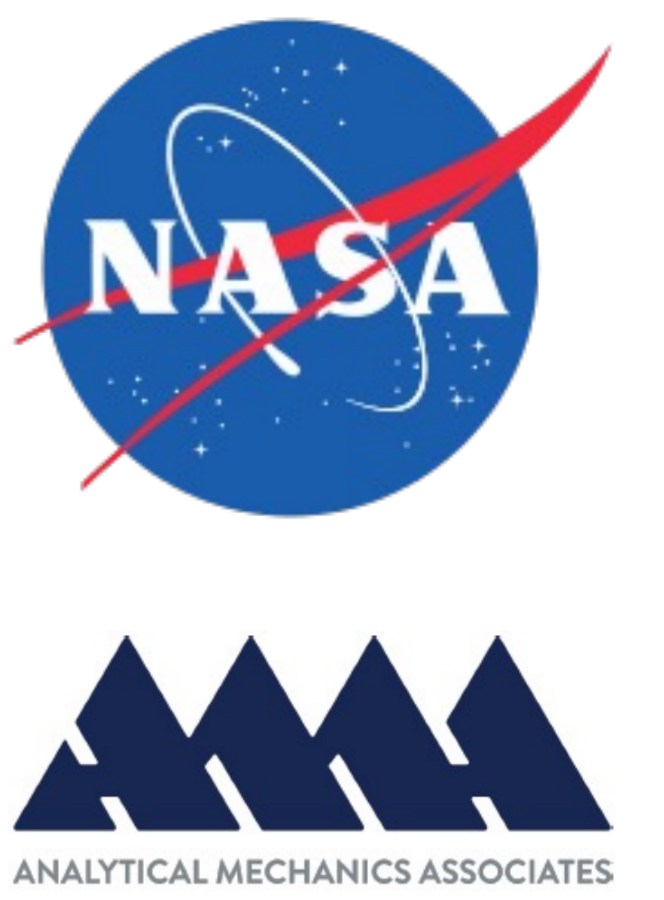


Recent Advancements in the PATO Material Response Code

John M. Thornton¹, Jeremie B.E. Meurisse¹, Sergio Fraile Izquierdo¹,
Bruno Dias¹, Georgios Bellas Chatzigeorgis¹, Nagi N. Mansour¹
Analytical Mechanics Associates, Inc. at NASA Ames Research Center¹



Objective

Predicting the complicated multi-physics phenomena during atmospheric entry requires high-fidelity modeling tools to refine estimates of mission risks during entry. To this end, new capabilities are being added to the Porous-material Analysis Toolbox based on OpenFOAM (PATO) [1,2,3]. PATO is an open-source software for Computational Material Response of reactive porous materials submitted to high-enthalpy environments.

Coupling with CFD

A loose coupling between PATO and the Data Parallel Line Relaxation (DPLR) [4] CFD code has been achieved by making use of a blowing boundary condition in DPLR. The entire iterative process is illustrated in Figure 1. This coupling strategy has been utilized in computing the MSL material response.

