HEATSHIELD ENTRY MODELING USING A DESIGN, ANALYSIS, AND OPTIMIZATION TOOLBOX

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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). The objective of this work is to showcase the capability of the Design, Analysis, and Optimization of Thermal Protection Materials (DAO-TPM) software. DAO-TPM is a Python based framework that works as a link between mission design, aerothermal and radiative environment computation, Thermal Protection Systems (TPS) microstructure analysis, material response and optimization tools. The toolbox has a Graphical User Interface (GUI) that allows the user to build as well as run the various software and utilities used to design, analyze and optimize a heatshield during atmospheric entry.

Applications in DAO-TPM

DAO-TPM includes a set of modeling tools. The General Mission Analysis Tool (GMAT) [2] provides an open source software system for space mission design, optimization, and navigation. The Direct Simulation Monte Carlo SPARTA code [3] computes the environment around the heatshield in the rarefied regime, while in the continuum regime, the aerothermal properties are computed using the Data Parallel Line Relaxation (DPLR) CFD code [4]. The environment radiative heating is provided by the Nonequilibrium AIR radiation (NEQAIR) program [5]. The Porous Microstructure Analysis (PuMA) software [6] provides the effective material properties of PICA through a combination of predictive simulations and experiments. Mutation++ library [7] computes the thermodynamic and chemistry properties. The Porous material Analysis Toolbox based on OpenFOAM (PATO) software [8,9,10] is used to perform the material response of the heatshield. The DAKOTA library [11] is used to calibrate physical models in PATO and PuMA. In future work, DAKOTA will be used to do sensitivity analysis and quantification of margins and uncertainty of the thermal response at the MISP locations.

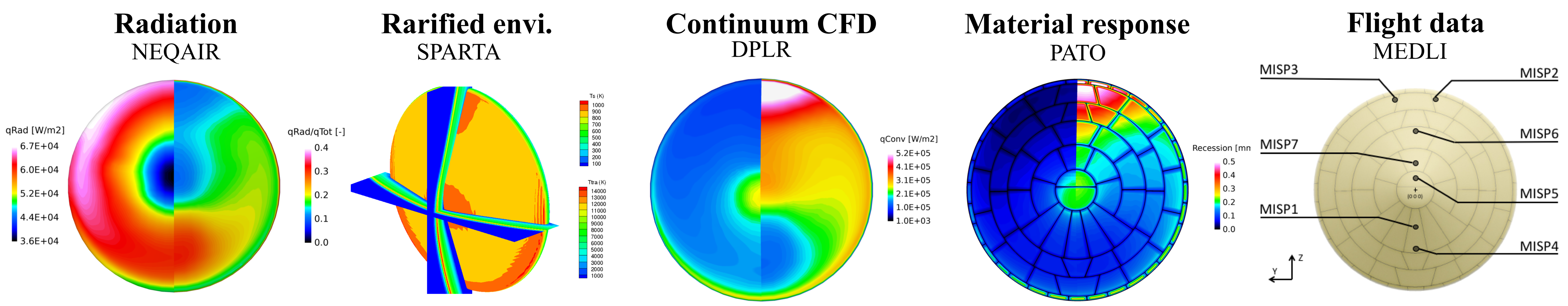

Fig. 1 MSL simulations at the macro-scale using NEQAIR, SPARTA, DPLR and PATO.

MSL simulations at the macro-scale

NASA's next mission to Mars, Mars 2020, will use the spare heatshield of the Mars Science Laboratory (MSL) for thermal protection during entry, descent and landing. In preparation for Mars 2020 post-flight analysis, the predictive material response capability is benchmarked against flight data from the MEDLI. This work represents an important milestone toward the development of validated predictive capabilities for designing thermal protection systems for planetary probes.

