

Introduction

NASA's next mission to Mars, the **Mars 2020**, will use the same heatshield of the Mars Science Laboratory (MSL) for thermal protection during entry, descent and landing. The heatshield is a tiled system made of Phenolic Impregnated Carbon Ablators (PICA) blocks [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 compare the thermal response of the MSL heatshield to the MISP flight data. In preparation to Mars 2020 post-flight analysis, the predictive material response capability is benchmarked against MEDLI 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) [2,3,4], a C++ top level module of the open source computational fluid dynamics software program **OpenFOAM**. The present work compares PATO simulations to MISP flight data using the shallowest thermocouple as thermal boundary conditions (TC1 driver) or the aerothermal environment boundary conditions including radiation (environment BC in Fig. 2-3) at different MISP locations. The PATO material response model, used in Fig. 4-9, includes the elemental mass conservation and the equilibrium chemistry using the composition of the elements.

Prediction methodology

Figure 1 shows the different tools used for the MSL material response. The aerothermal environment at various Knudsen regimes is fed to **PATO** as surface boundary conditions. In the rarified regime, the environment around the MSL aeroshell is computed using the Direct Simulation Monte Carlo code **SPARTA** [5], while in the continuum regime the CFD code Data Parallel Line Relaxation (**DPLR**) [6] is used. The radiation heating from the environment is added to the surface energy balance by computing radiative flux at Mars entry conditions using the Nonequilibrium air radiation (**NEQAIR**) program [7]. Effective material properties for PICA are obtained through a combination of experiments and predictive simulation using the Porous Microstructure Analysis (**PuMA**) software [8]. The pyrolysis reactions are calibrated using experimental data [11] and **Dakota**. 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 [9].

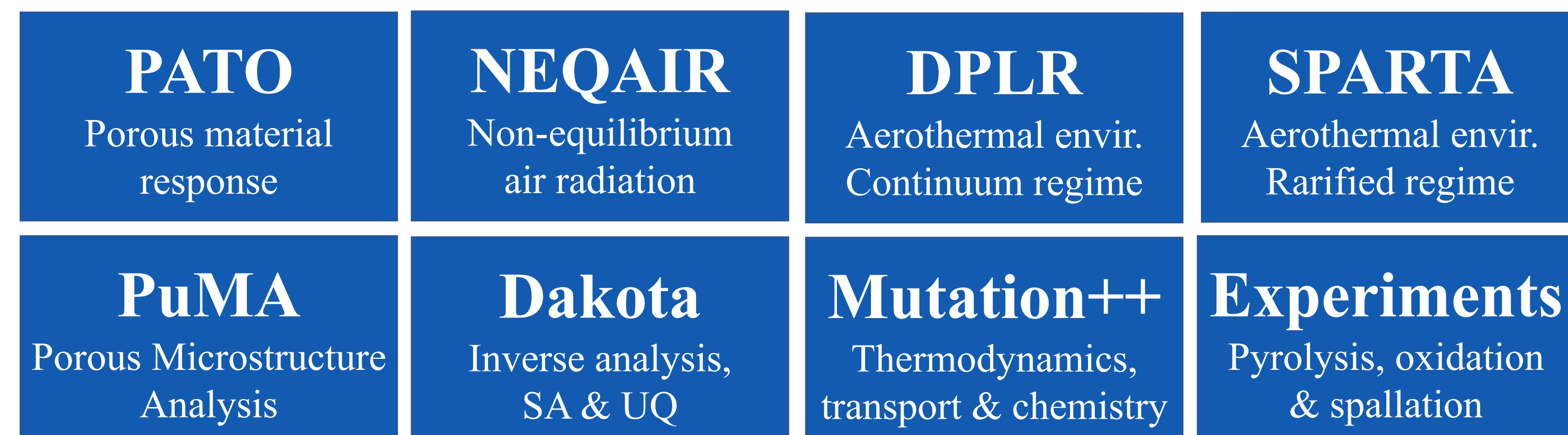


Fig. 1 Tool collections for material response prediction of thermal protection systems

