Inverse estimation methodology

The inverse problem is handled by the DAKOTA library [12]. A multi-objective genetic algorithm and a trust-region method for nonlinear least squares are used to estimate key uncertain material parameters that influence the material response model. We follow the strategy of Mahzari et al. [2,3] by using first the thermocouple driver approach to estimate uncertain parameters of the material model (TC1 driver). In this case, the temperature is imposed at the location of the shallowest MISP thermocouple. Then, the aerothermal environment is estimated by fitting the in-depth measured thermocouple response flight measurements. Finally, the laminar and turbulent environments from the Data Parallel Line Relaxation Code (DPLR) [11] are compared to the inverse solutions. This work represents an important milestone toward the development of validated predictive capabilities for designing Thermal Protection Systems for planetary probes.

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 van Kriman 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.

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\text{TC1 driver results} \quad \quad \text{Inverse environment results} \quad \quad \text{Comparison to DPLR results}
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- 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

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\text{Fig. 1 Software architecture of the Porous material Analysis Toolbox based on OpenFOAM (PATO) version 3}
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\text{Fig. 2 MEDLI Integrated Sensor Plug (MISP) [7]}
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\text{Fig. 3 MEADS pressure sensor [13]}
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\text{Fig. 4 MISP [13]}
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\text{Fig. 5 MSL EDL Instrument (MEDLI) Suite assembling [13]}
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\text{Fig. 6 Thermal response at MISP4 using TC1 driver}
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\text{Fig. 7 Thermal response at MISP4 using the inverse environment}
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\text{Fig. 8 Inverse and DPLR environment results}
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References