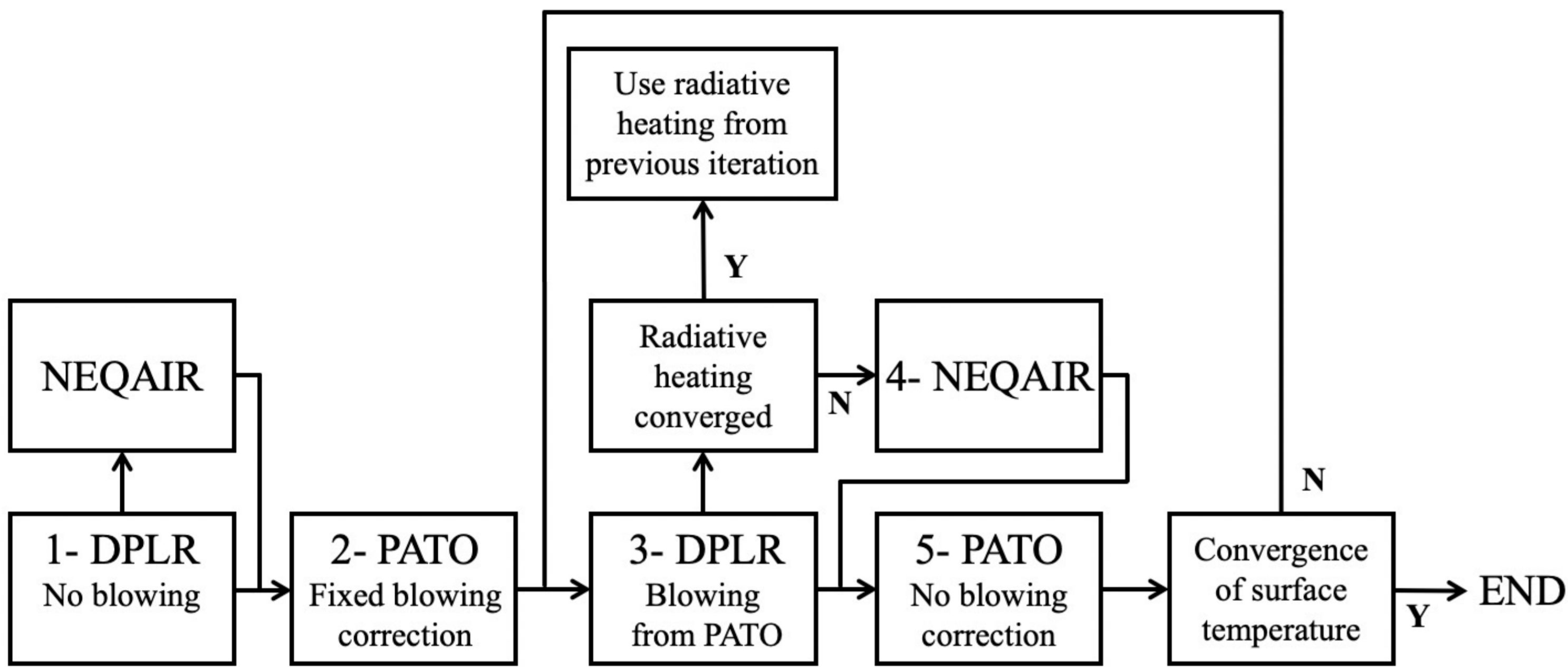


Fig. 1 Diagram showing the coupling process. DPLR and NEQAIR [5] provide inputs to PATO which is initially run with a fixed blowing correction parameter λ . The blowing rates and species computed by PATO are then used as inputs to DPLR in a blowing boundary condition. Aerothermal environment (DPLR), radiative heating (NEQAIR), and material response (PATO) computations are then iterated without blowing corrections.

