

## Introduction

The Mars Science Laboratory (MSL) Entry, Descent and Landing Instrumentation (MEDLI) collected in-flight data largely used by the ablation community to verify and validate physics-based models for the response of the Phenolic Impregnated Carbon Ablator (PICA) material [1-4]. MEDLI data were recently used to guide the development of NASA's high-fidelity material response models for PICA, implemented in the Porous material Analysis Toolbox based on OpenFOAM (PATO) software [5-6]. A follow-up instrumentation suite, MEDLI2, is planned for the upcoming Mars 2020 mission [7] after the large scientific impact of MEDLI. Recent analyses performed as part of MEDLI2 development draw the attention to significant effects of a protective coating to the aerothermal response of PICA. NuSil, a silicone-based overcoat sprayed onto the MSL heatshield as contamination control, is currently neglected in PICA ablation models. To mitigate the spread of phenolic dust from PICA, NuSil was applied to the entire MSL heatshield, including the MEDLI plugs. NuSil is a space grade designation of the siloxane copolymer, primarily used to protect against atomic oxygen erosion in the Low Earth Orbit environment. Ground testing of PICA-NuSil (PICA-N) models all exhibited surface temperature jumps of the order of 200 K due to oxide scale formation and subsequent NuSil burn-off. It is therefore critical to include a model for the aerothermal response of the coating in ongoing code development and validation efforts.

