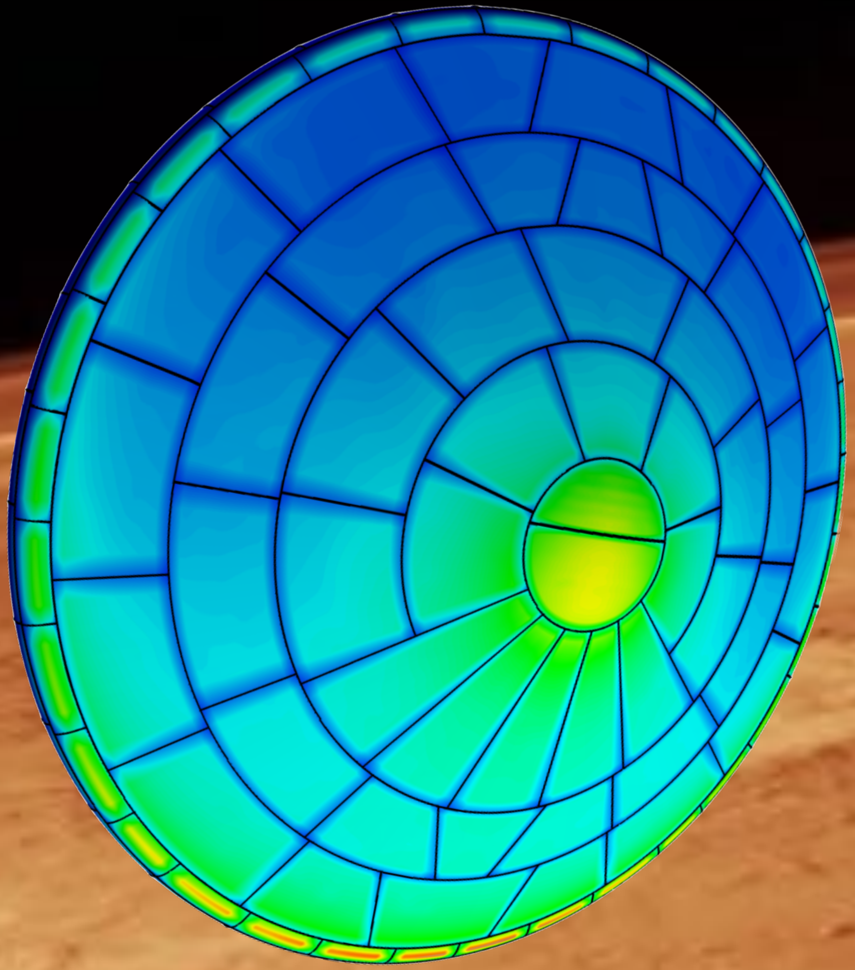

Full-scale Mars Science Laboratory Tiled Heatshield Material Response

9th Ablation Workshop

Montana State University, August 30th - 31st, 2017

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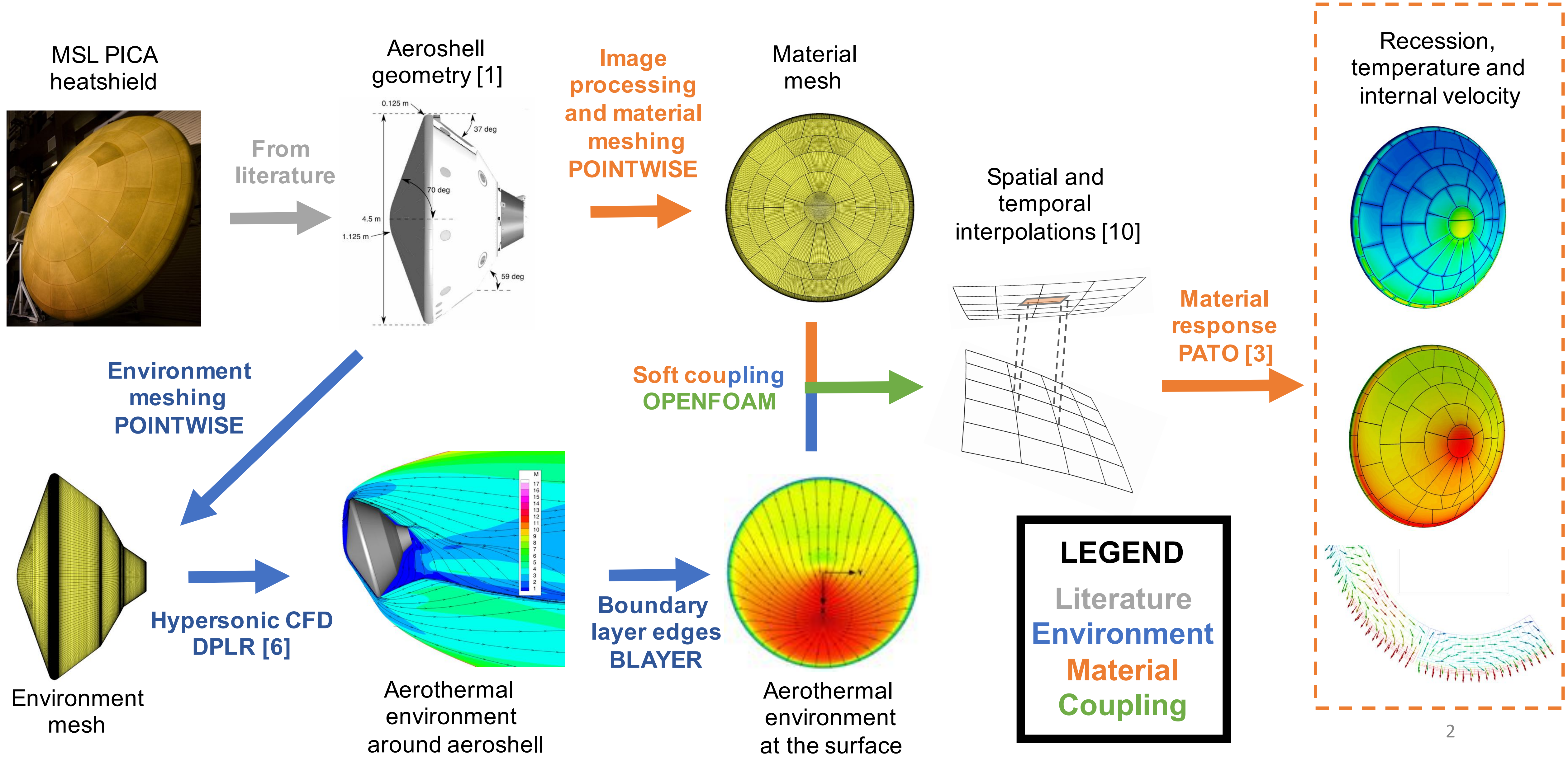
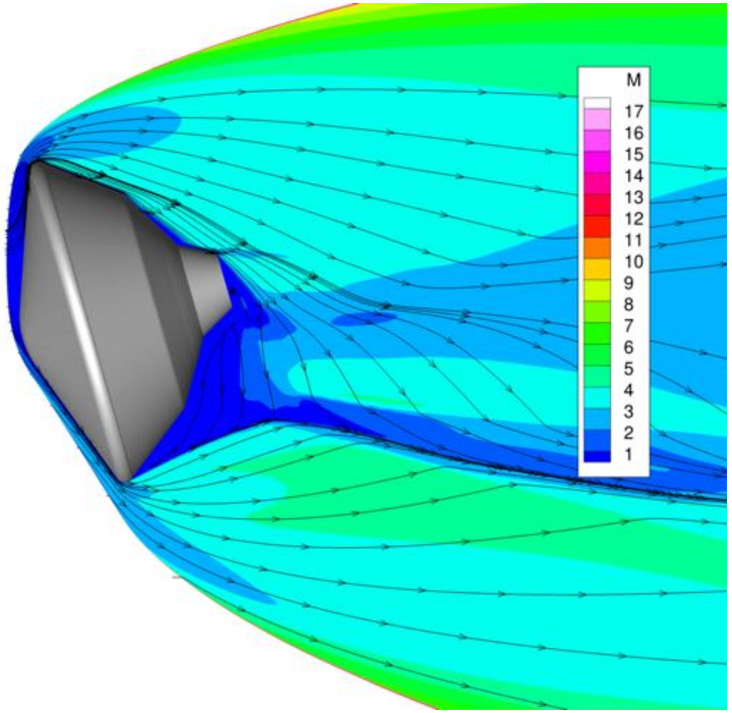
Overview – Coupling aerothermal environment and material response



Aerothermal environment computed from DPLR*

DPLR assumptions

- **Laminar** boundary layer
- **Non-blowing** & smooth wall
- Chemical and thermal non-equilibrium
- Radiative equilibrium
- Super-catalytic wall
- Mars atmosphere: $y_{CO2} = 0.97$, $y_{N2} = 0.03$
- 12 reactions & 8 species [12]

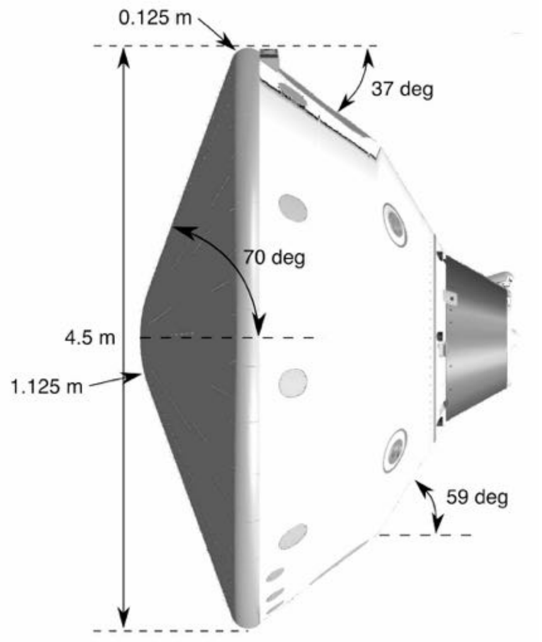


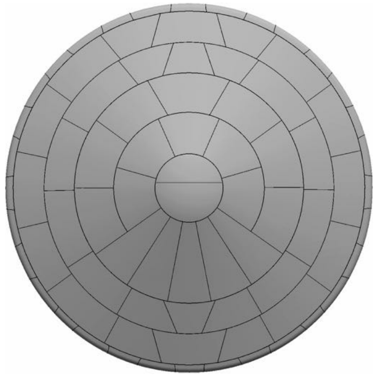
BLAYER calculates the **boundary layer edges** using a curvature-based method