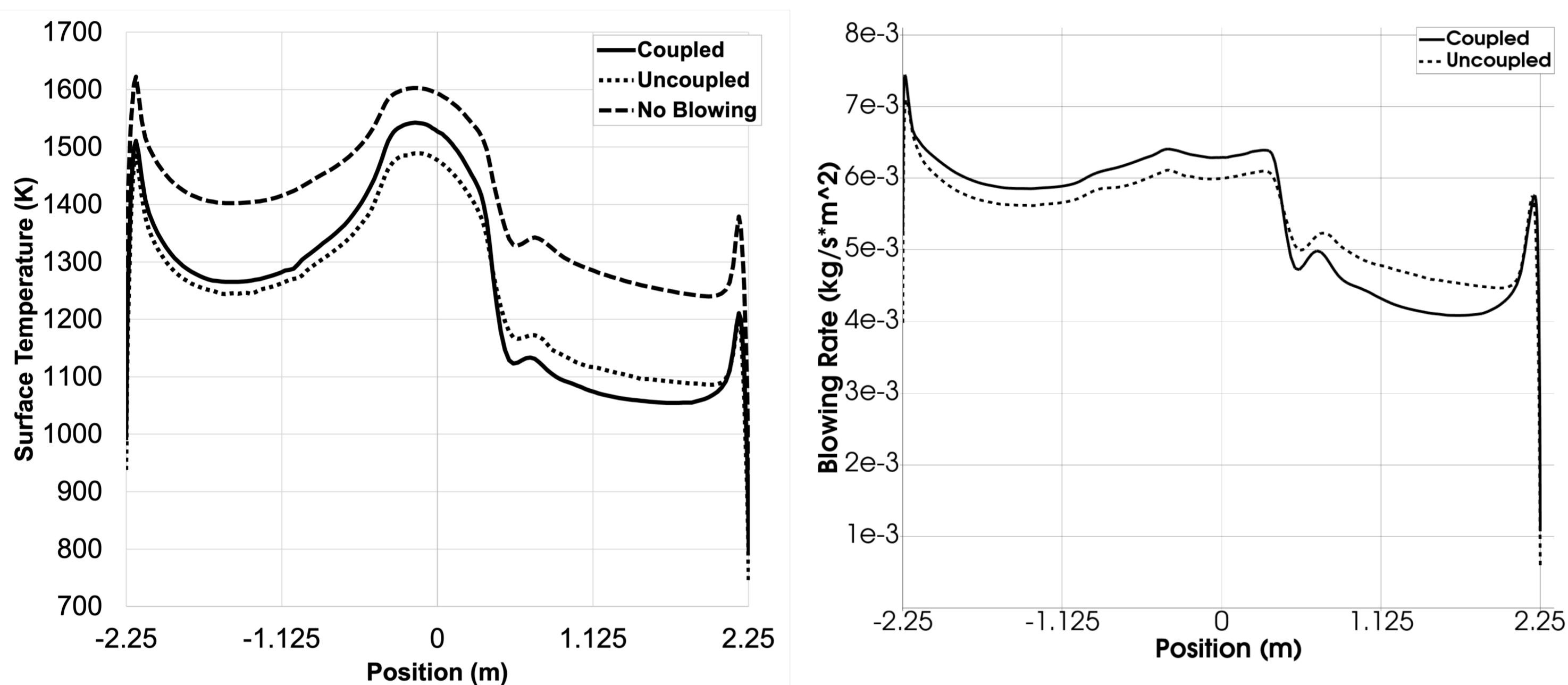


Fig. 2 Centerline plots of temperature (left) and blowing rate (right) at 65s at the heatshield surface.

Mechanical Erosion Modeling

The mechanical erosion model accounts for mass removal induced by high shear conditions. The modeling process at each timestep consists of computing the stress tensor and displacement fields of the material. A failure criteria model determines regions where stress exceeds the ultimate strength of the material resulting in additional surface recession.

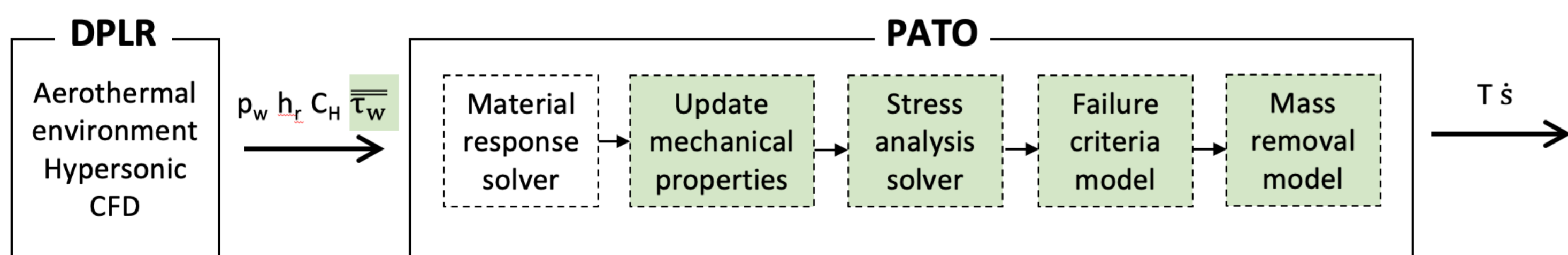


Fig. 3 Diagram showing mechanical erosion modeling process.