Environment Boundary Conditions

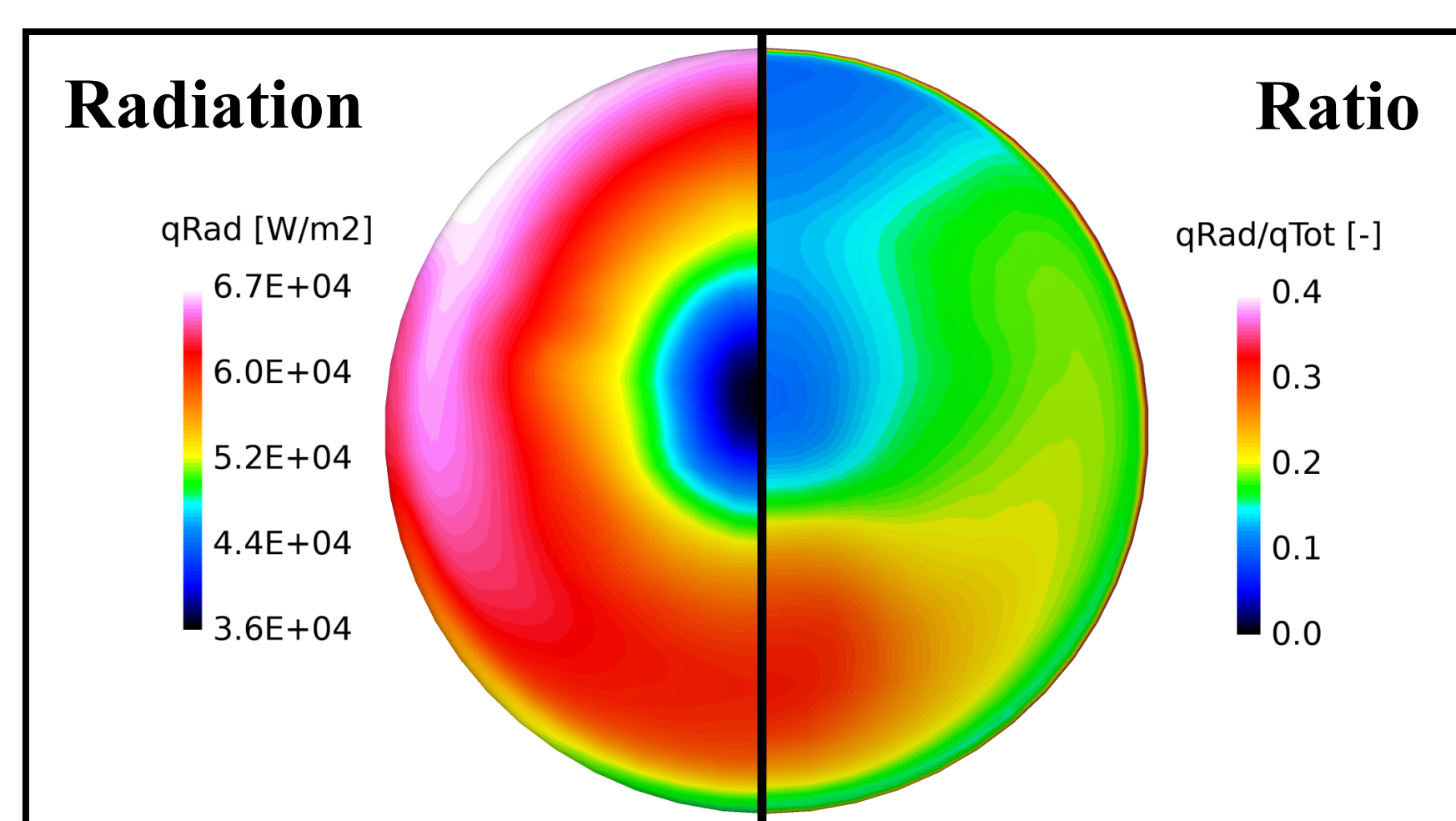


Fig. 2 Radiative heat flux at the heatshield front surface (75 s)

