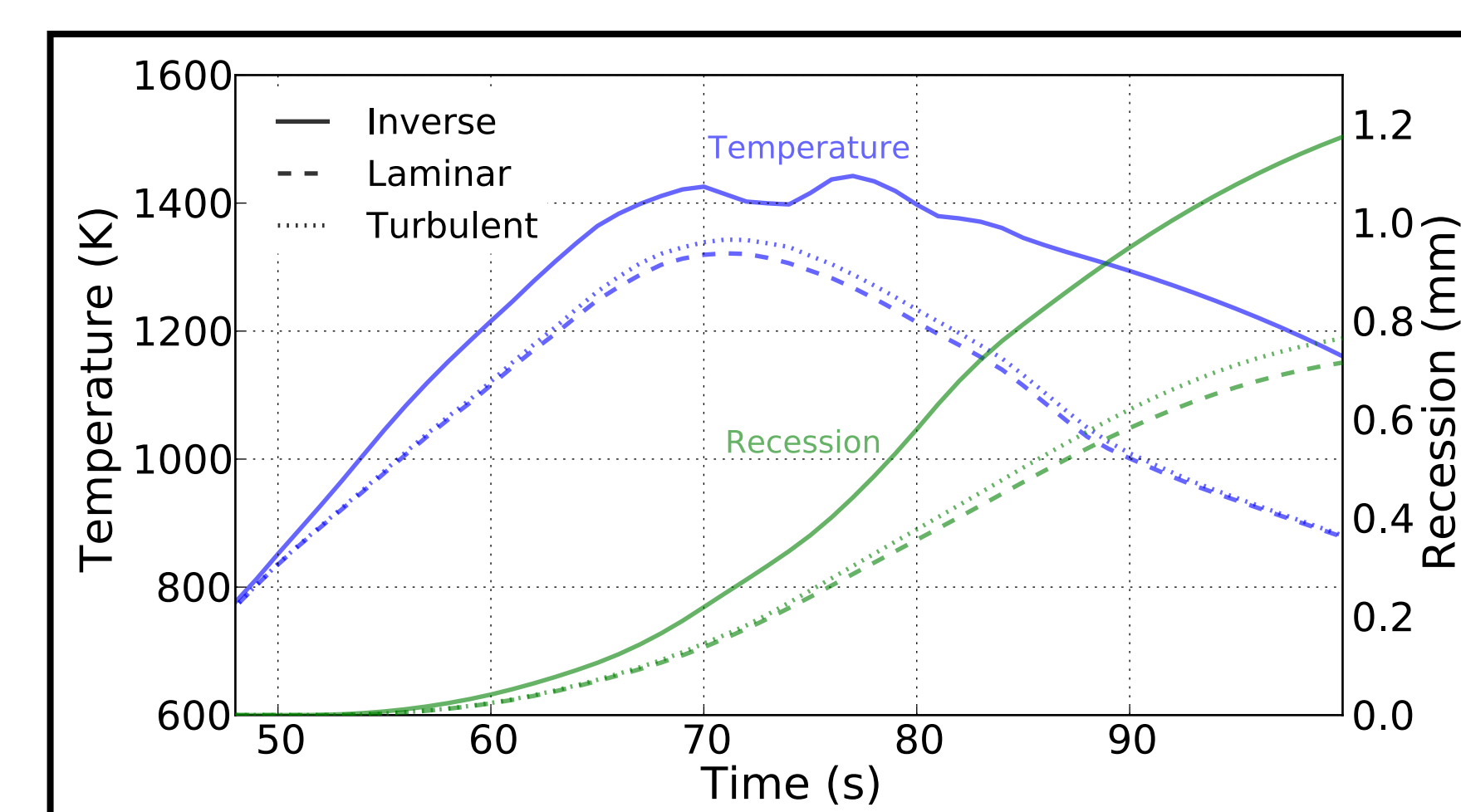


Fig. 8 Inverse and DPLR environment results

- Estimation of material properties
- Shallowest MISP 4 thermocouple
- Imposed wall temperature
- Equilibrium chemistry [7]
- Calibrated pyrolysis [9]
- TC4 hump due to water [10]

- Estimation of surface convective heat flux and char ablation rate
- Calculated temperature and recession using surface mass and energy balance
- Material properties from TC1 driver
- Note oscillations of wall temperature

- Comparison of inverse derived environment with laminar and turbulent DPLR derived aerothermal environments
- DPLR environment underestimate temperature and recession at stag. point

References

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