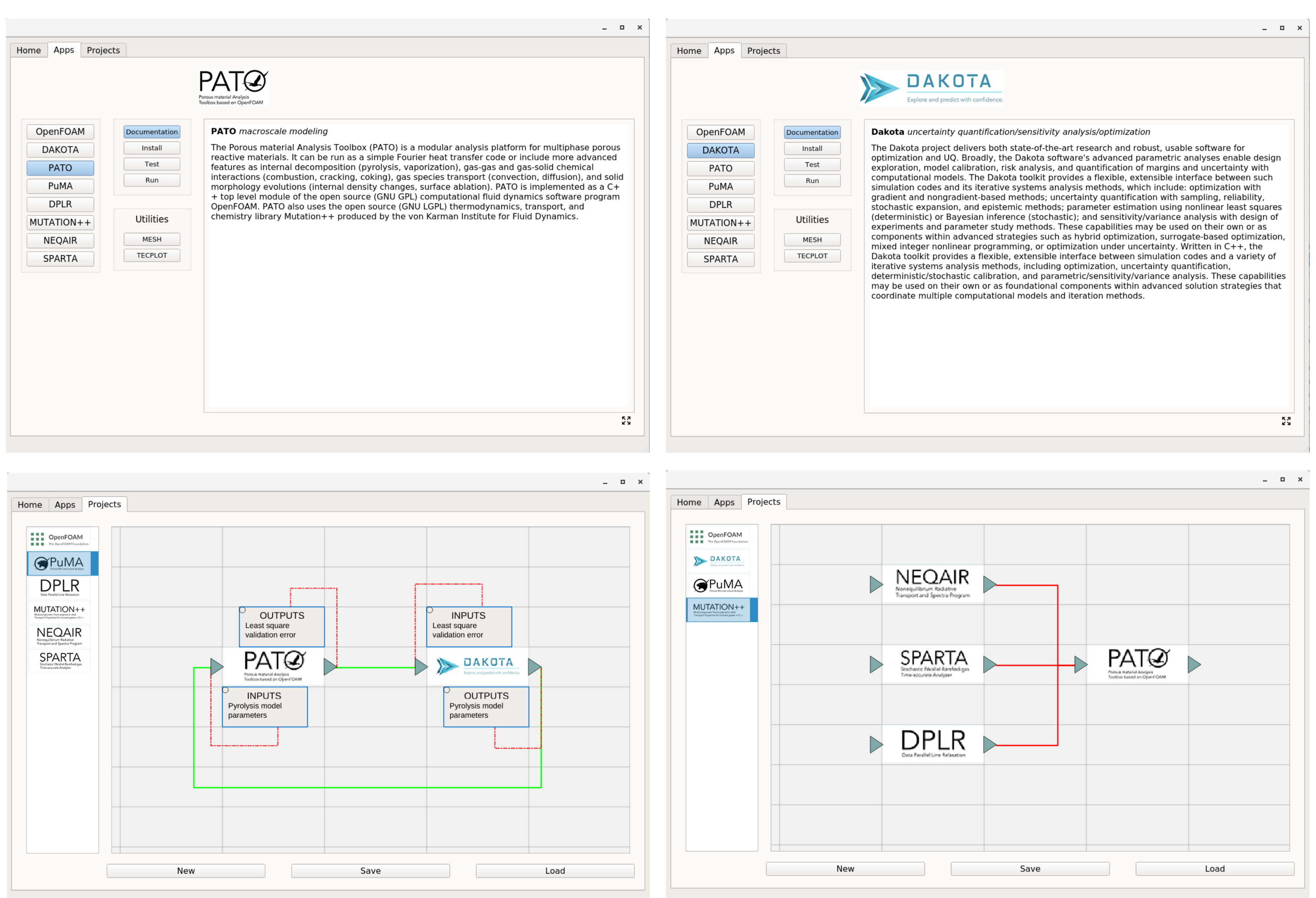

Fig. 2 DAO-TPM: Apps and Projects.

Calibration of PICA pyrolysis gases

A new model for the PICA pyrolysis is developed and calibrated [12] based on high fidelity thermal decomposition experiments [13]. The model calibration is achieved by coupling PATO with Dakota. The calibration is based on precise quantification of pyrolysis gases. These are obtained from mass spectroscopy analysis during thermal decomposition at fast heating rates. The experimental data are fit using a multi-objective genetic algorithm by optimizing the model parameters for an element based formulation. This new model captures both the material mass loss and the gaseous elements produced during pyrolysis.