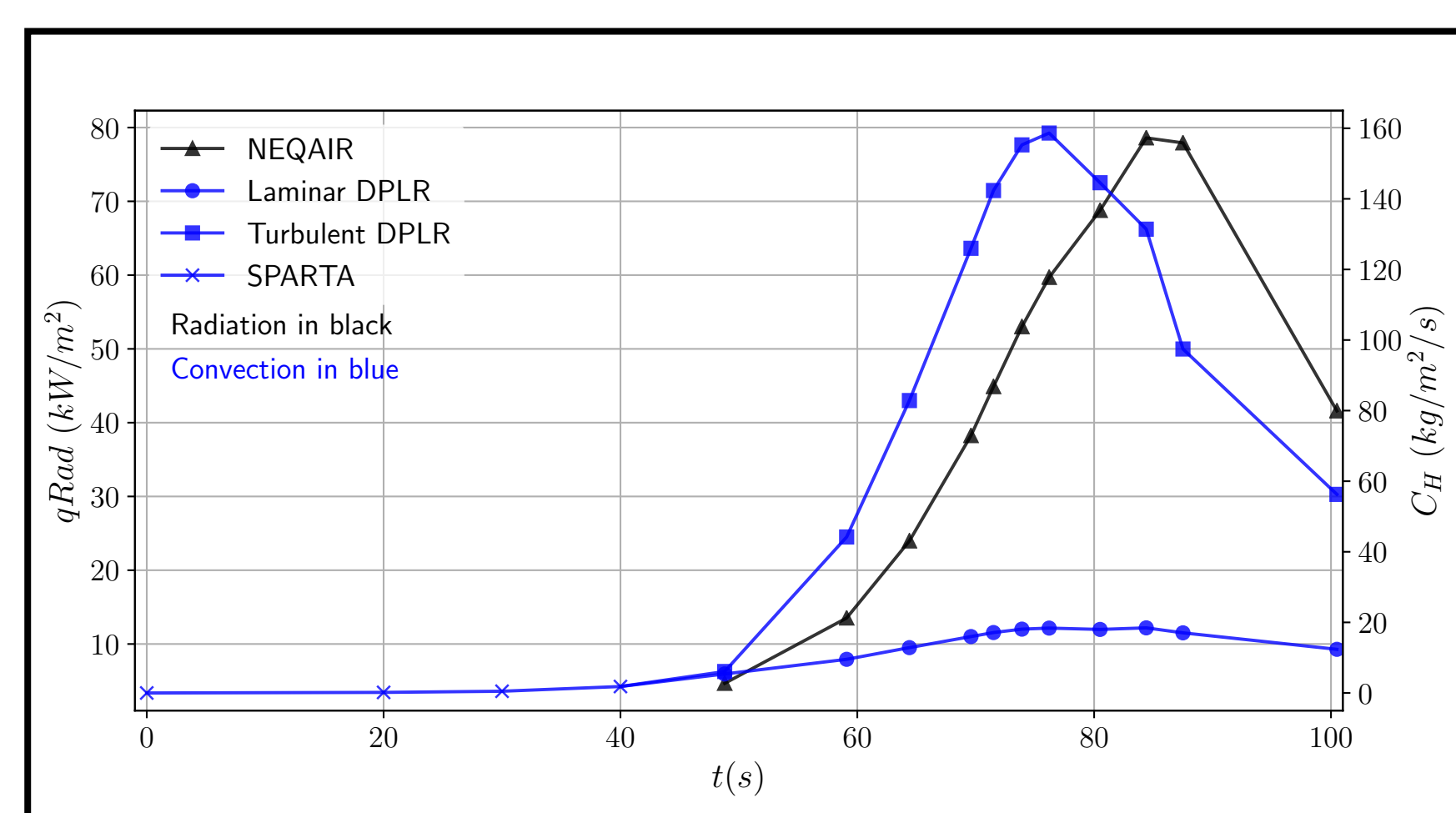


Fig. 3 Radiative and convective inputs over time at MISP2

- Mars non-equilibrium chemistry with 8 species in SPARTA, DPLR and NEQAIR
- 3D mapping method from Tecplot files using local Galerkin projection [4]
- Radiation analysis was run on all 11 CFD trajectory points at 202 radial points on the half-body heatshield solutions. 172 points used tangential slab method and 30 points used full angular integration methods in NEQAIR [7]
- 4 trajectory points in SPARTA [5] which uses Variable Soft Sphere (VSS) model with high temperature transport calibration [5]
- 11 trajectory points in DPLR which uses a laminar or a Menter Shear Stress Transport (SST) turbulence model [6]
- Radiative heat flux is up to 35% of the total heat flux at the heating peak (75 s)

PATO simulation vs MISP flight data: Elemental conservation + equilibrium chemistry