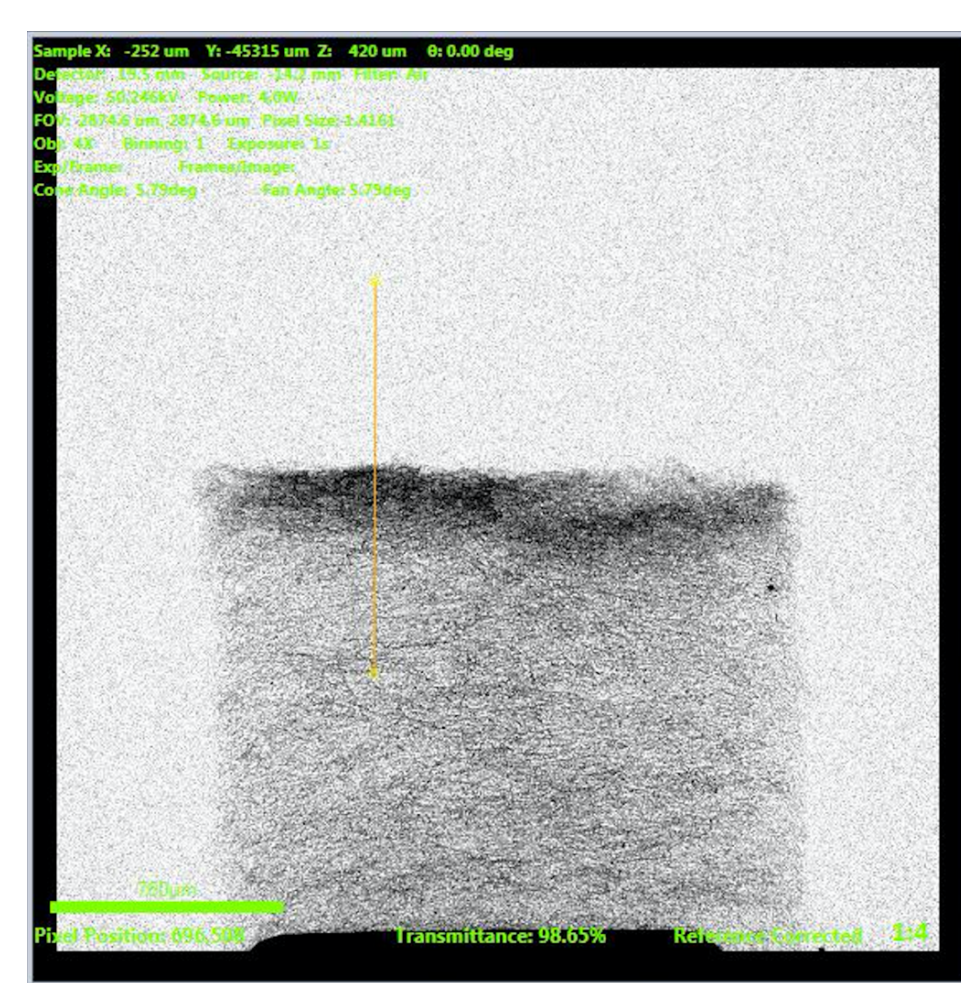


Fig. 1 Micro tomography of PICA-N

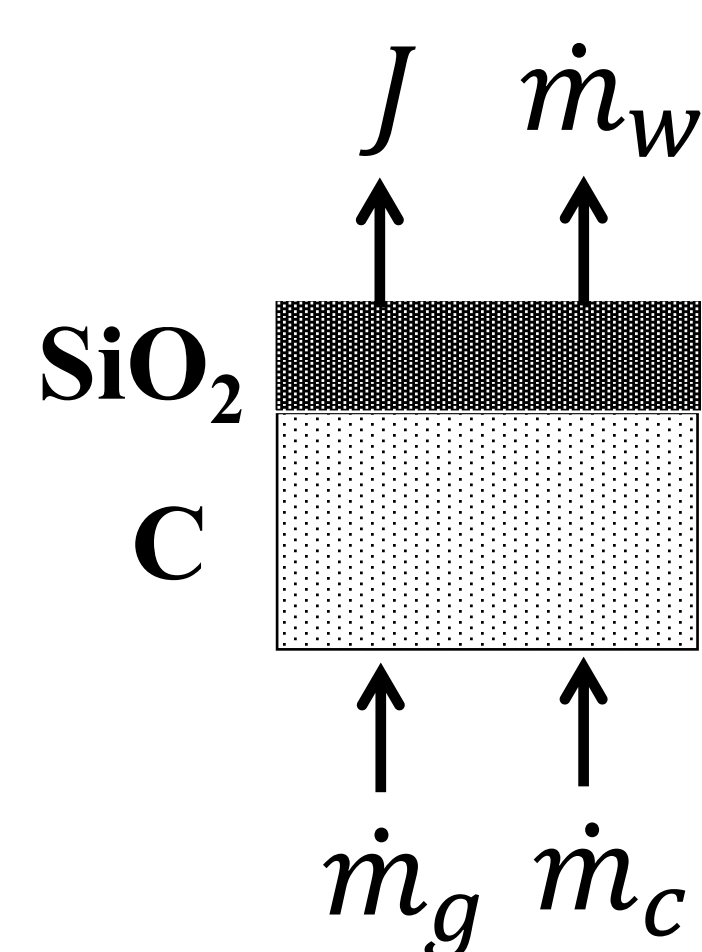


Fig. 2 PICA-N model in PATO

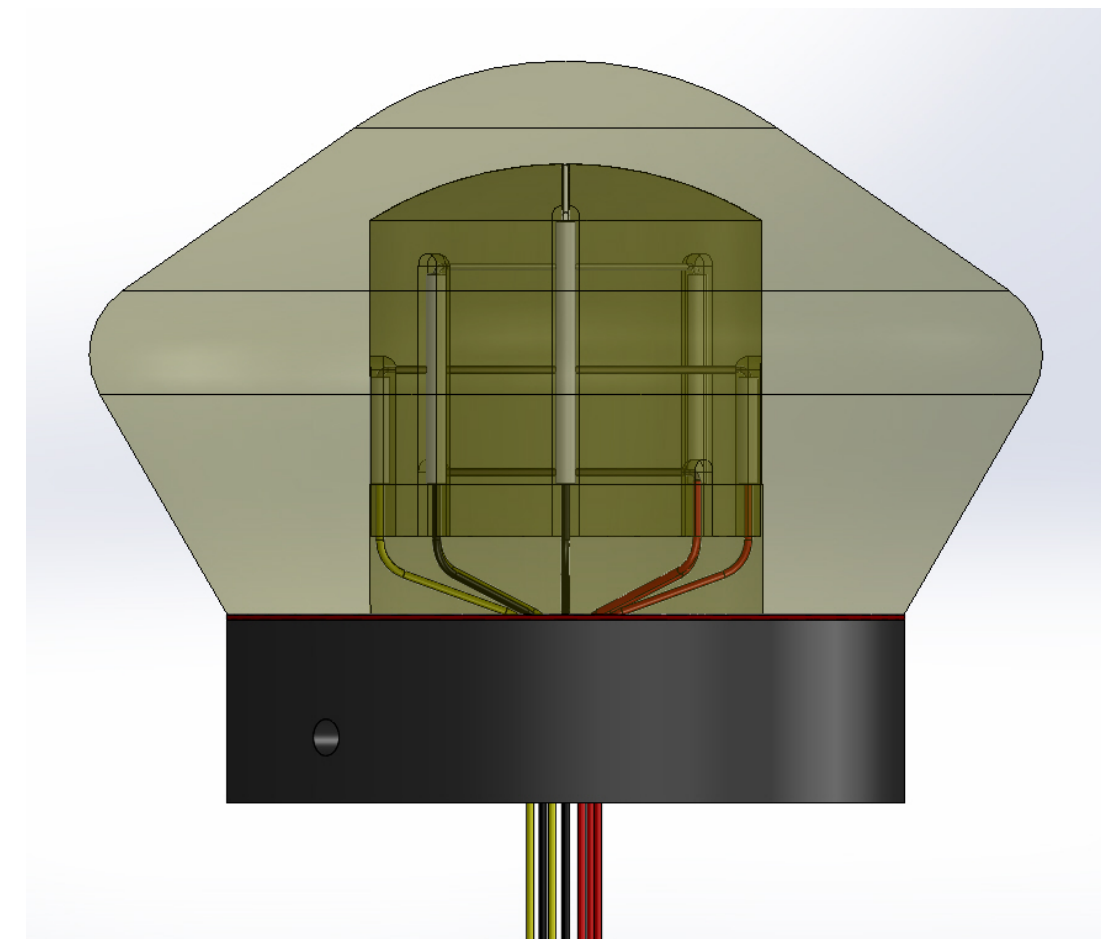


Fig. 3 Baby-SPRITE sample of HyMETS test campaign

## Surface model of PICA-N using equilibrium chemistry

In this work, we present progress toward formulating a high-fidelity material response model for PICA-N in PATO and analyze the effect of NuSil. First, the surface mass balance formulation (Eq. 1) for multi-elemental composition at the wall is described. Figure 4 shows the dimensionless char blowing rate ( $B'_c$ ) for carbon and silicon dioxide (Eq. 2) using  $\text{CO}_2$  environment. Figure 5 shows the wall enthalpy ( $h_w$ ) for carbon and silicon dioxide. The wall enthalpy has a major impact on the surface energy balance (Eq. 3).

$$C'_H(z_{e,k} - z_{wg,k}) + z_{wg,k} (\dot{m}_g + \dot{m}_c) = z_{g,k} \dot{m}_g + z_{c,k} \dot{m}_c \quad (1)$$

$$B'_c = \frac{\sum_k^{N_e} z_{e,k} - \sum_k^{N_e} z_{wg,k} + B'_g (\sum_k^{N_e} z_{g,k} - \sum_k^{N_e} z_{wg,k})}{\sum_k^{N_e} z_{wg,k} - 1} \quad (2)$$

$$-\left(\bar{k} \cdot \frac{\partial T}{\partial n}\right) \cdot \mathbf{n} = C'_H(h_e - h_w) + \dot{m}_g(h_g - h_w) + \dot{m}_c(h_c - h_w) - \varepsilon\sigma(T^4 - T_\infty^4) + \alpha q_{rad} \quad (3)$$