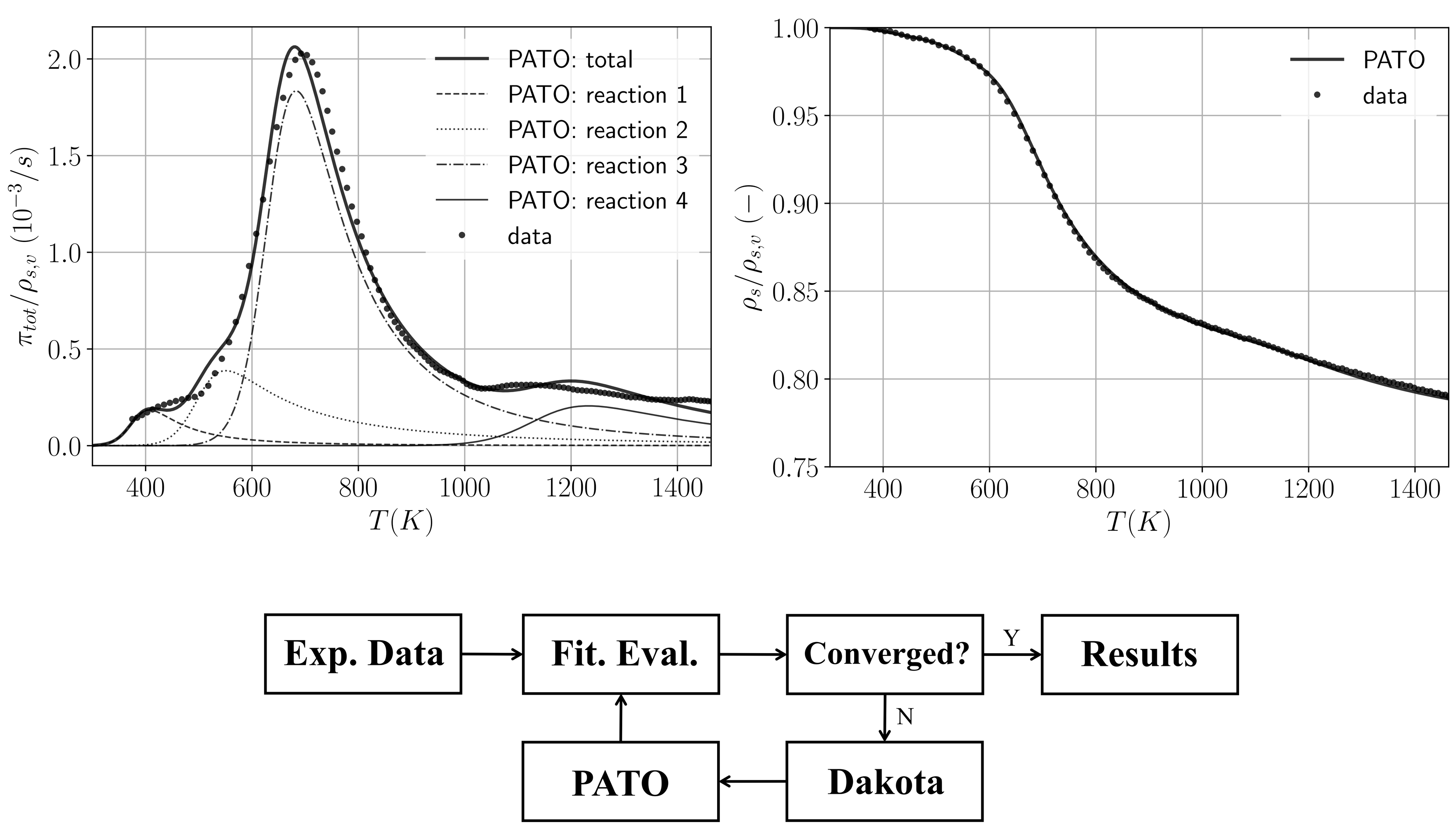

Fig. 3 Calibration of PICA pyrolysis

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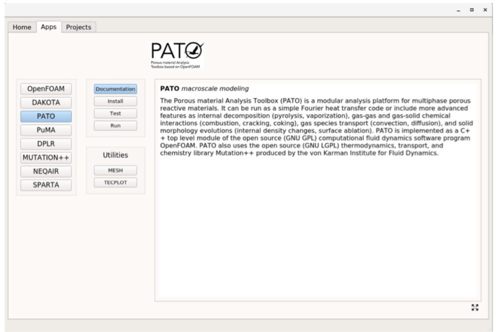
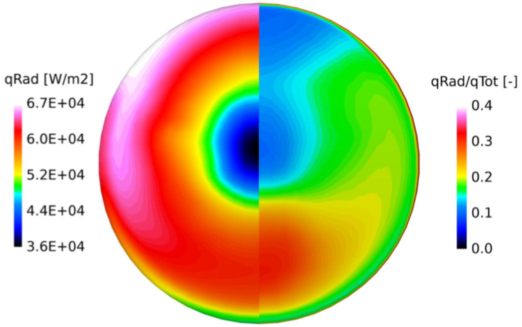
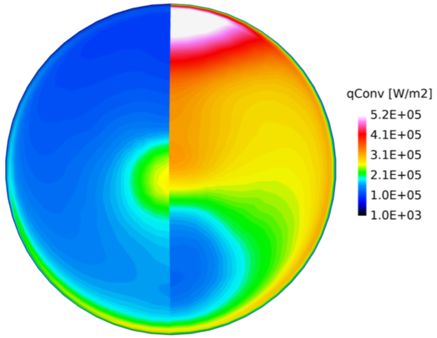
Design - Analysis