Surface pressure p_w, heat transfer coefficient C_H and **enthalpy h_e** at the **boundary layer edges** are used as inputs in the **material response** code: **PATO**

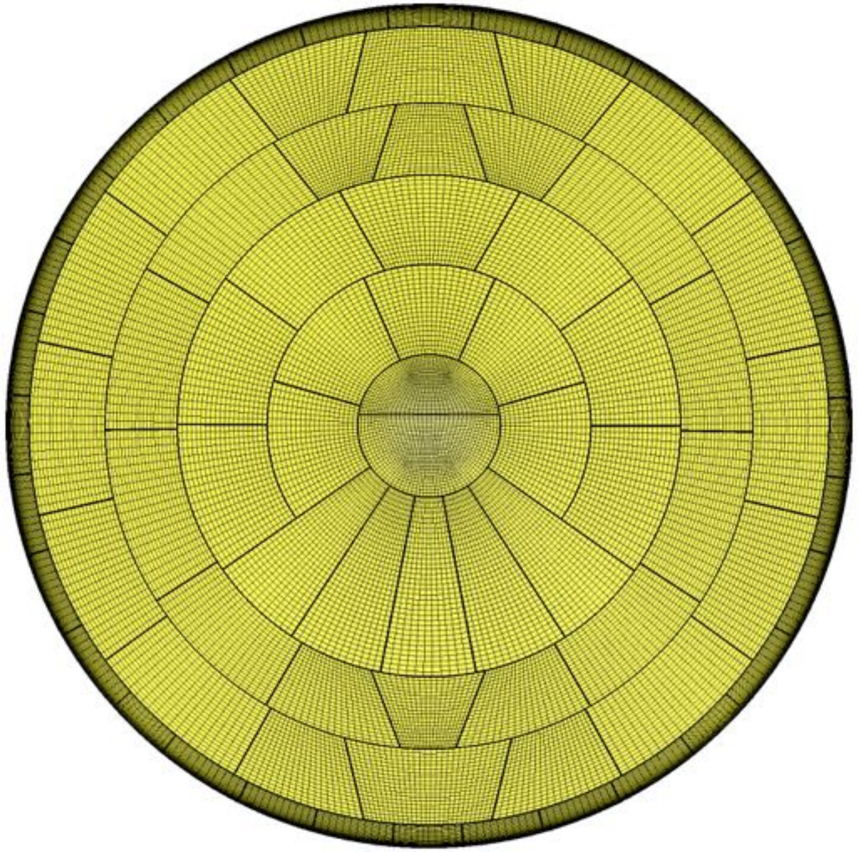
* DPLR = Data Parallel Line Relaxation [6]

Computational domain of the material response

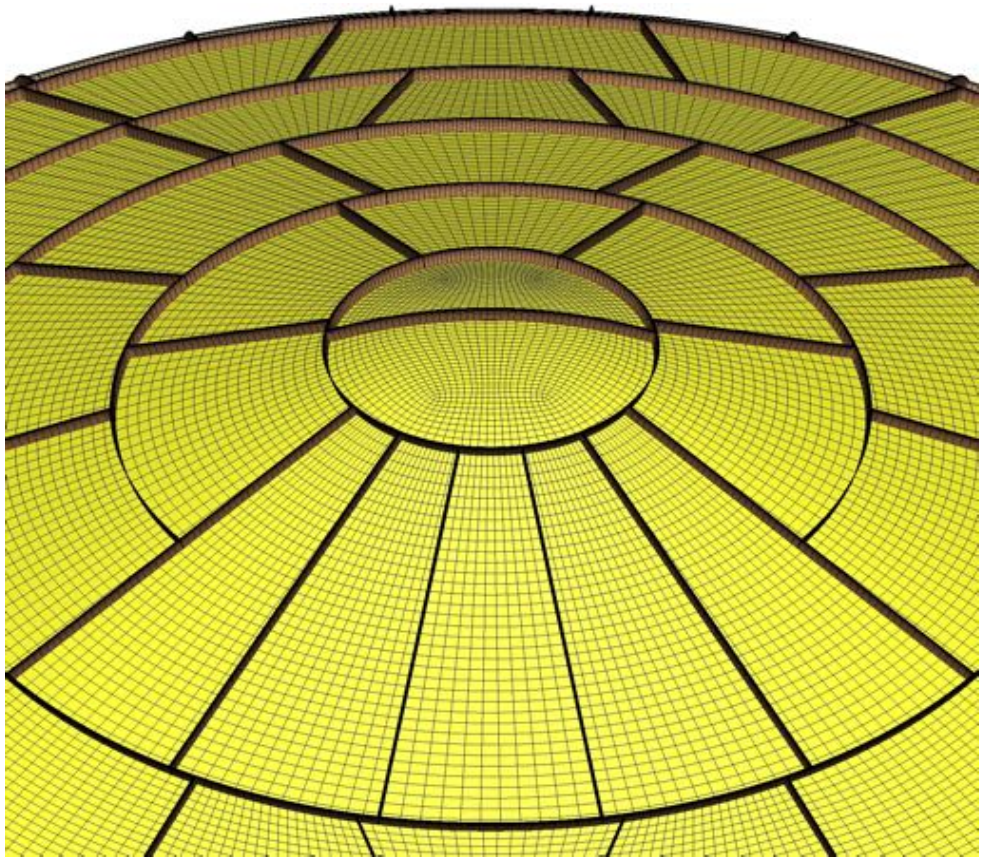




Aeroshell geometry with 113 PICA tiles [1]

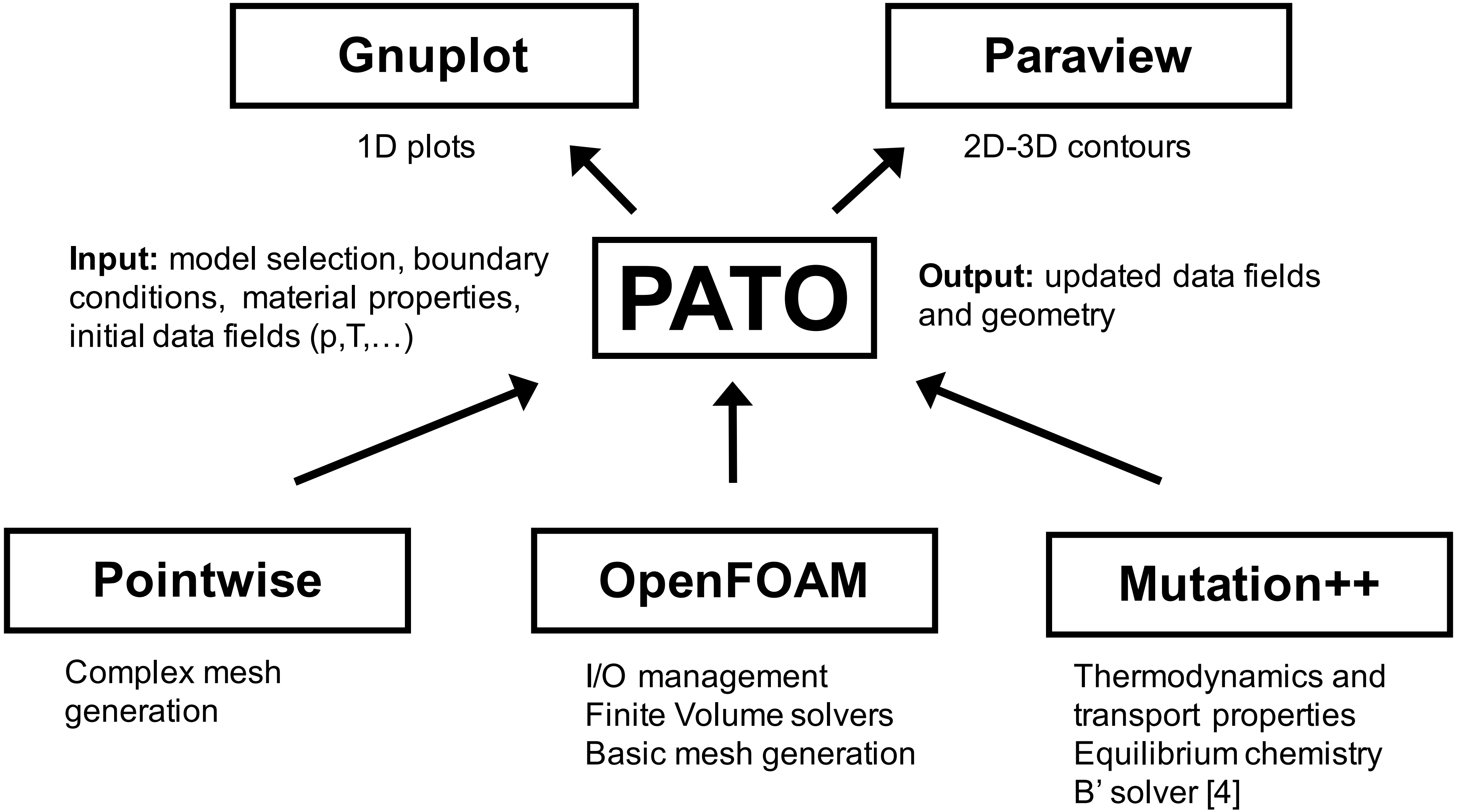


2 million cells mesh of the tiled heatshield



Heatshield material in 2 regions
gap filler + porous tiles

PATO* is used for the material response model



* PATO = Porous material Analysis Toolbox based on OpenFOAM [3]
Open Source Release http://pato.ac

PATO is used for the material response model

Mass and momentum conservation

$$\boldsymbol{v}_g = -\frac{1}{\epsilon_g}\left(\frac{1}{\mu}\,\bar{\bar{\boldsymbol{K}}} + \frac{1}{p}\,\bar{\bar{\boldsymbol{\beta}}}\right).\,\boldsymbol{\partial}_x p_g$$