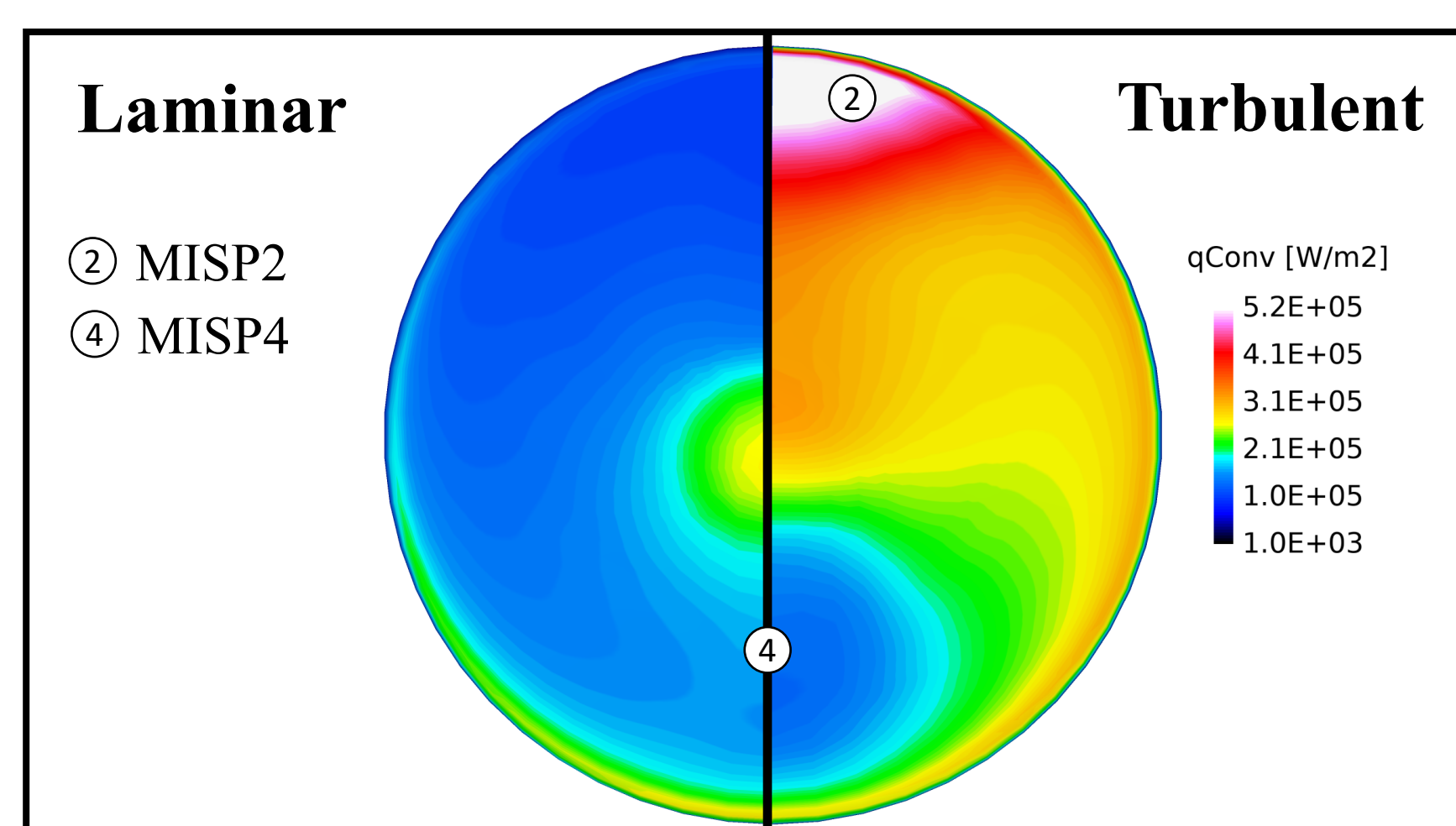


Fig. 4 Convective heat flux at the heatshield front surface (75 s)