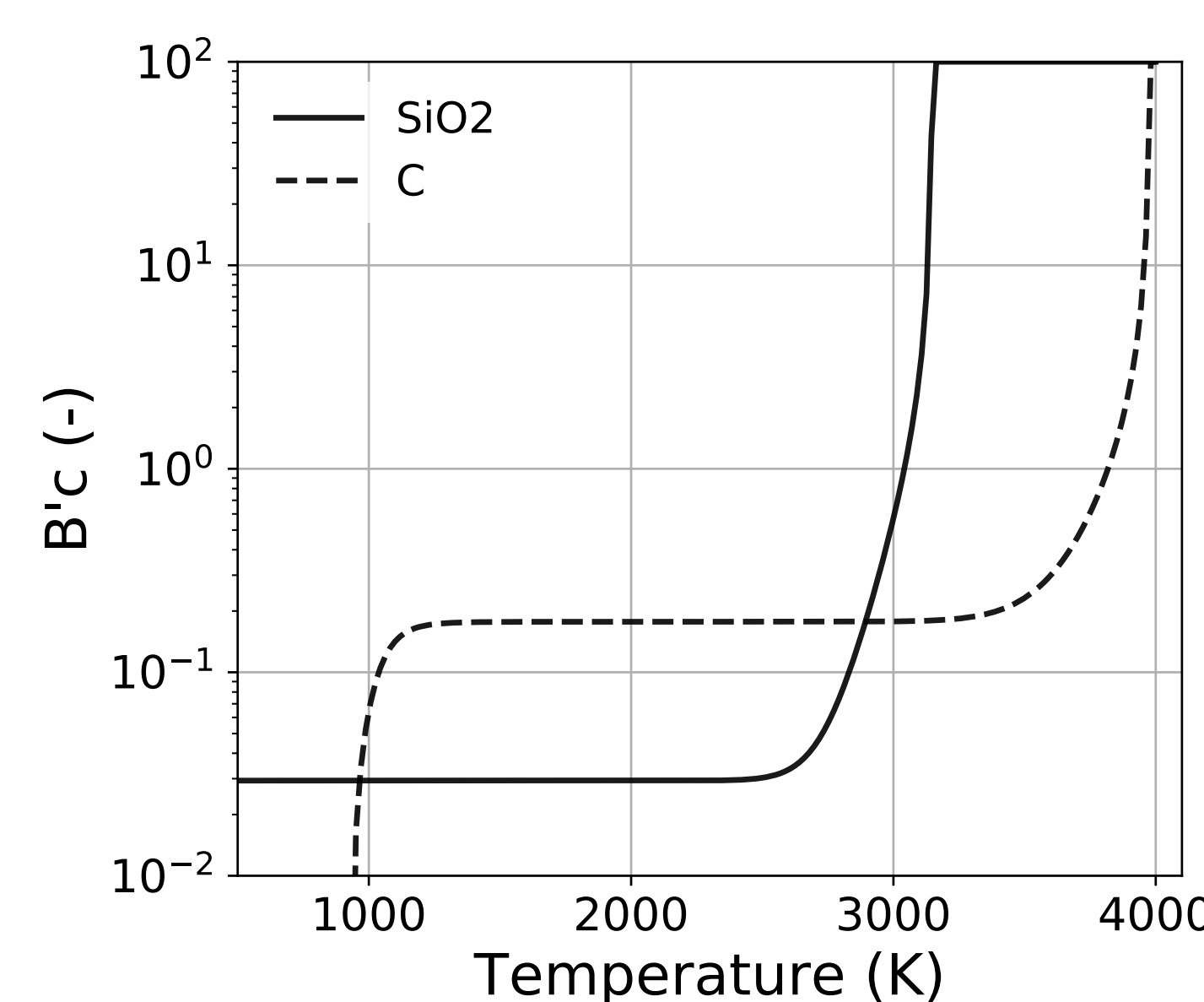


Fig. 4  $B'_c$  in function of temperature for  $\text{SiO}_2/\text{C}$

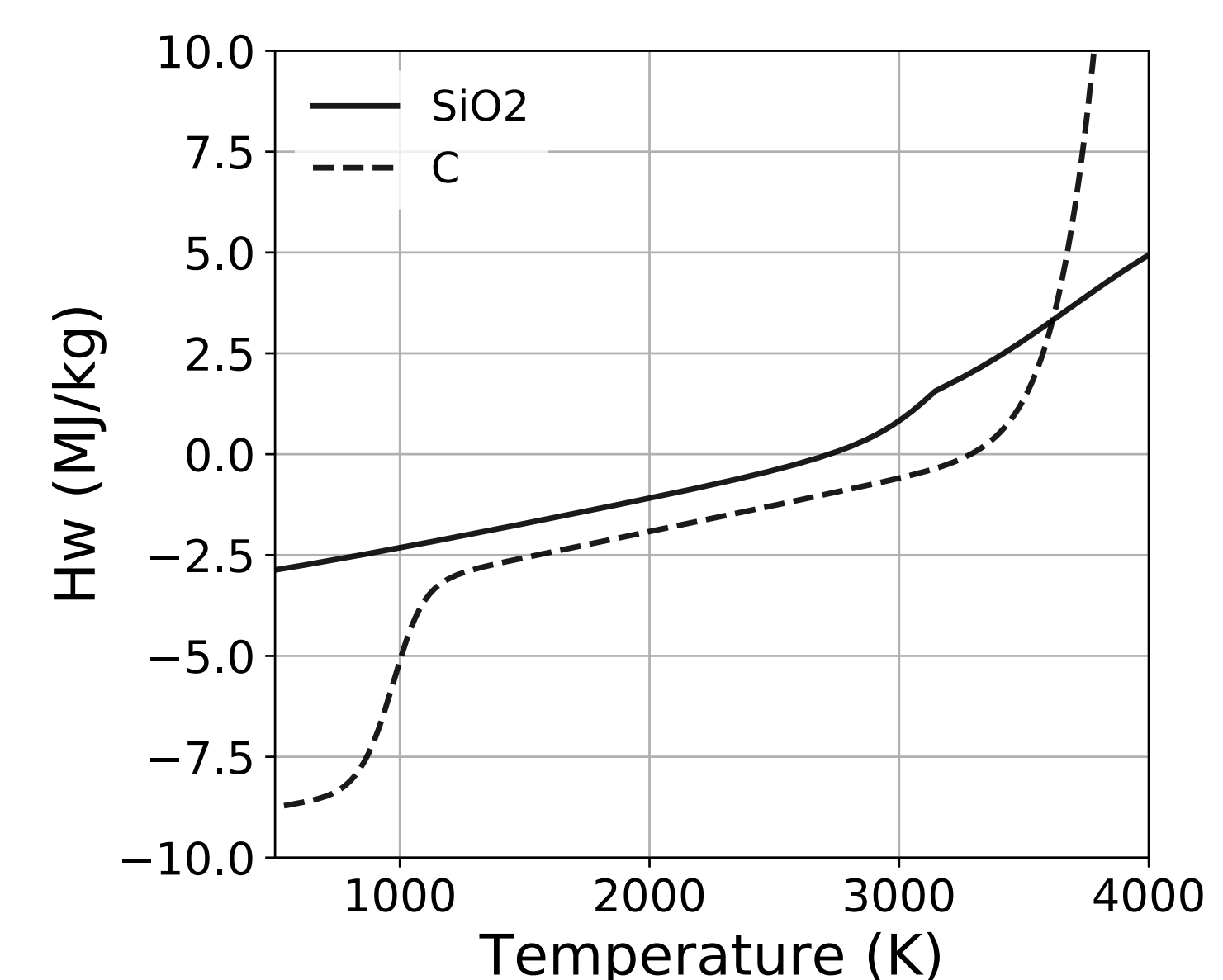


Fig. 5  $h_w$  in function of temperature for  $\text{SiO}_2/\text{C}$

## PATO simulations of PICA-N compared to HyMETS experimental data

The computational model is a generic mass and heat transfer model for porous reactive materials where each control volume contains 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 PATO, a C++ top level software of the open source computational fluid dynamics software program OpenFOAM. Tests have been conducted at the Hypersonic Materials Environmental Test System (HyMETS) facility to screen the response of PICA-N and gather detailed data on its behavior. The PATO modeling results are compared to the HyMETS data. The material response simulations of a 620 micron layer of NuSil on top of PICA are presented. Figure 6 shows the 1D thermal response of PICA-N under  $\text{CO}_2$  condition compared to the experimental data. The HyMETS data stopped the heating at 35 s and did not have a surface temperature jump. The PATO simulation shows a temperature jump of 200 K at 40 s due to the removal of the  $\text{SiO}_2$  layer. The 1D simulation predicts that this HyMETS test case will need to heat the sample 5 s longer in order to see a temperature jump at the surface. Figure 7 shows the recession results of PICA-N for the same conditions. Figure 8 shows the 2D axi-symmetric simulation of the Baby-SPRITE (Small Probe Re-entry Investigation of TPS Engineering) sample made of PICA-N after 43 s of heating. The environment inside the HyMETS facility is computed using DPLR [8].