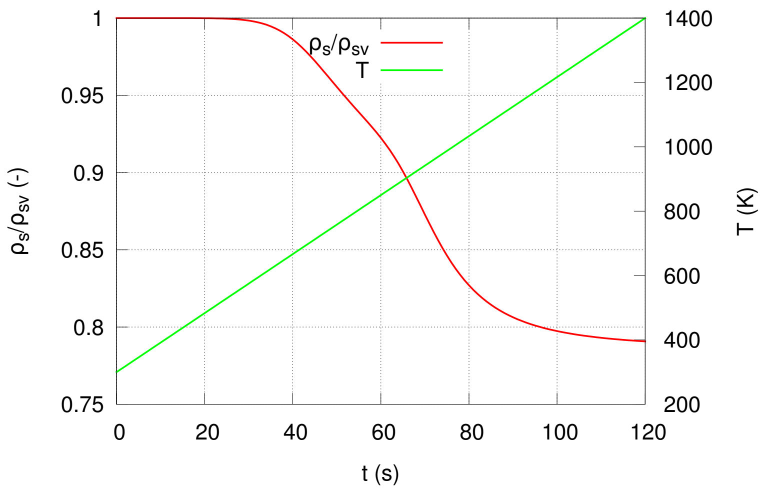
$$\partial_t \epsilon_g \rho_g \; - \; \boldsymbol{\partial}_{\boldsymbol{x}} \,.\, \left(\epsilon_g \rho_g \boldsymbol{v}_g\right) = \Pi$$

Pyrolysis

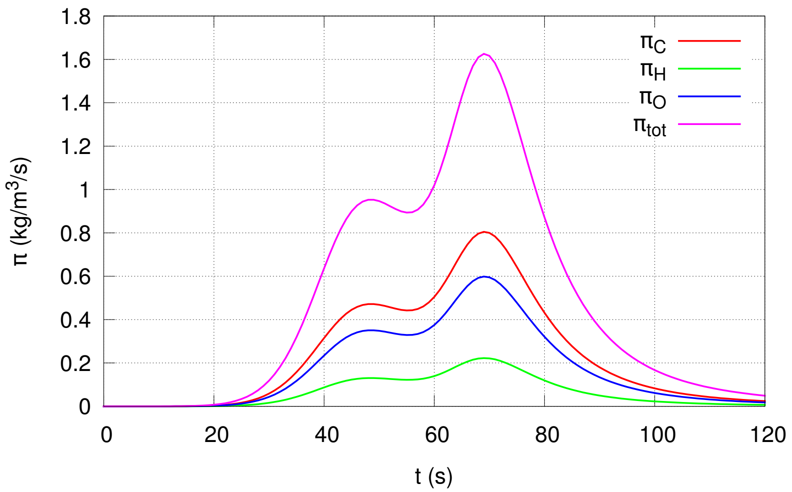
$$\partial_t \chi_{i,j} = (\,1 \; - \; \chi_{i,j}\,)^{m_{i,j}} \, T^{n_{i,j}} \, A_{i,j} \; exp\left(\frac{-E_{i,j}}{RT}\right)$$

$$\Pi = \sum_{i=1}^{N_p} \sum_{j=1}^{P_i} \sum_{k=1}^{N_g} \zeta_{i,j,k} \, \epsilon_{i,0} \, \rho_{i,0} \, F_{i,j} \, \partial_t \chi_{i,j}$$

Mass loss and temperature



Pyrolysis production rates



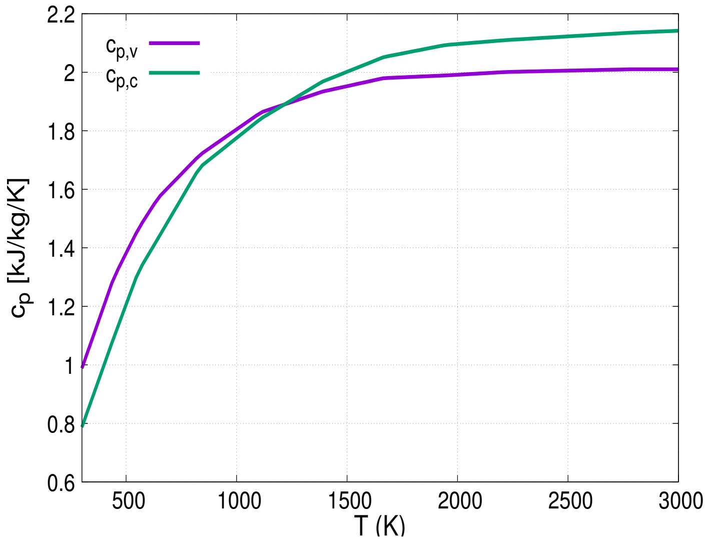
PATO is used for the material response model

Energy conservation

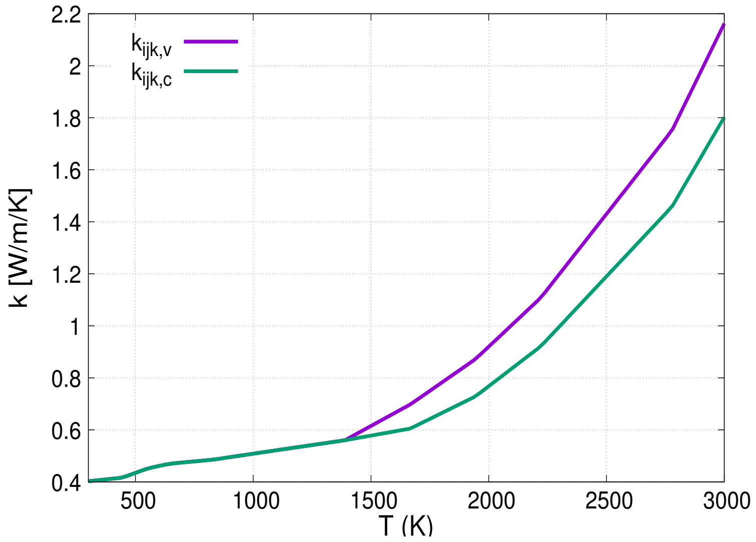
$$\sum_{i=1}^{N_p}\left[\left(\epsilon_i \rho_i c_{p,i}\right) \partial_t T\right] - \boldsymbol{\partial_x} \cdot \left(\overline{\overline{\boldsymbol{k}}} \cdot \partial_x T\right) = \sum_{i=1}^{N_p}\left[h_i \partial_t(\epsilon_i \rho_i) \right] - \partial_t\left(\epsilon_g \rho_g h_g - \epsilon_g p_g\right) + \boldsymbol{\partial_x} \cdot \left(\epsilon_g \rho_g h_g \boldsymbol{v}_g\right)$$

Isotropic TACOT properties

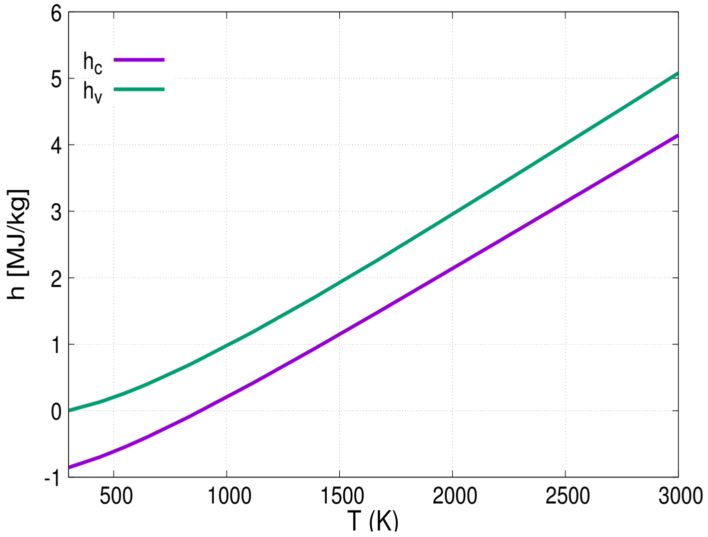
Virgin and char specific heat



Virgin and char thermal conductivity [13]