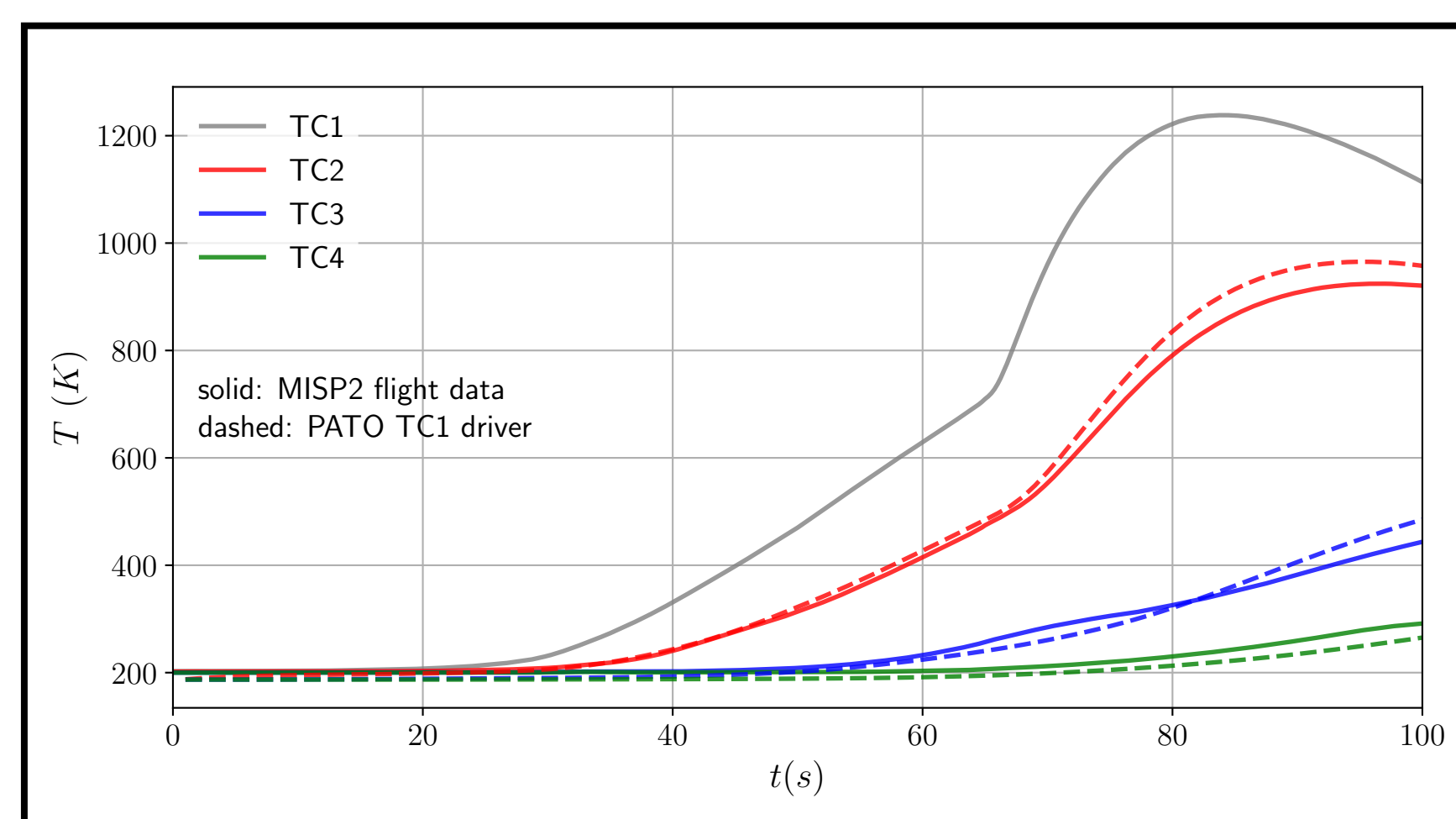


Fig. 5 PATO response using TC1 driver compared to MISP2

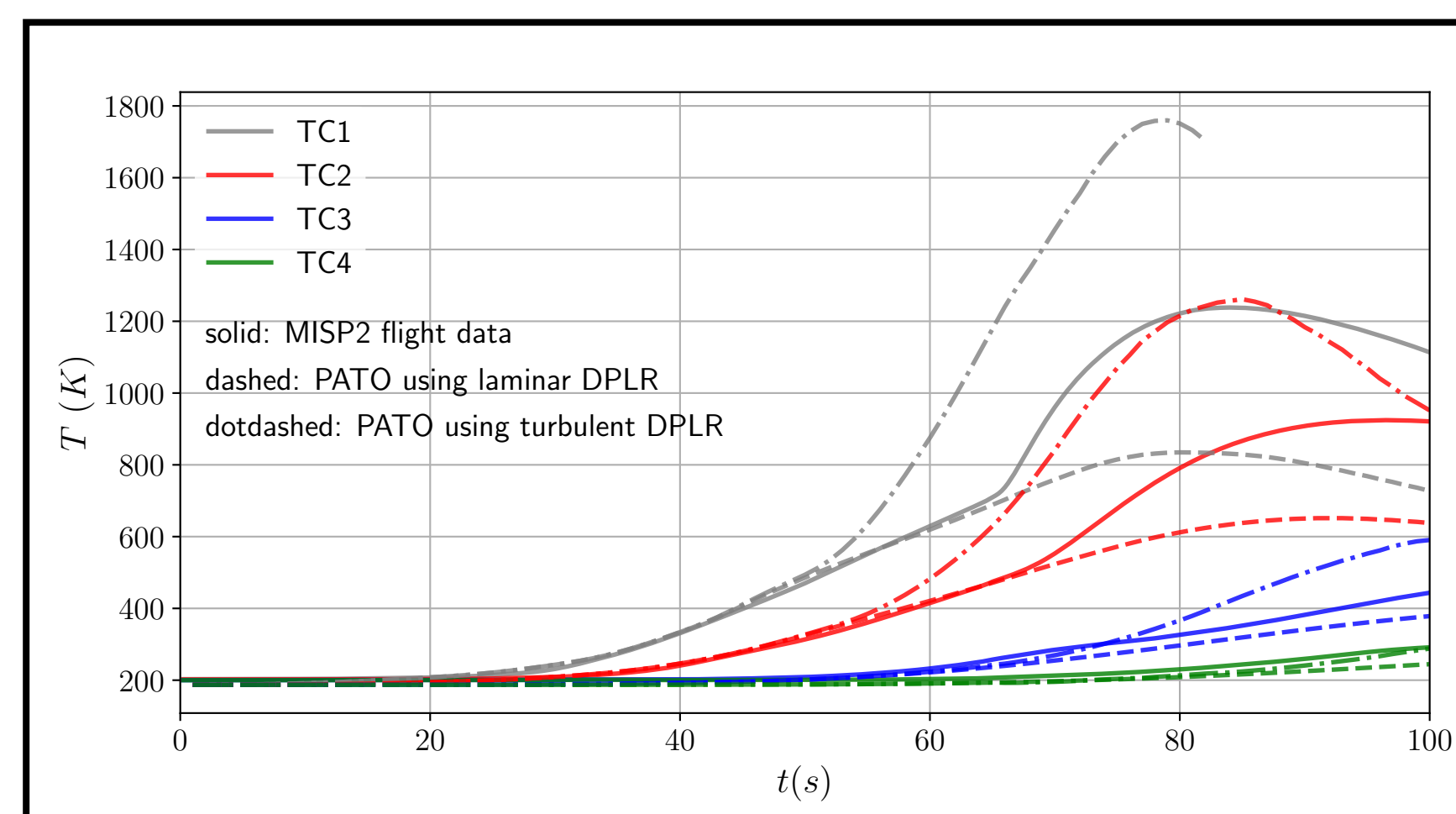