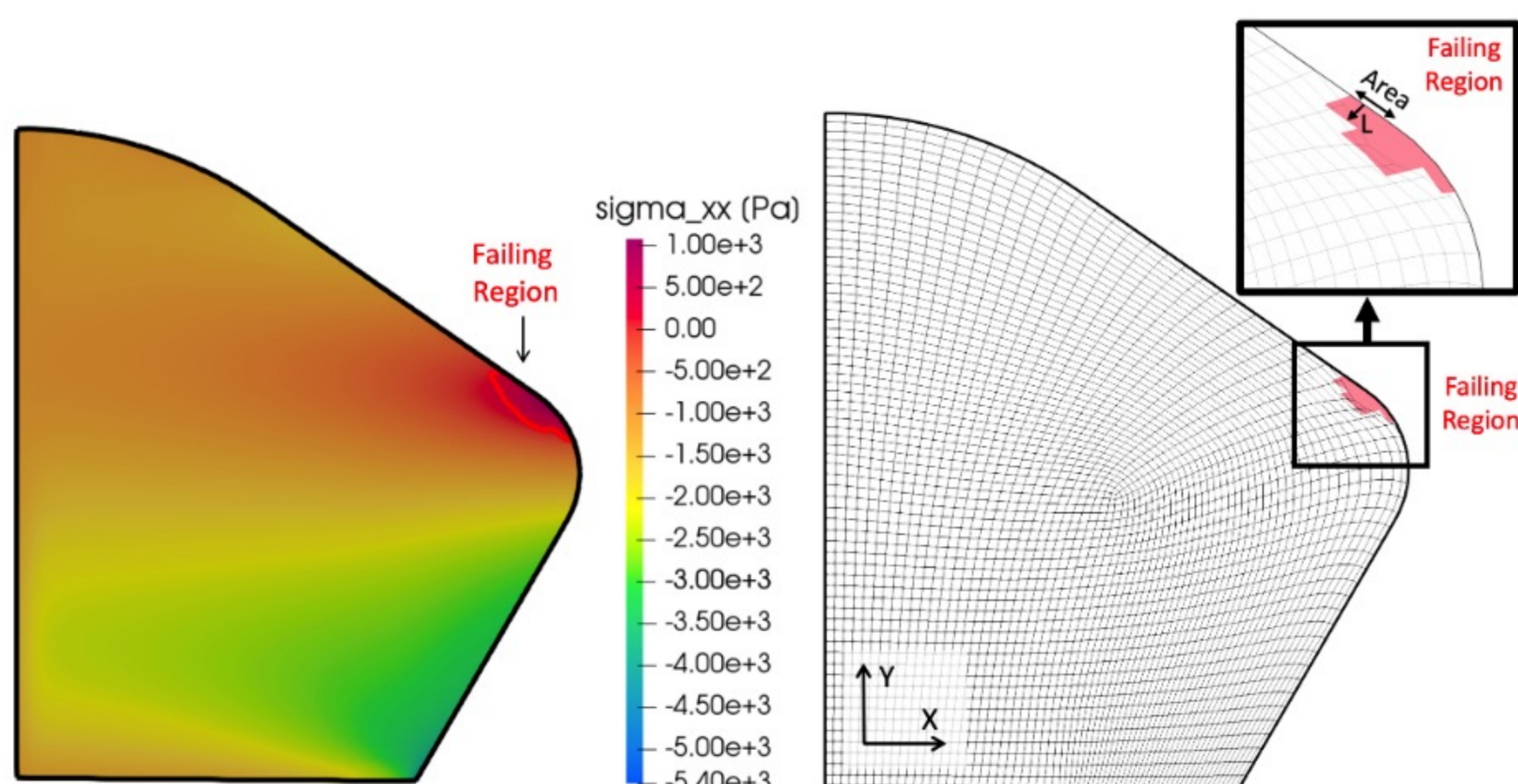


Fig. 4 Computed XX component of the stress tensor and failing region (left) and mass removed using dynamic mesh motion in PATO (right).