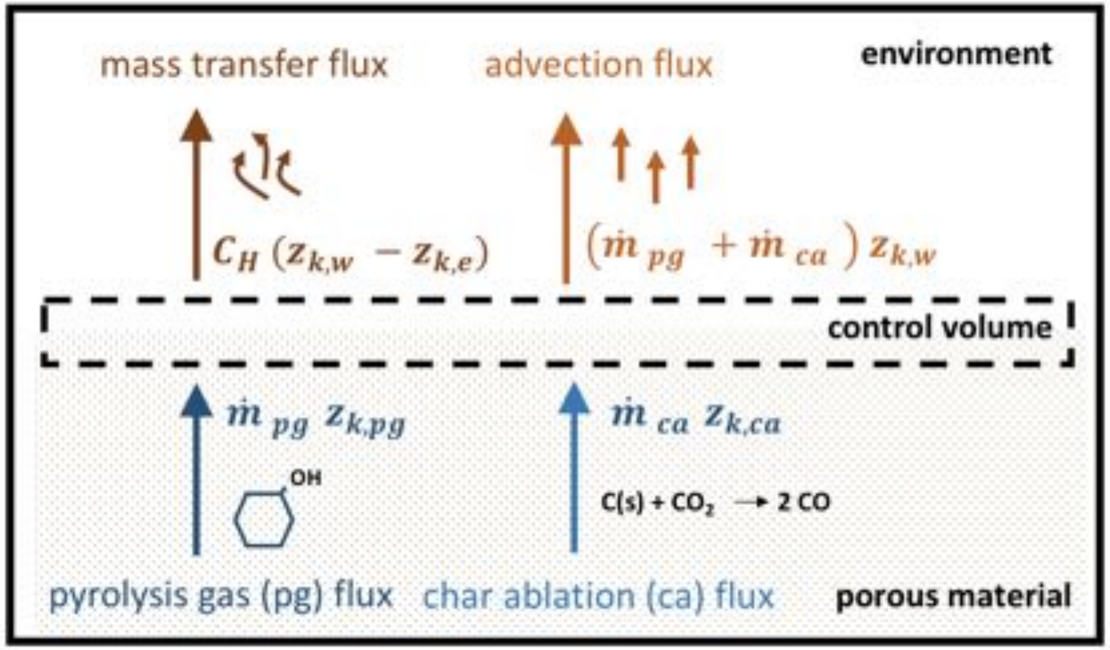
Virgin and char enthalpy



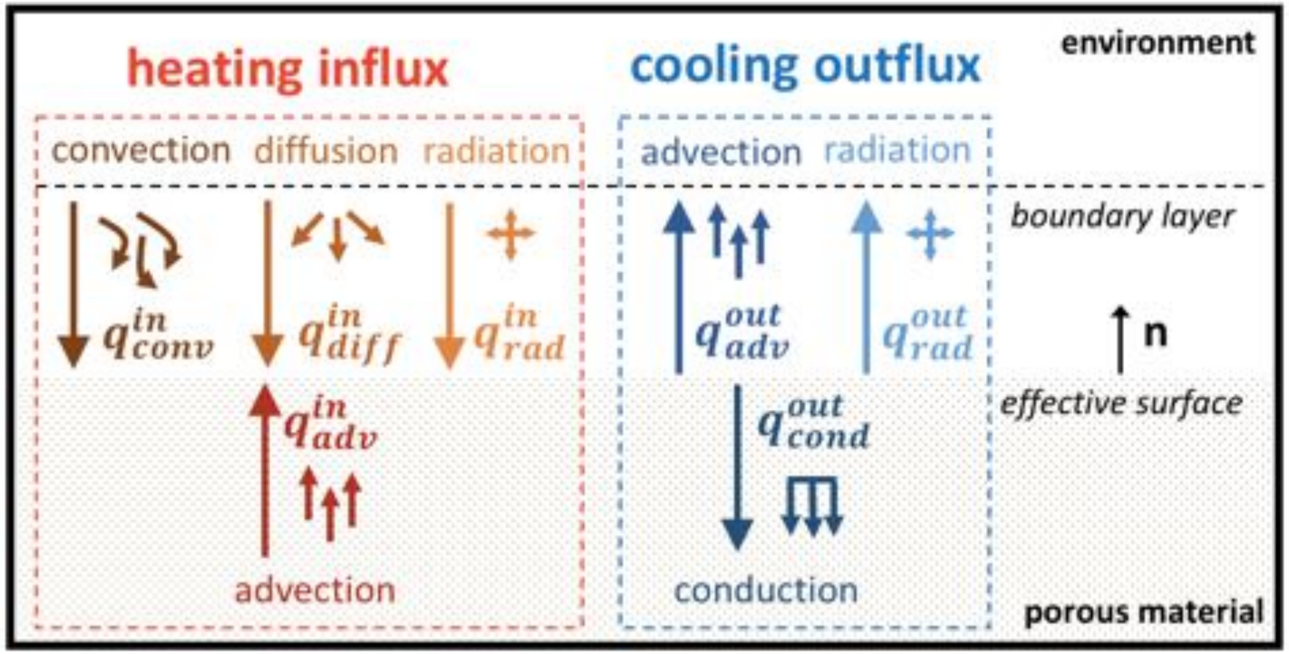
PATO is used for the material response model

Boundary Conditions

Surface mass balance [7]



Surface energy balance [8,9]