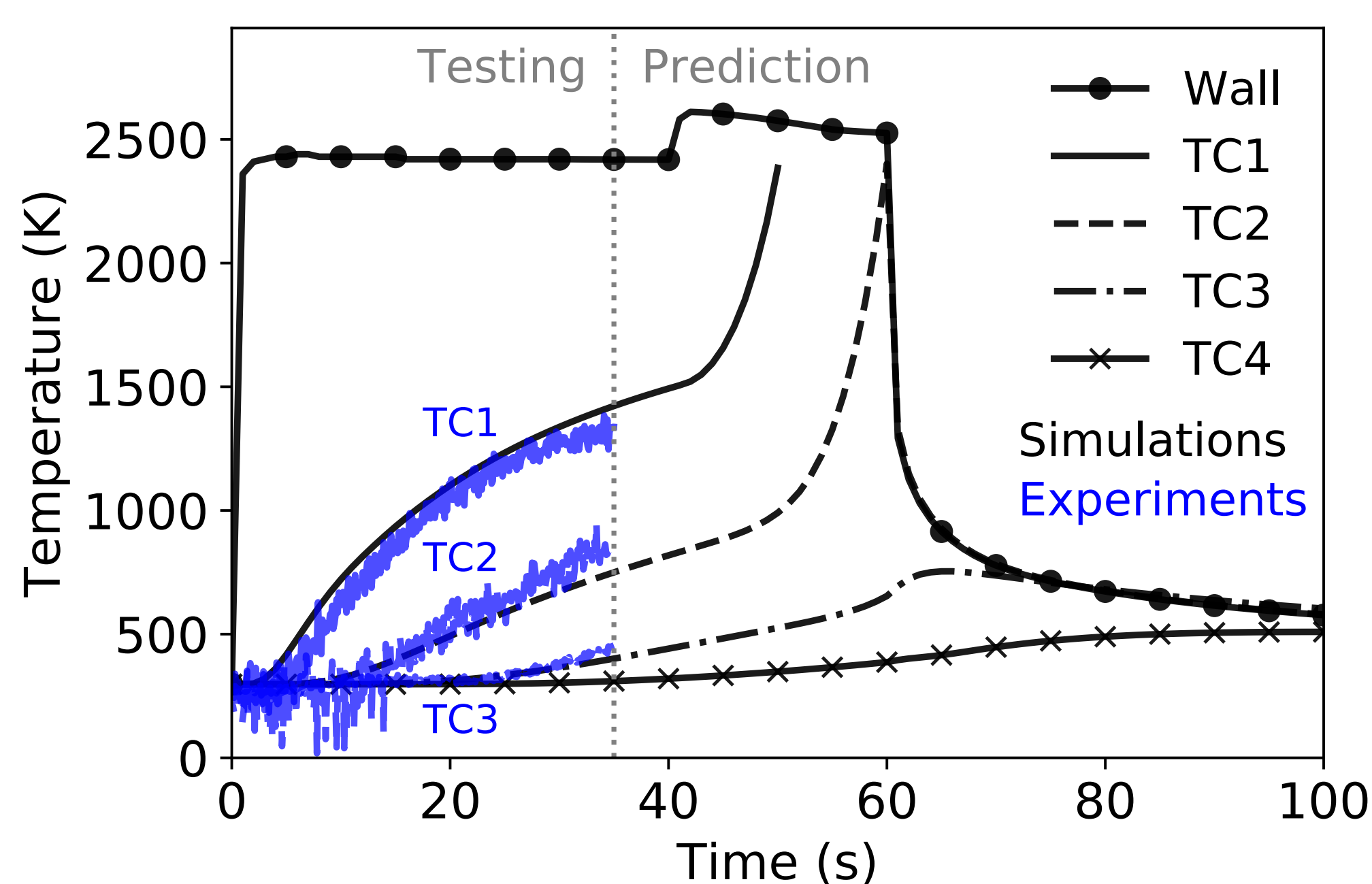


Fig. 6 1D thermal response of the Baby-SPRITE sample

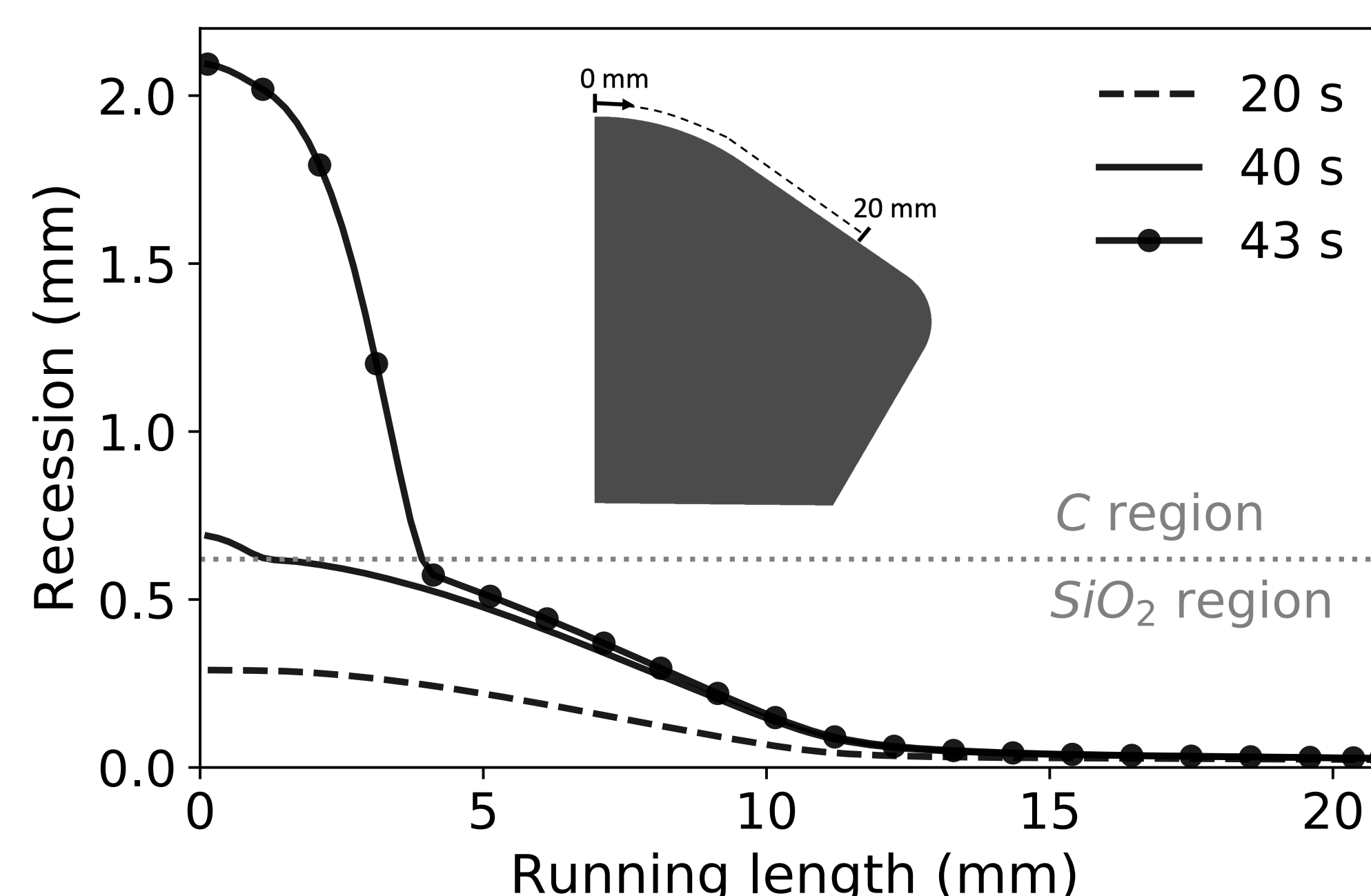


Fig. 7 2D recession response of the Baby-SPRITE sample