PICA-NuSil Modeling

NuSil, a silicone-based coating, was sprayed onto the MSL and Mars 2020 heatshields to mitigate shedding of phenolic dust. A new material response model has been added in PATO in which the equilibrium of the charred NuSil surface is modeled as pure silica and a constant offset to the char blowing rate and wall enthalpy are added to reproduce HyMETS experimental results.

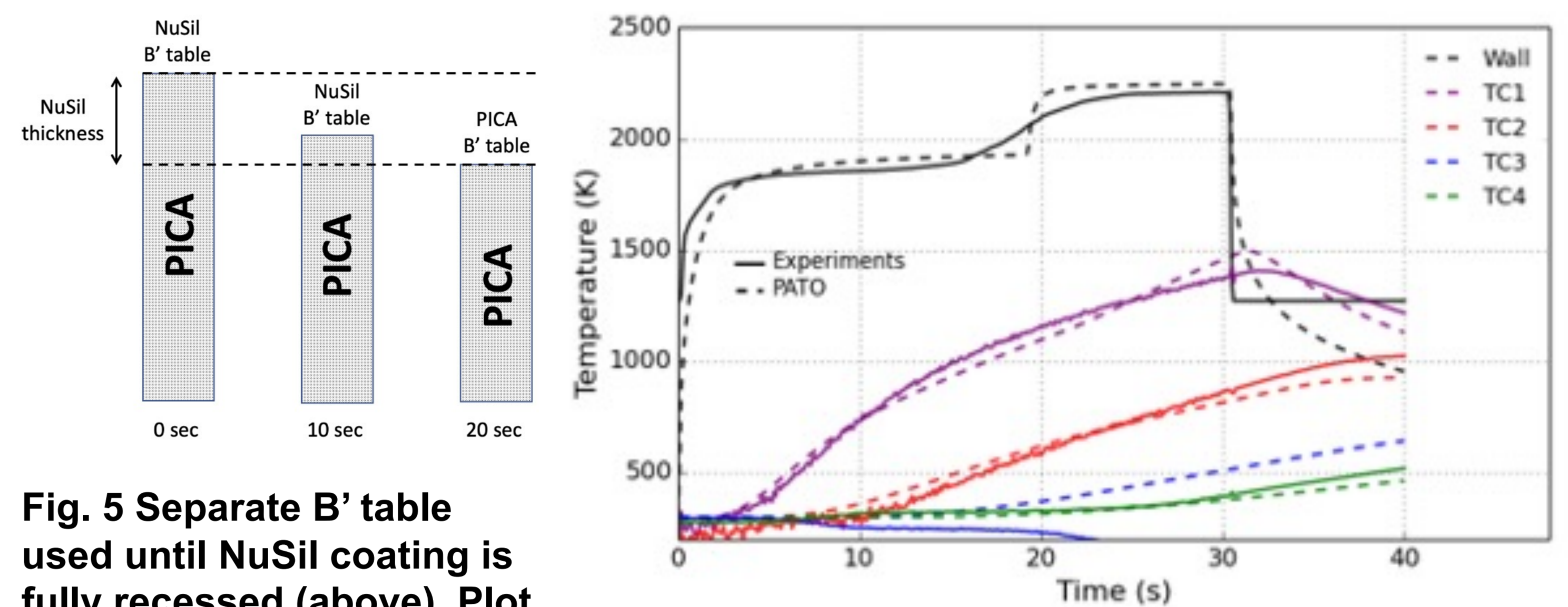


Fig. 5 Separate B' table used until NuSil coating is fully recessed (above). Plot showing temperature profiles from HyMETS compared with computed profiles from PATO (right).