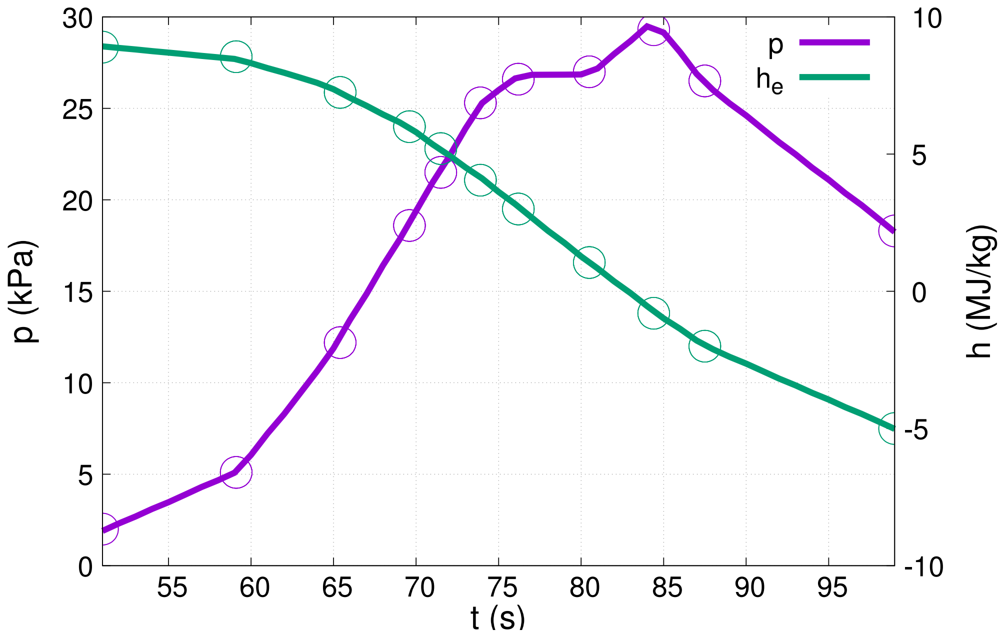
Enthalpy at the wall h_w

Char ablation rate $\dot{m}_{ca}$

Temperature at the wall T_w

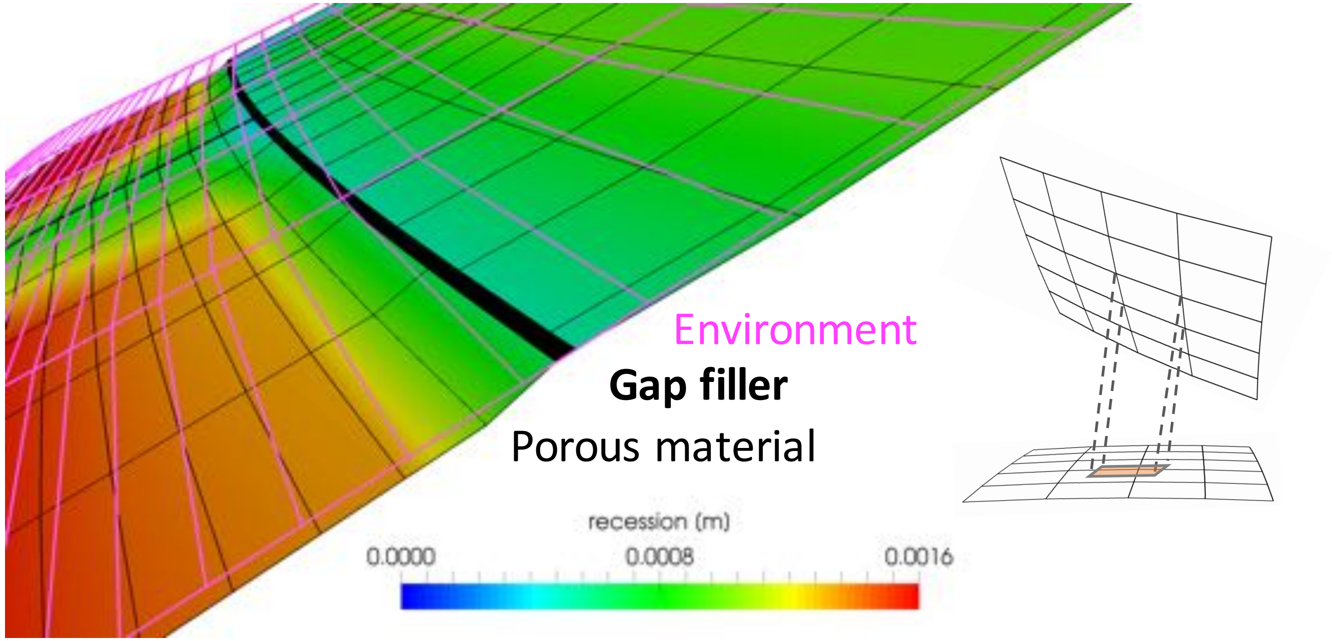
Temporal and spatial interpolations

Temporal interpolation



11 **discrete** times
(50s to 100s of MSL entry)
linear interpolation

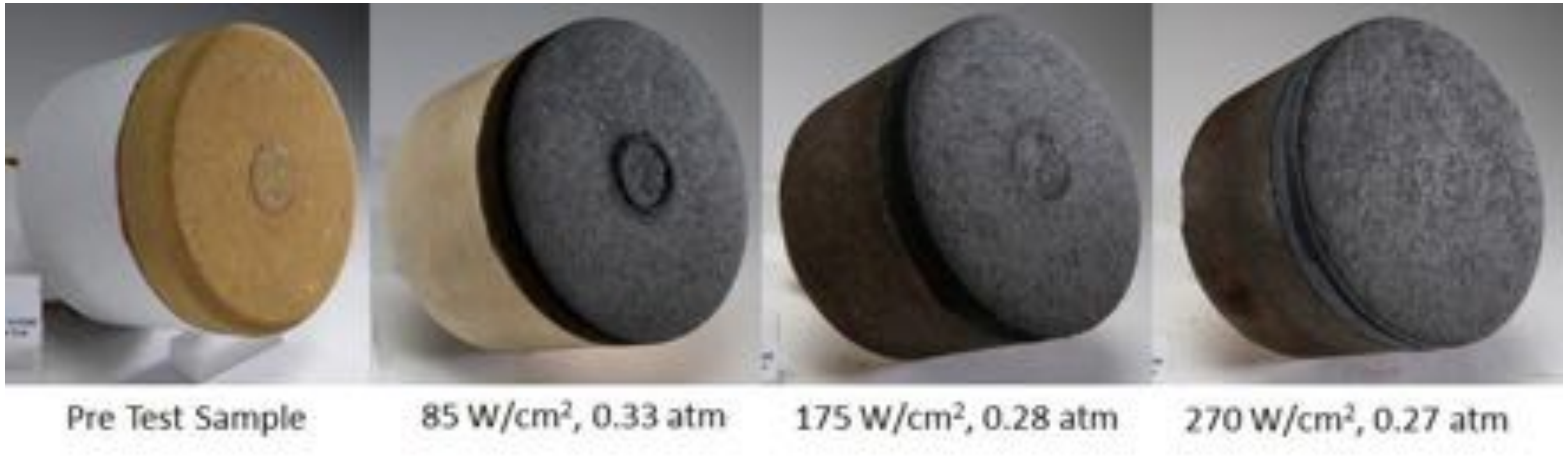
Spatial interpolation



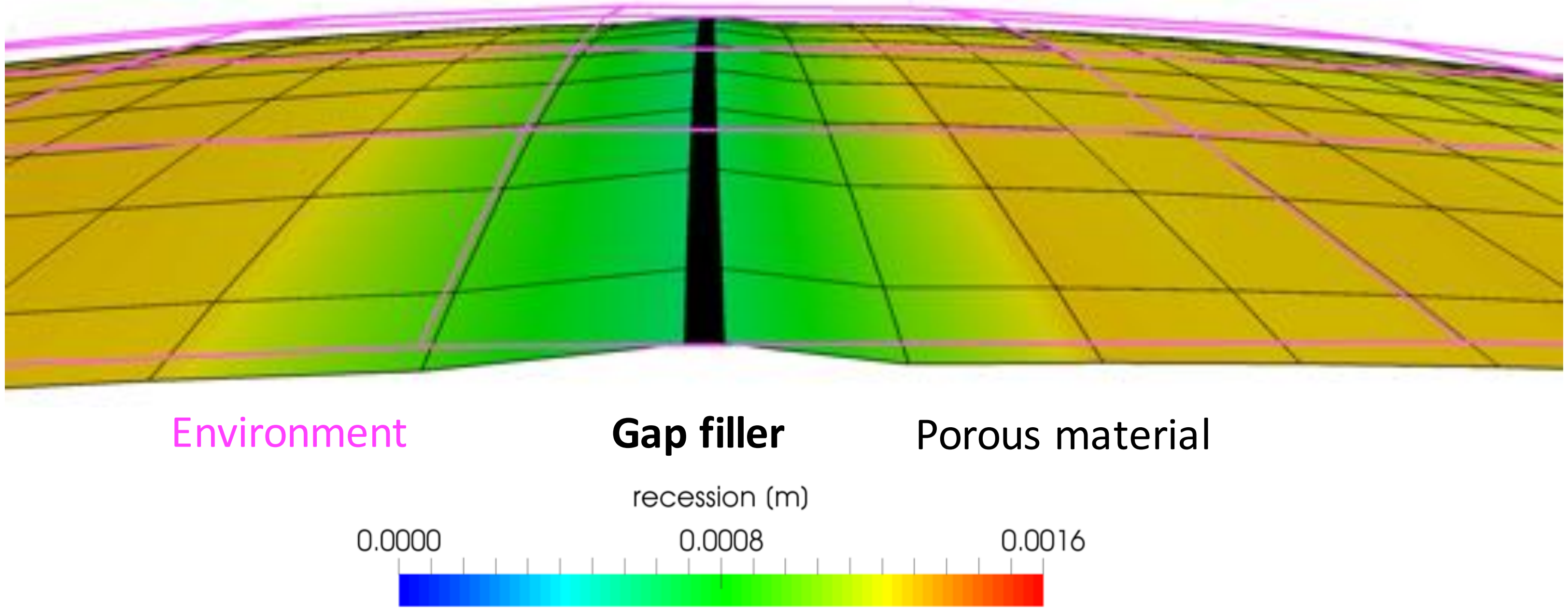
Separate mesh regions are numerically **connected** by the **Arbitrary Mesh Interface** (**AMI**) utility using local **Galerkin projection** [10] implemented in **OpenFOAM**

"Fencing" effect at tile interfaces

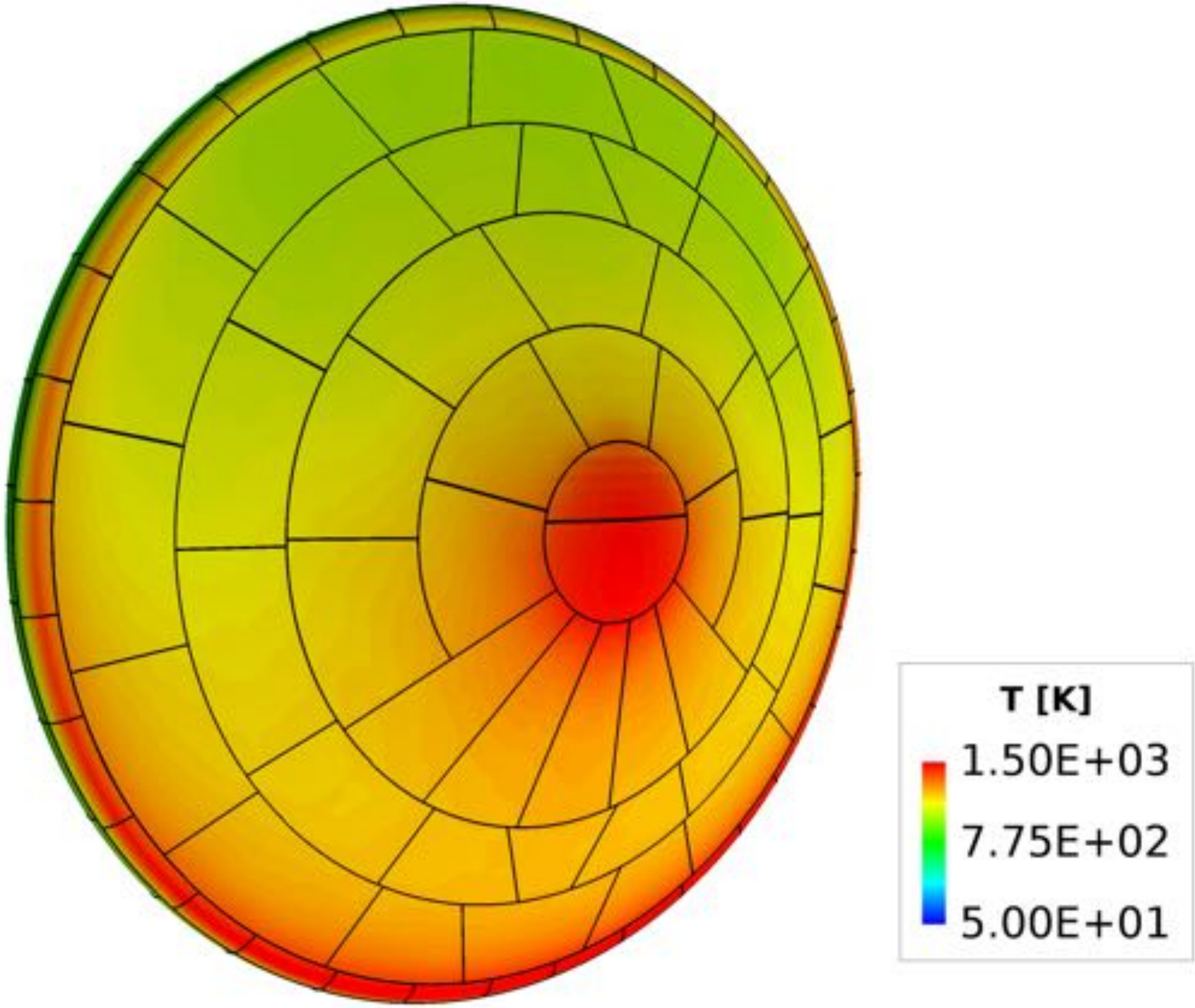
Post-test arcjet coupons [5]

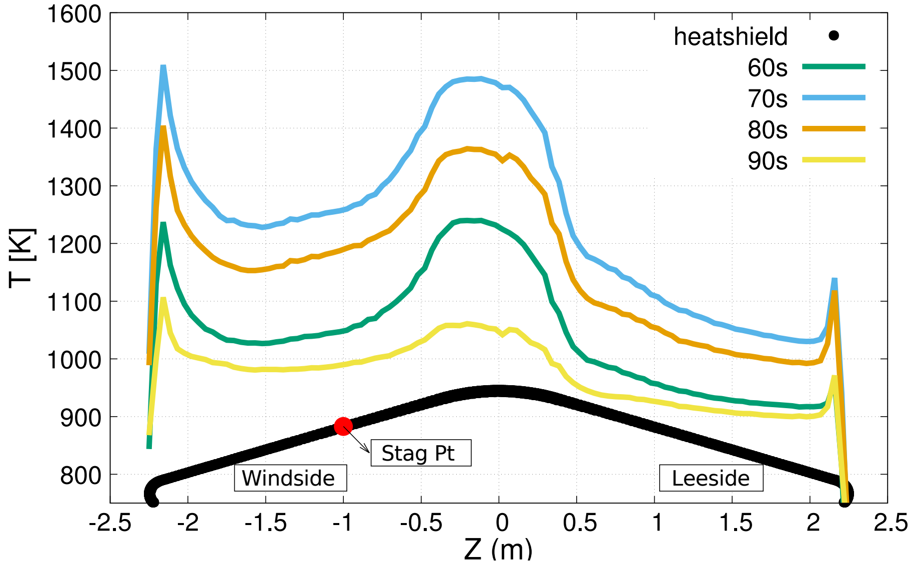


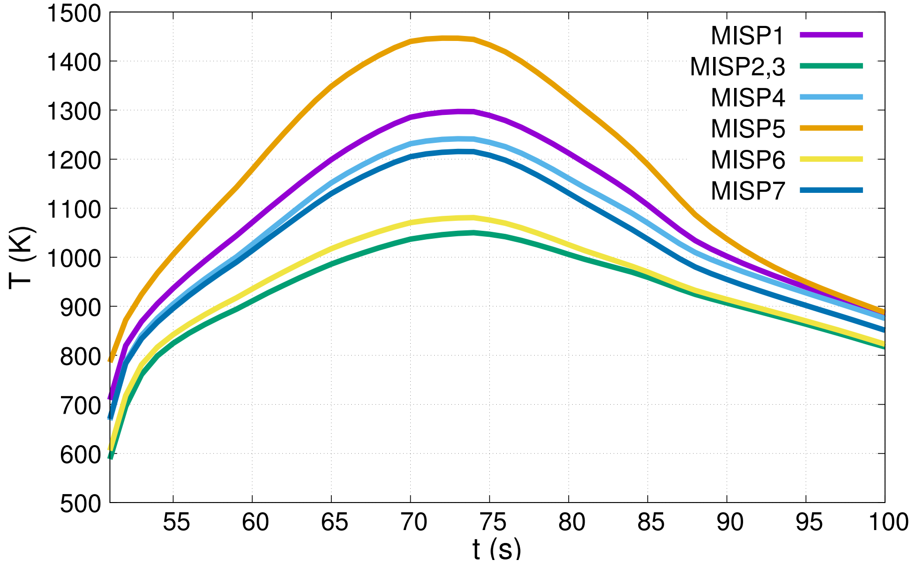
MSL heatshield front surface at the nose