Fig. 6 PATO response using the environment BC compared to MISP2

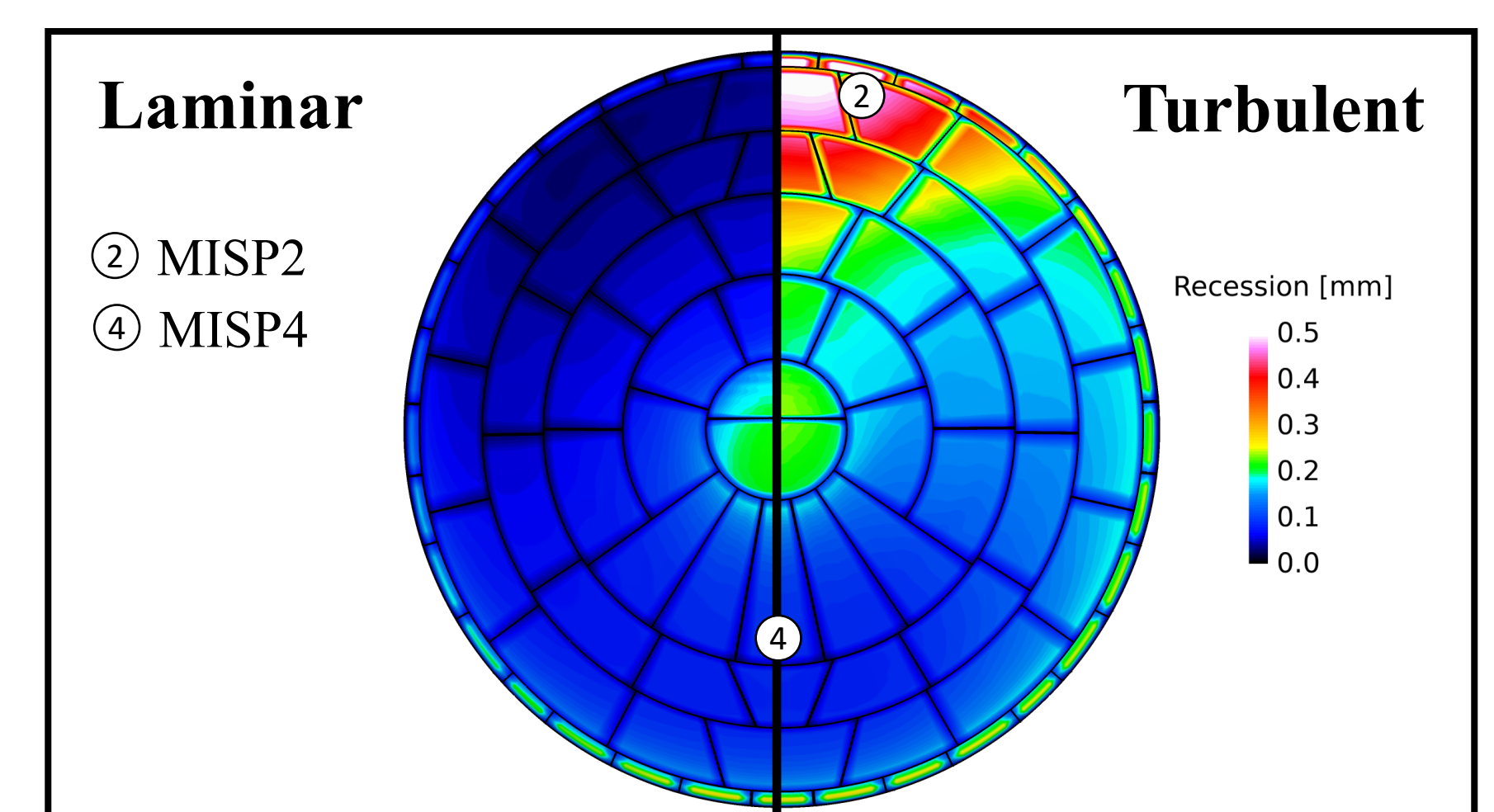


Fig. 7 Recession solution at the heatshield front surface (75 s)