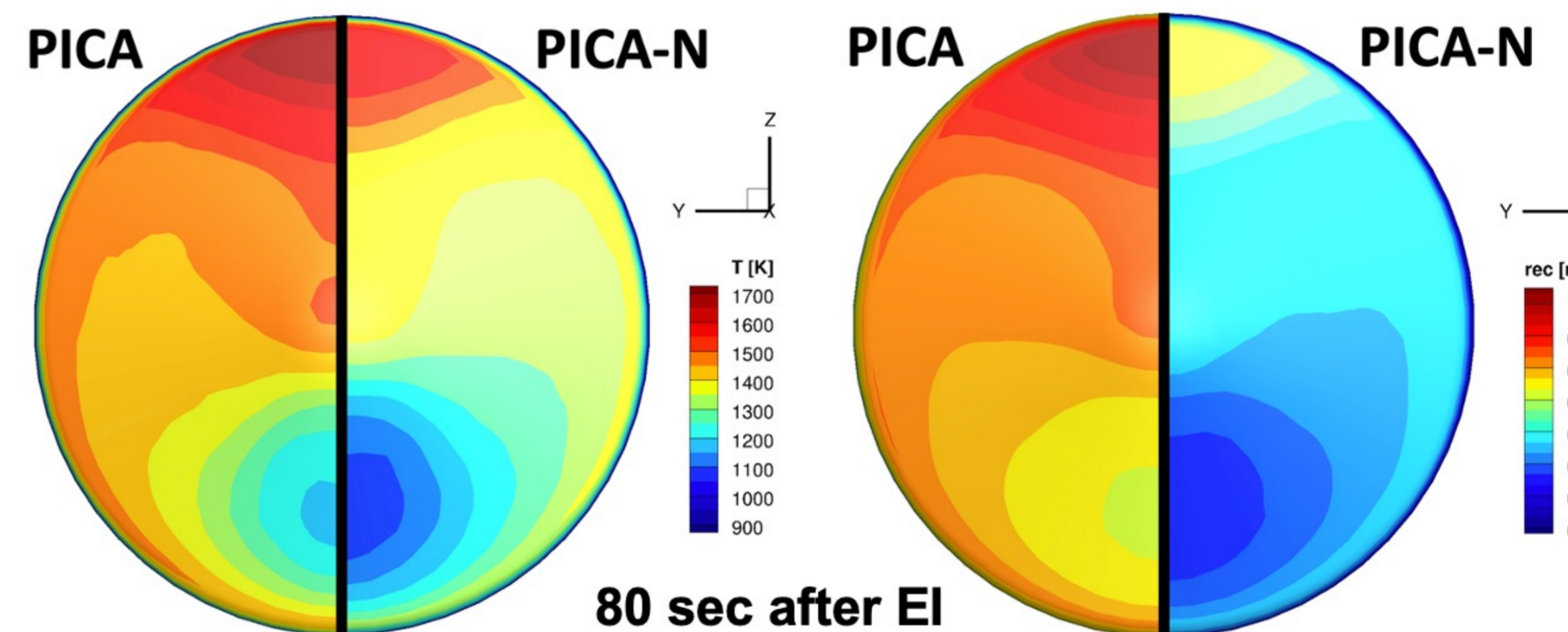


Fig. 6 Plots showing temperature (left) and recession (right) from computed 3D material response of the MSL heatshield using PICA and PICA-NuSil for a fully turbulent environment from DPLR [6]. The NuSil layer thickness was estimated at 200 μm .

Unified Solver

The multiphase unified solver couples the environment (plain-fluid phase) and the porous-material phase. The solver is based on the volume averaged conservation of mass, momentum, and energy for the macroscale with closure models which include microscale effects through effective physicochemical properties. The solver has been tested on flow through a porous plug [7] and on the Beavers and Joseph problem [8].