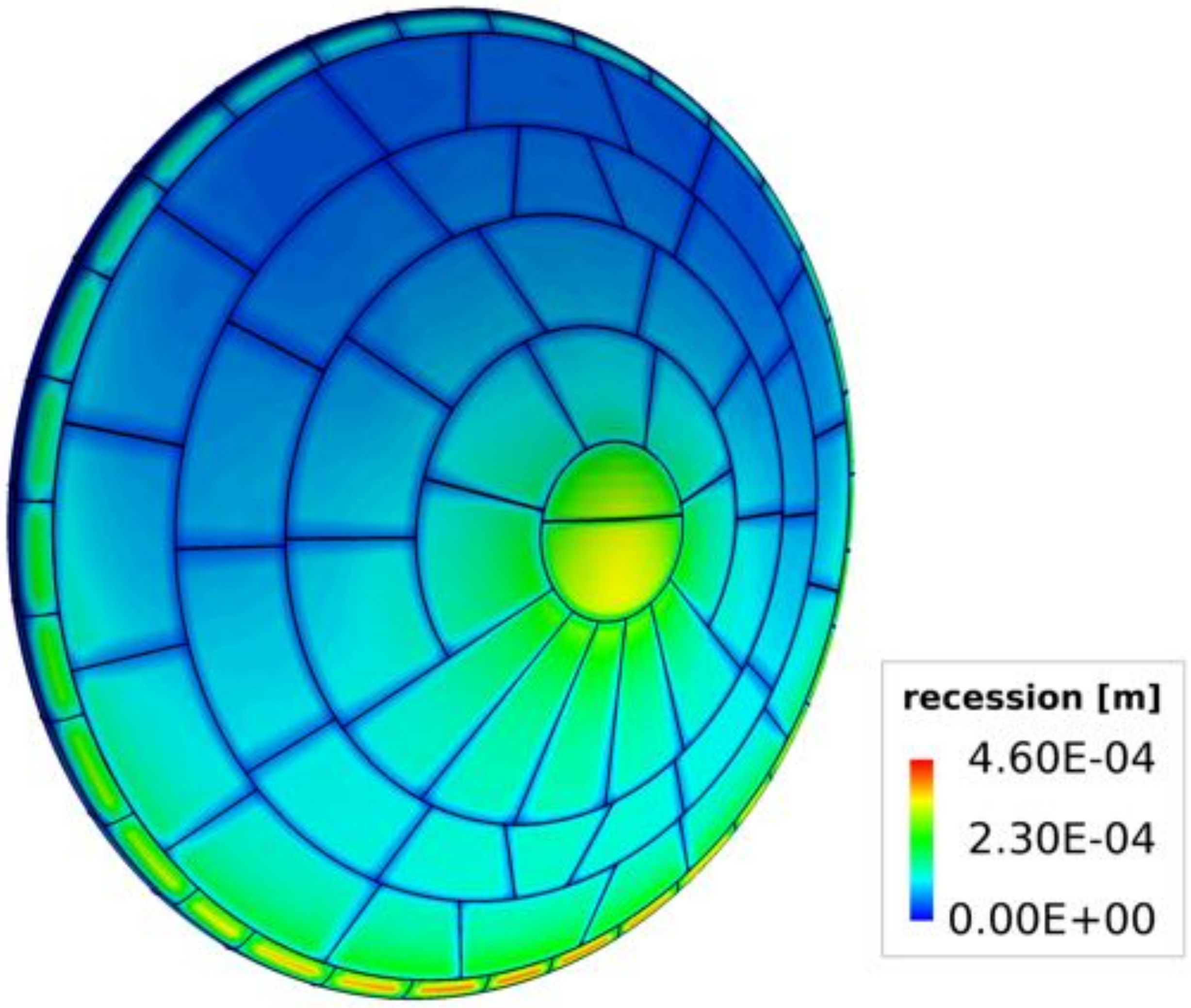
Temperature from PATO

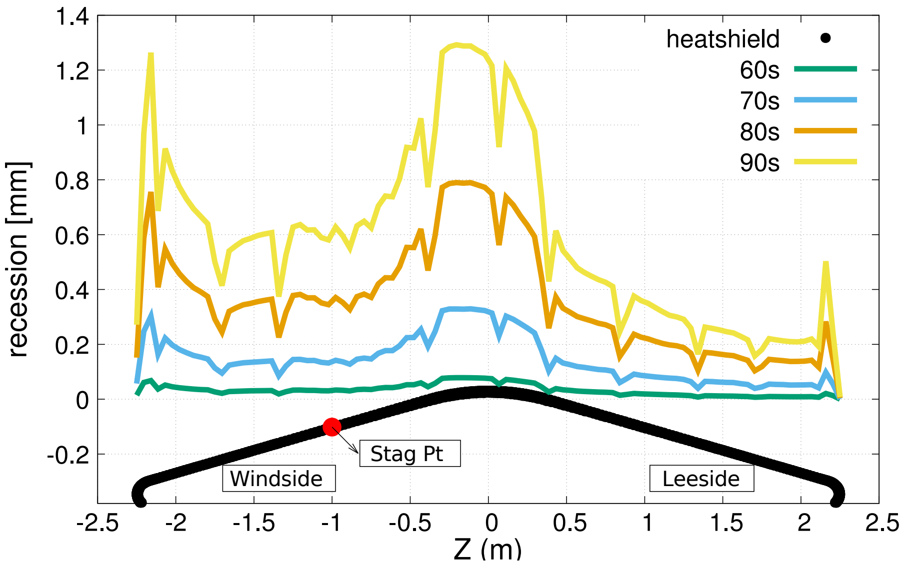


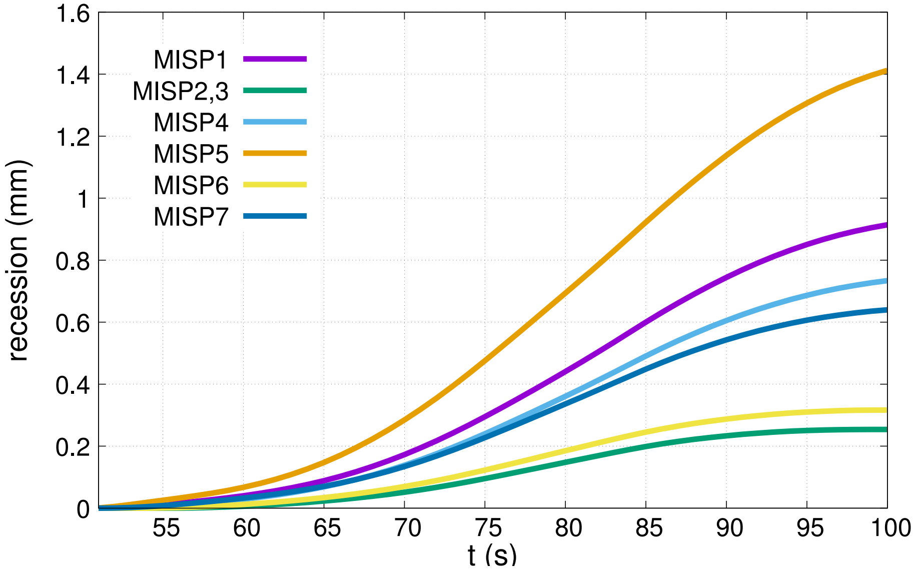




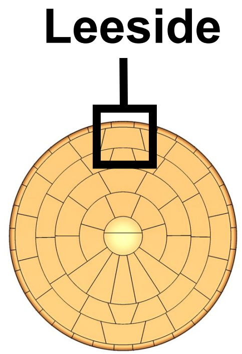
Recession from PATO

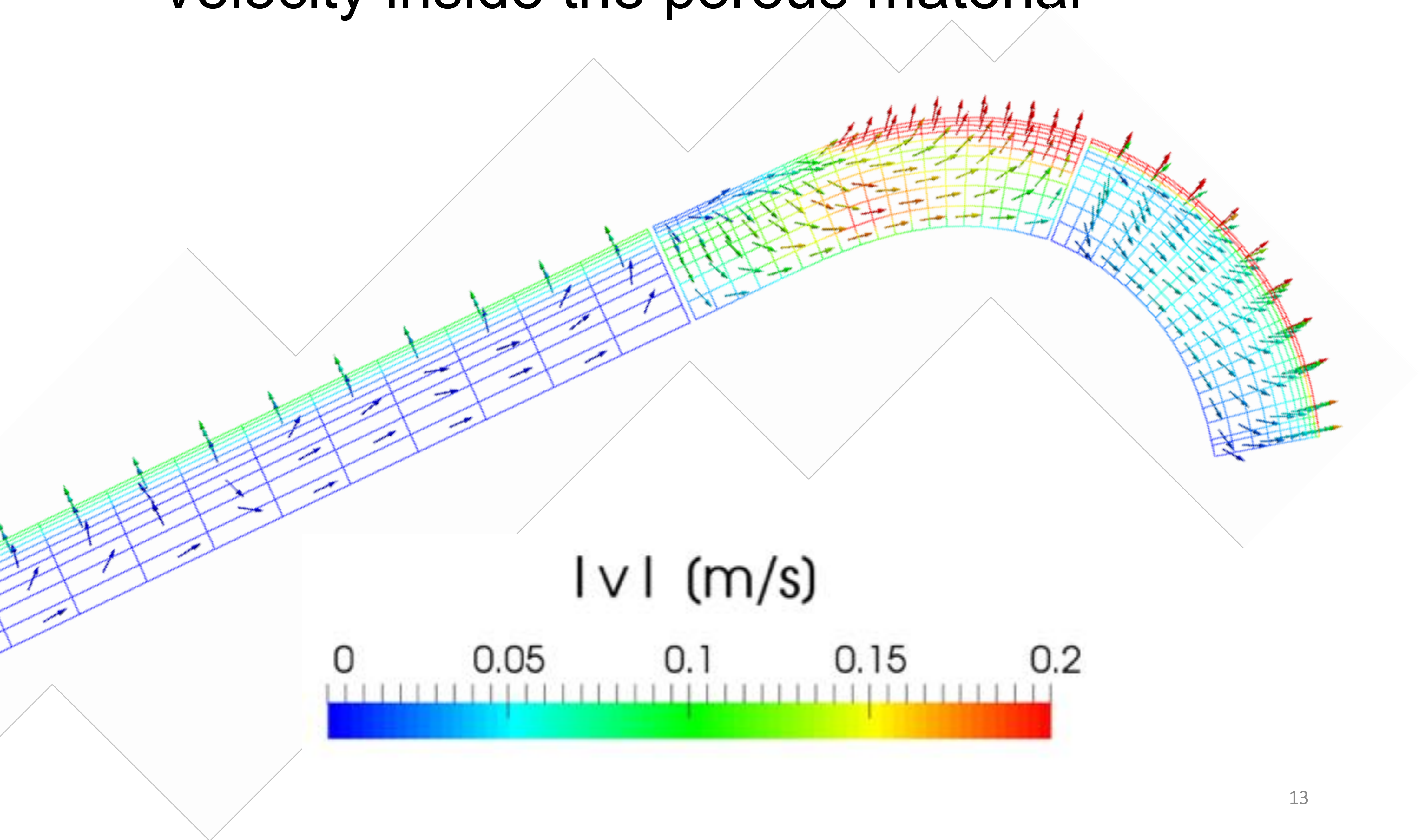




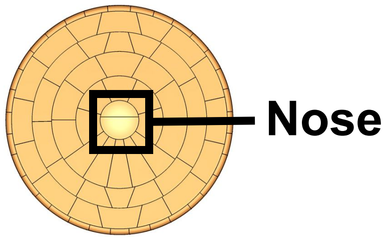