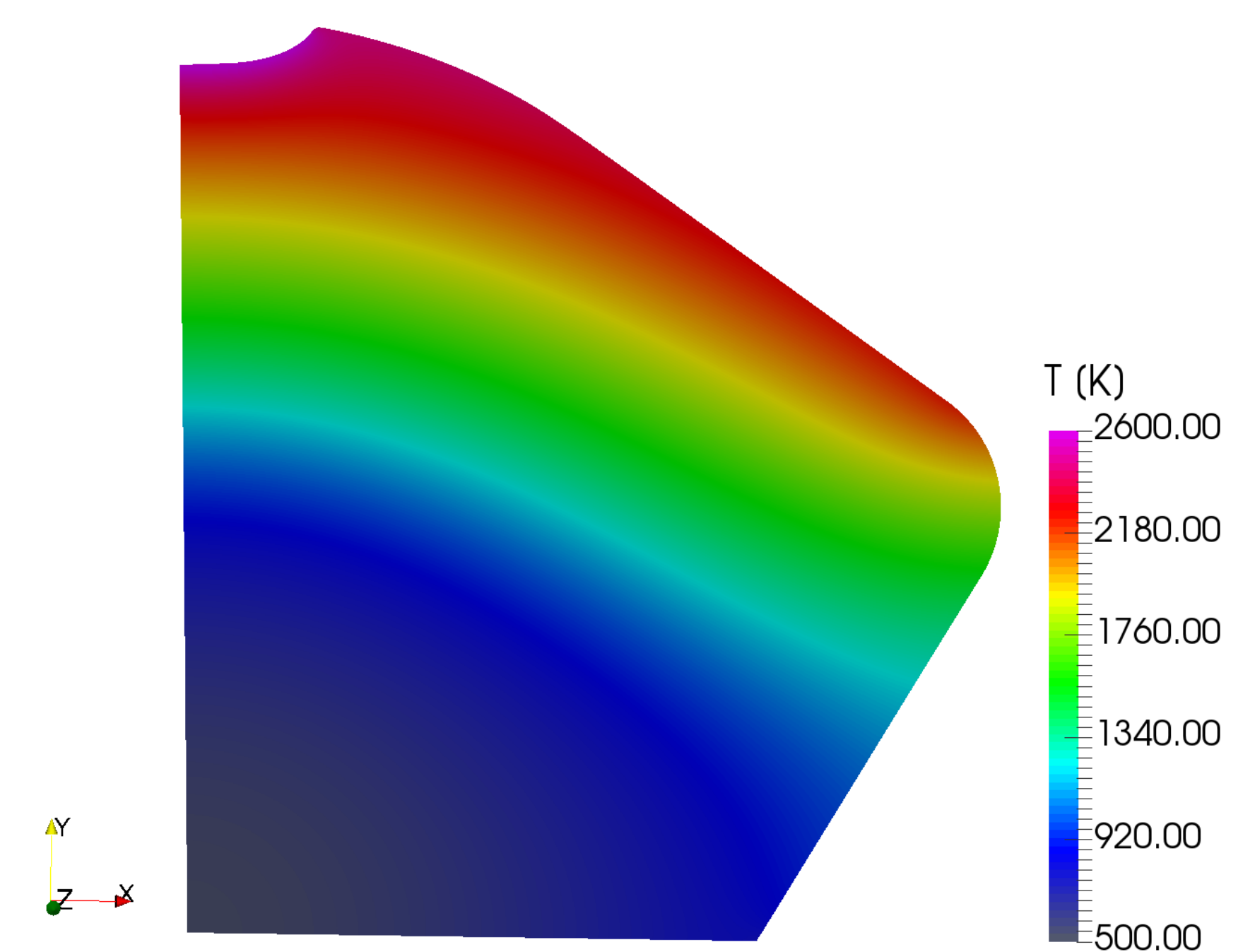


Fig. 8 2D thermal response of Baby-SPRITE sample

## References

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[2] M. Mahzari *et al.* (2013), *51st AIAA Aerospace Science Meeting*.

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[8] P. Ventura Diaz *et al.* (2019), *AIAA Aviation Forum*.