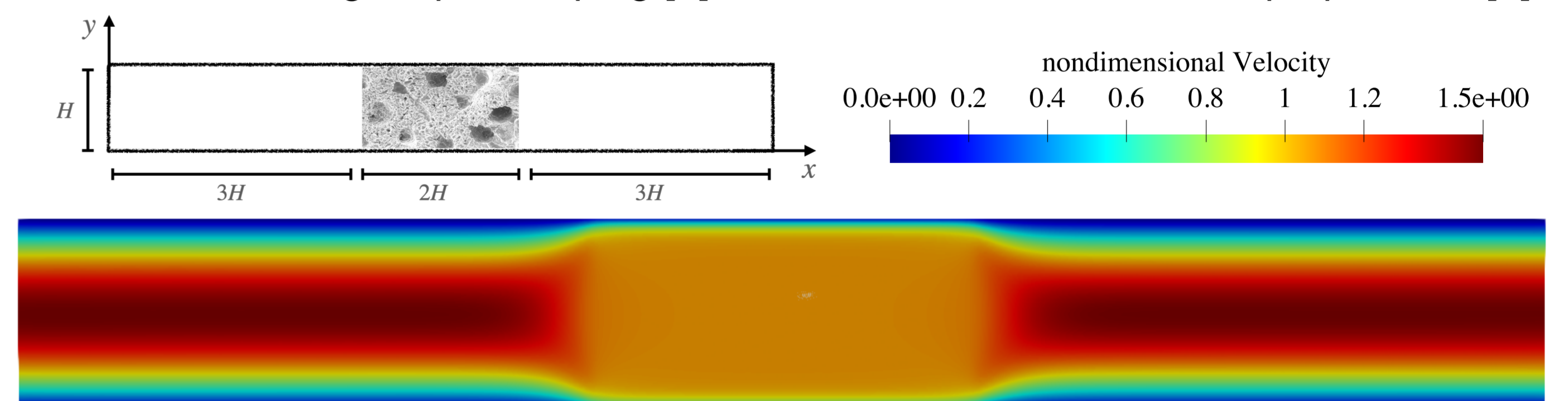
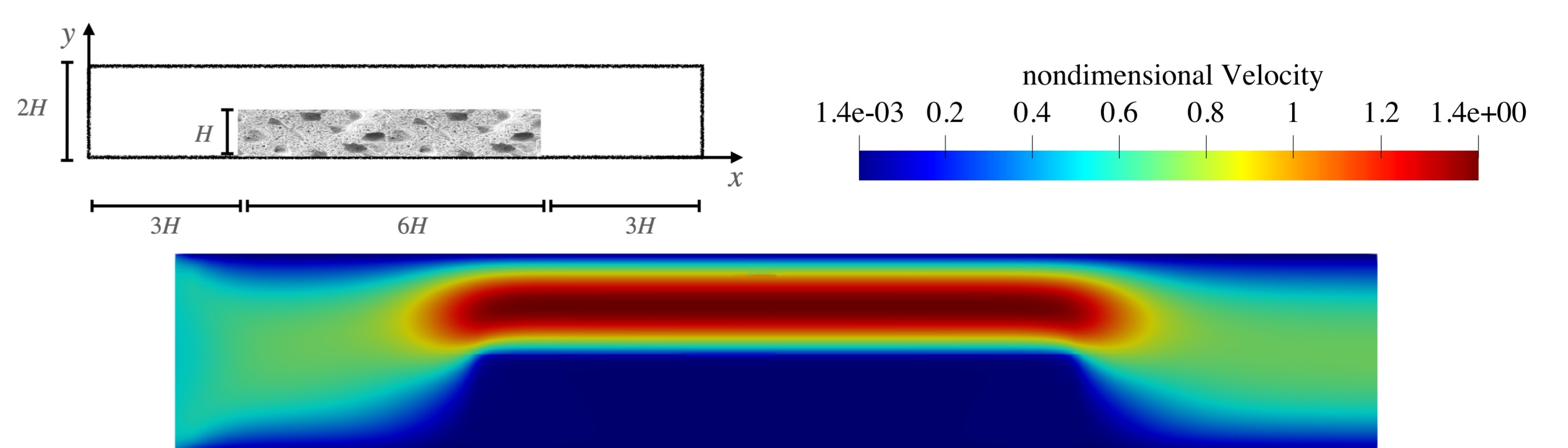


Fig. 7 Computed flow through porous plug from Betchen [7] (above) and Beavers and Joseph problem [8] (below).



References

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