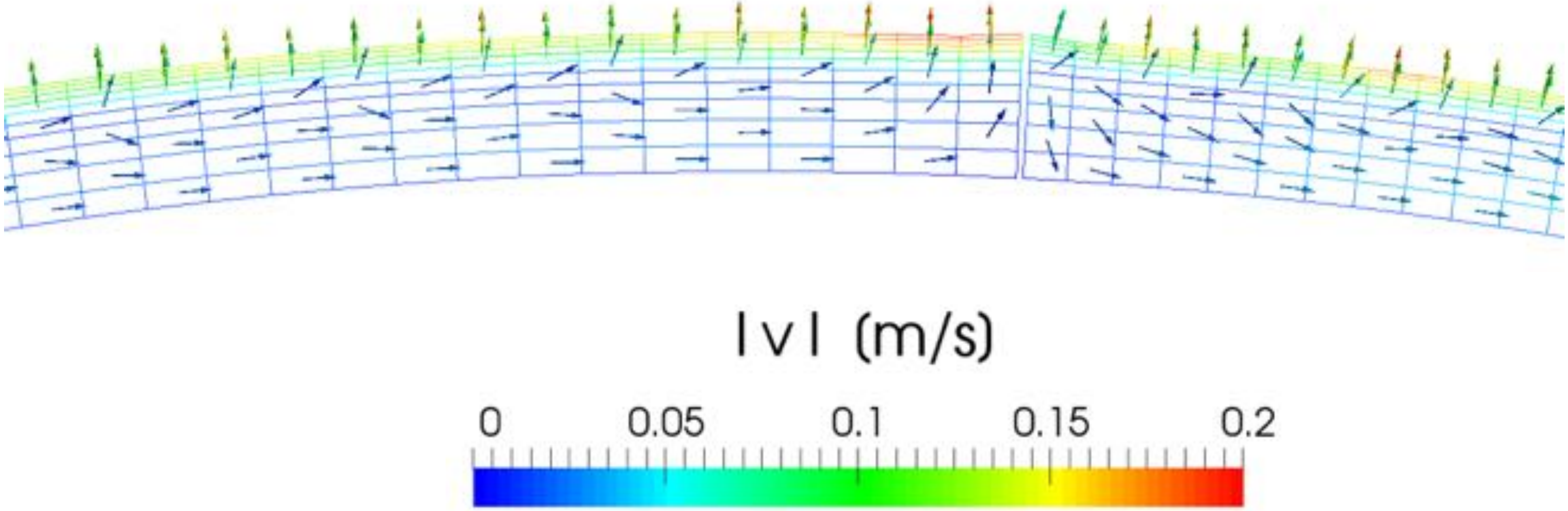
Velocity inside the porous material





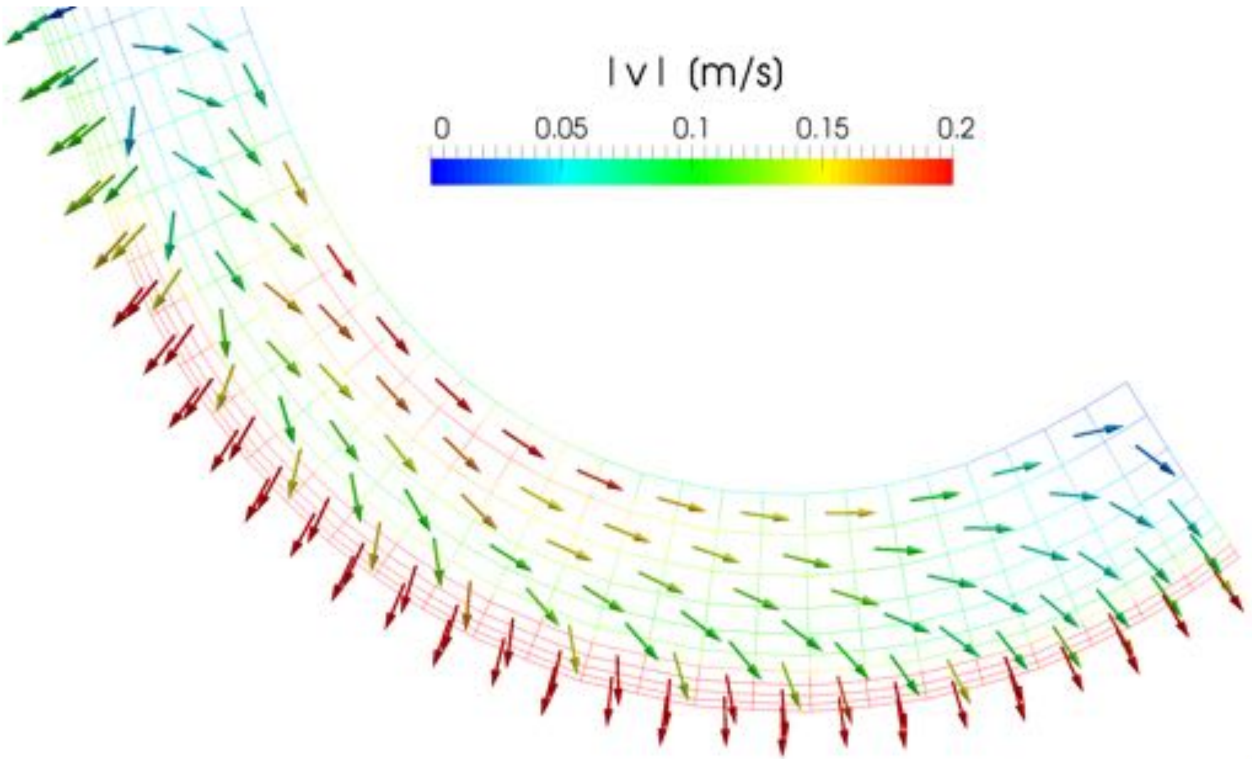
Velocity inside the porous material



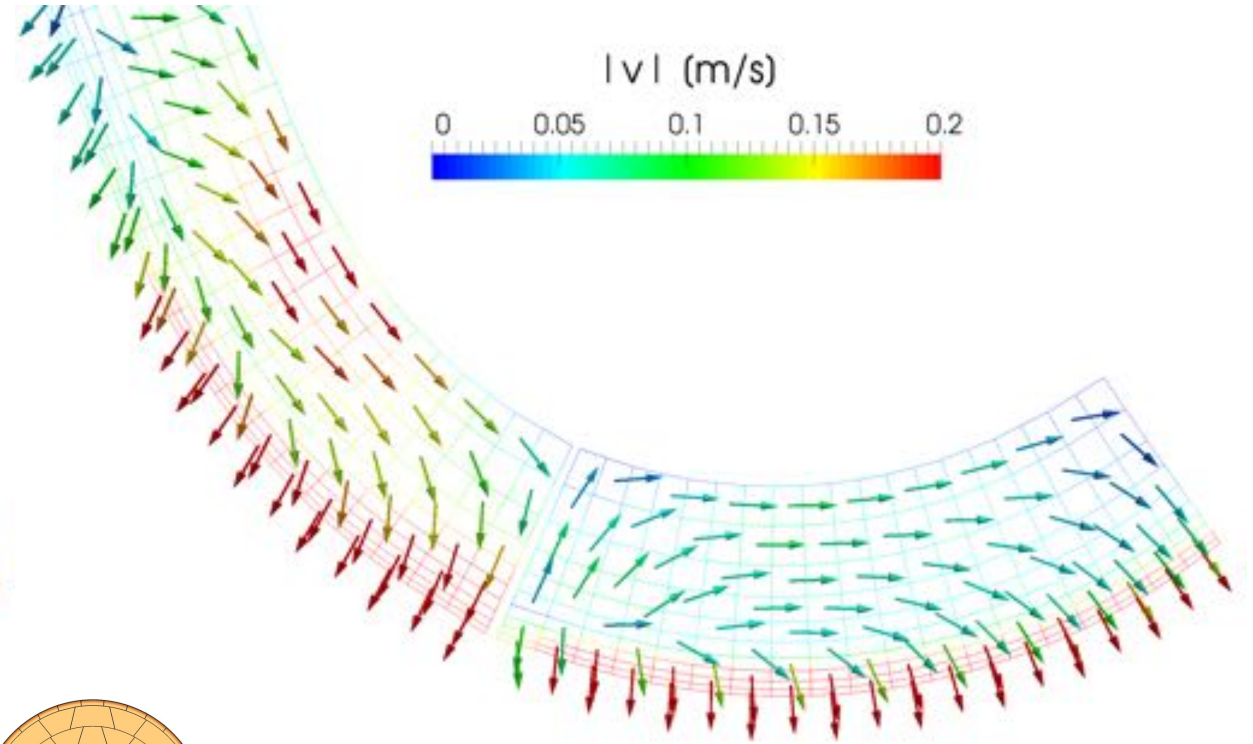


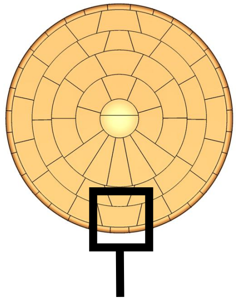
Tiled configuration changes the flow inside the material