DAO-TPM



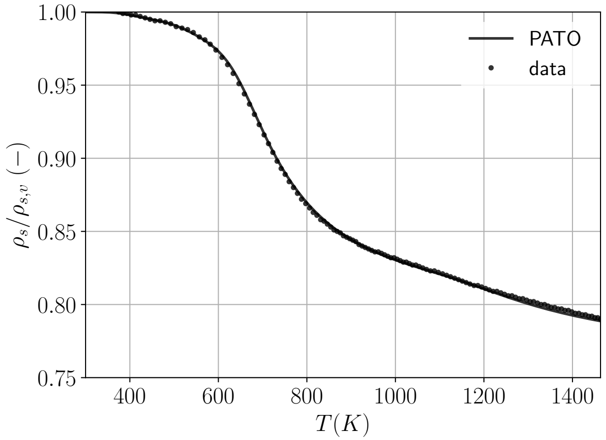
Radiation
NEQAIR



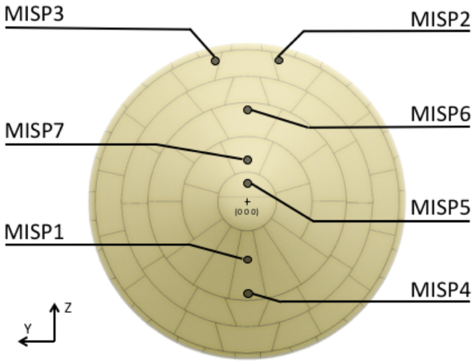
Continuum CFD
DPLR



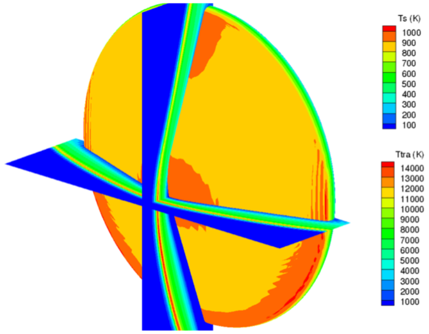
Calibration
Dakota



Flight data
MEDLI



Rarified envi.
SPARTA



Material response
PATO