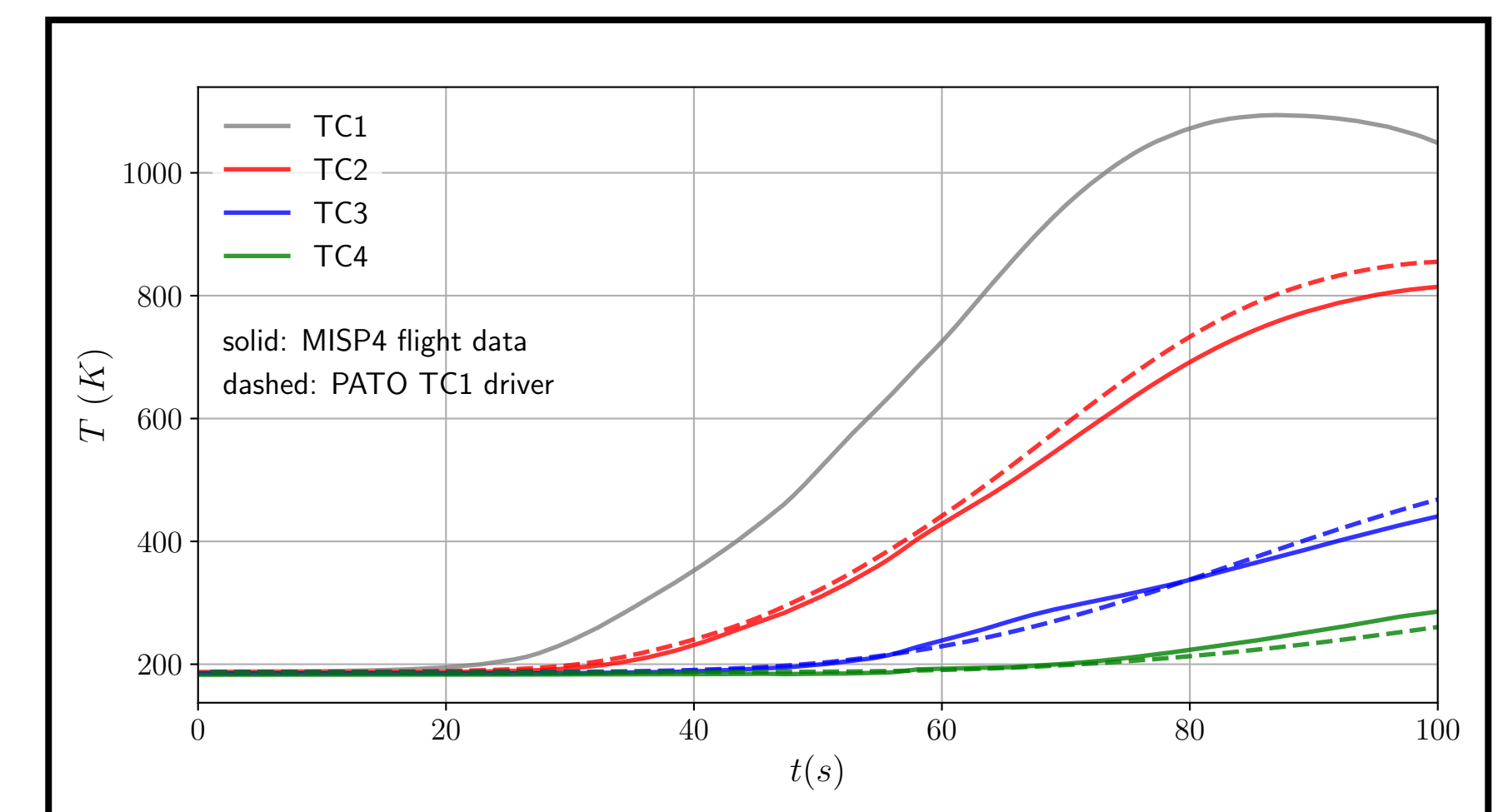


Fig. 8 PATO response using TC1 driver compared to MISP4

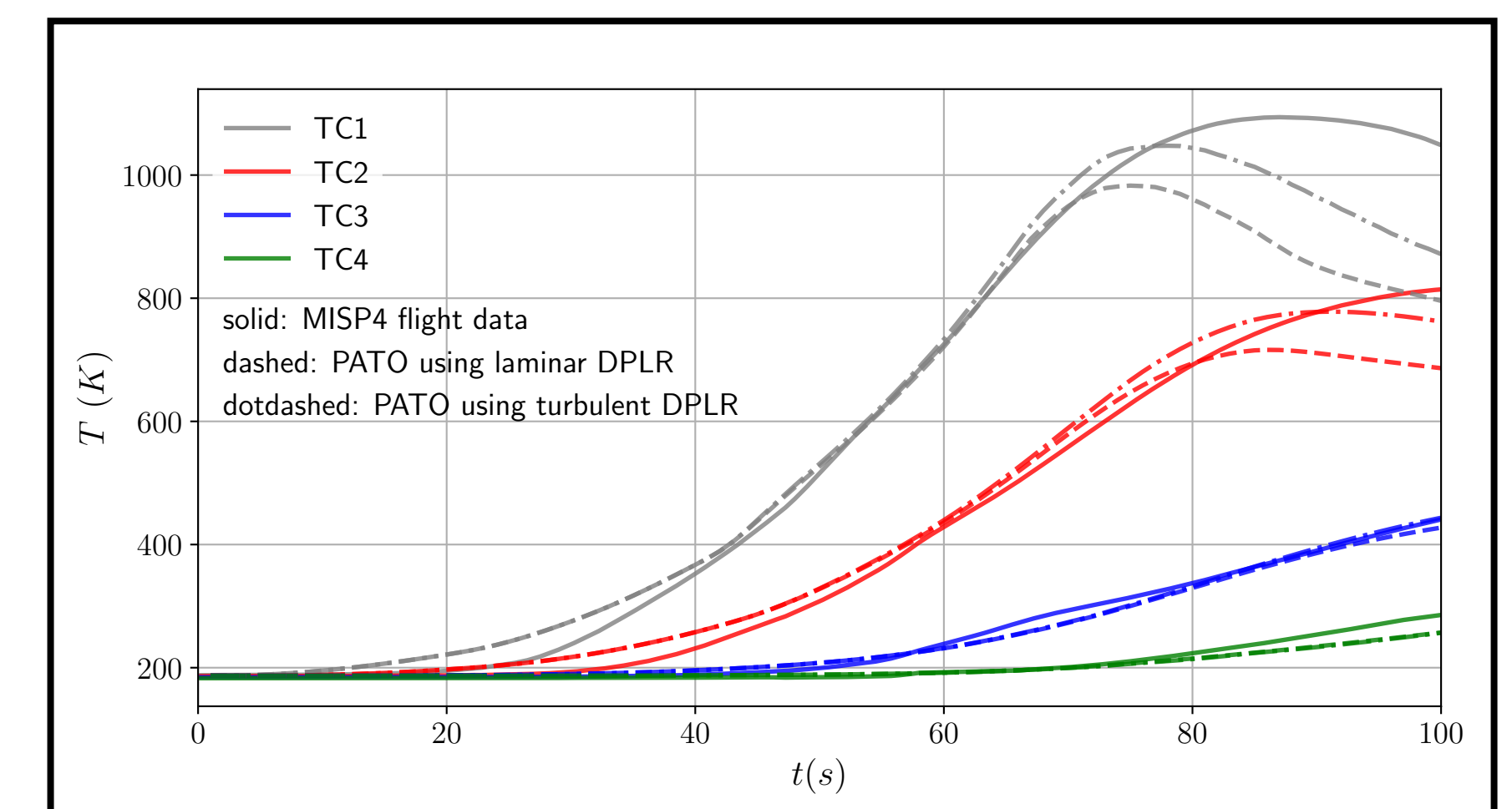


Fig. 9 PATO response using the environment compared to MISP4

- PICA v3.3 material properties [10] V&V by FIAT, TITAN and experimental arc jet data
- Porosity and permeability properties using PuMA and 3D tomography images [8]
- Elemental pyrolysis reactions calibrated by experimental data [11] using Dakota library
- PATO thermal response using TC1 driver in good agreement with MISP2 and MISP4 flight data
- MISP2 data is located between the PATO response using laminar and turbulent DPLR environment
- MISP4 data is higher at the heating peak than the PATO thermal response

References

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