Monolithic configuration



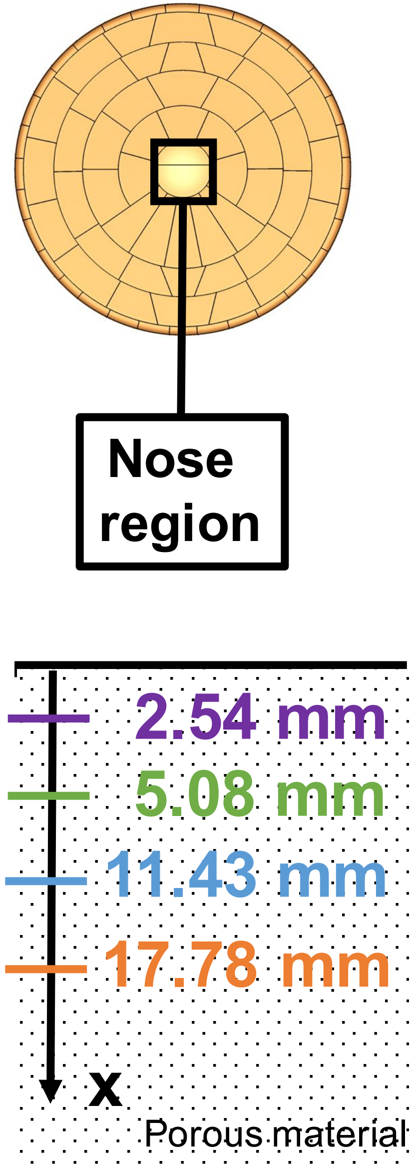
Tiled configuration

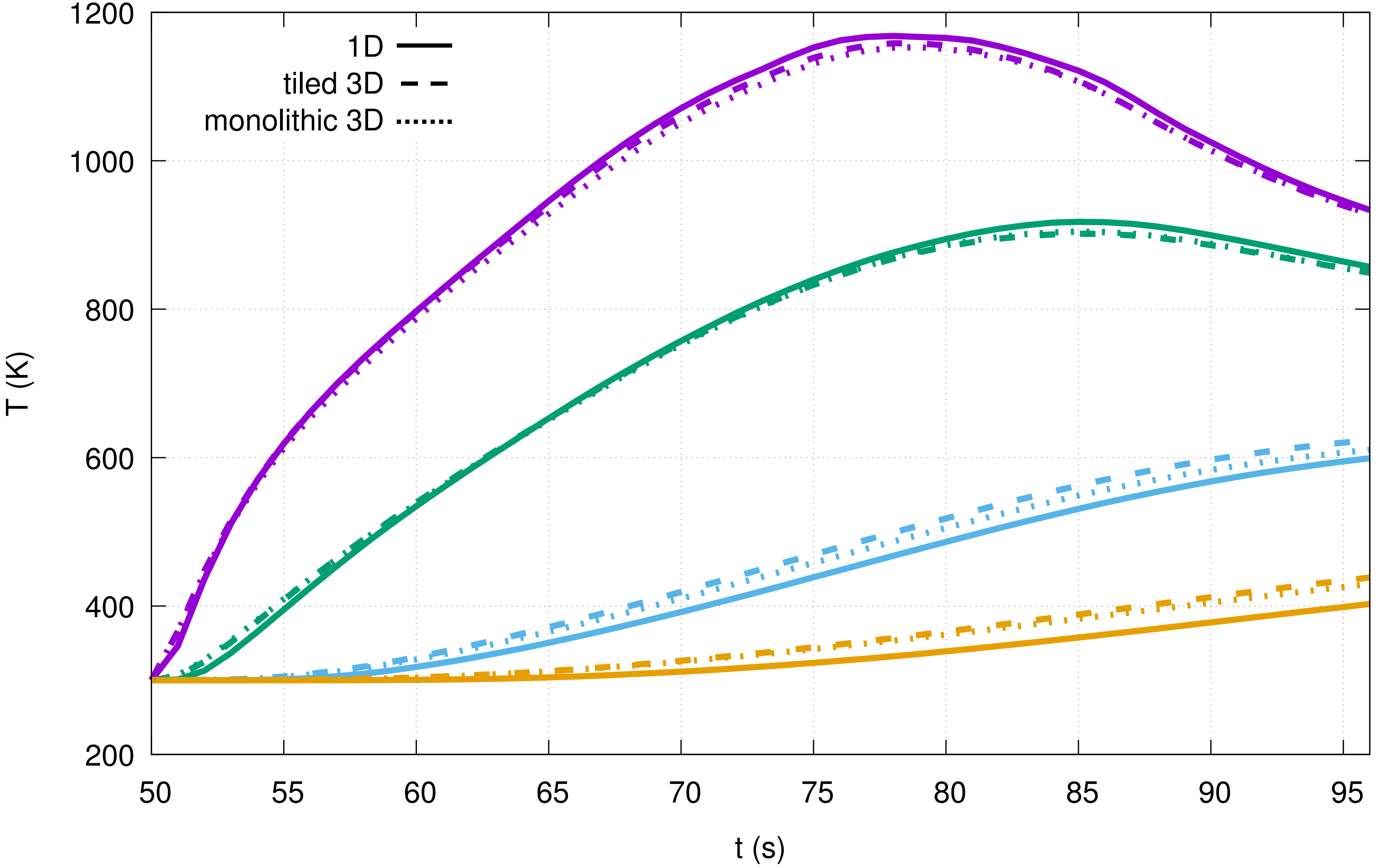




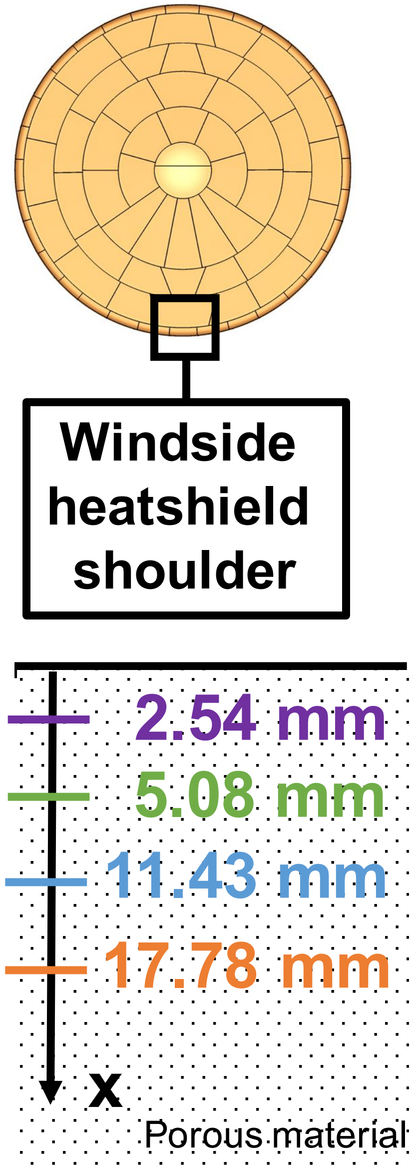
Windside

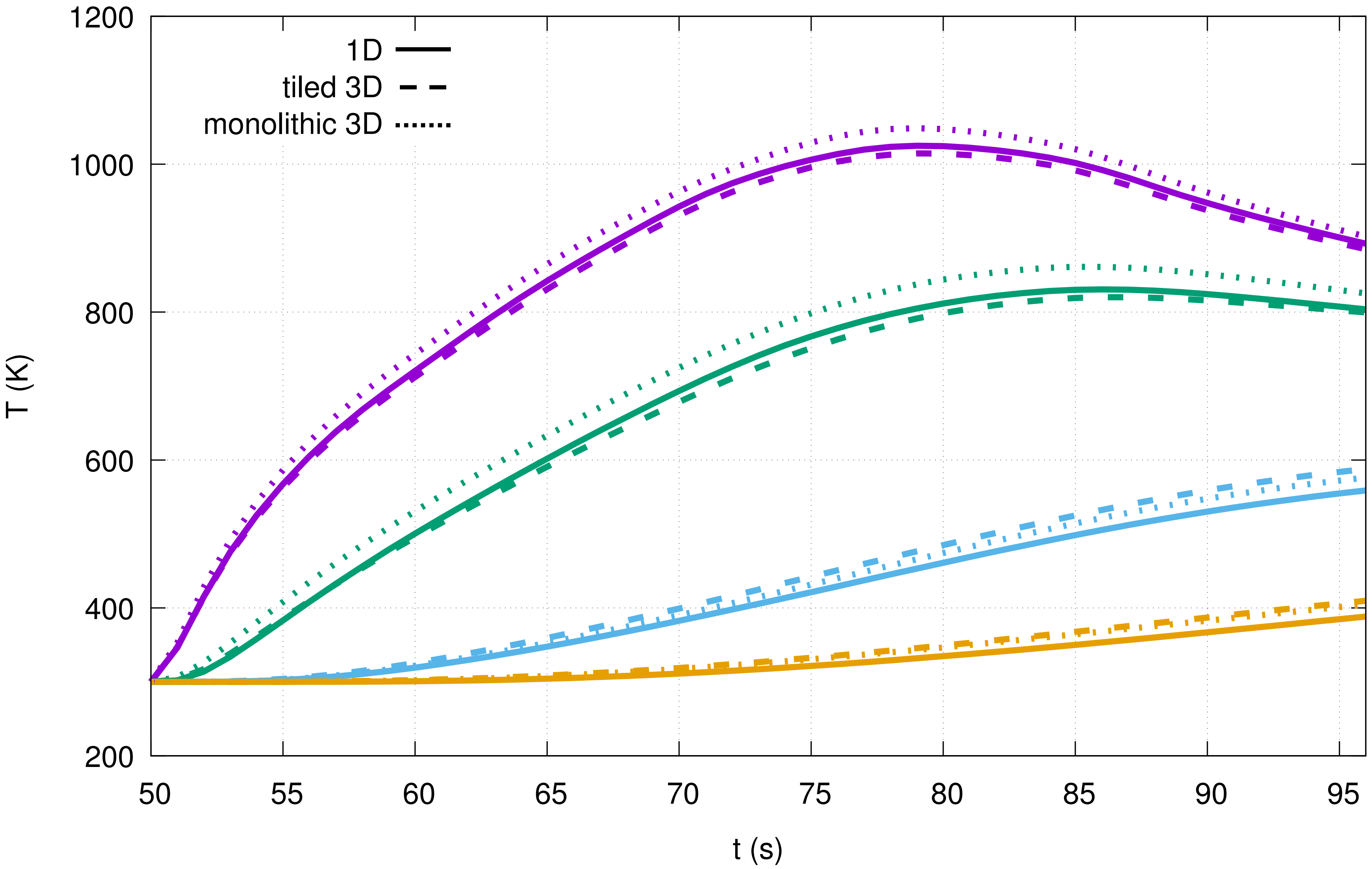
1D and 3D material response comparison – nose





1D and 3D material response comparison – shoulder





Future work

Hypersonic environment (DPLR)

- Laminar
- Super-catalytic wall
- Non-blowing
- 8 species & 12 reactions

Strong coupling

Linear in time
Conservative in space by local Galerkin projection

Future work includes blowing from pyrolysis & moving mesh from recession

Porous material response (PATO)

- Pyrolysis
- CMA-type BL approx.
- No finite-rate
- Equilibrium

New technology

- 2020 mission
- Non-uniform thickness
- Transient turbulent
- MMOD & micro-scale

New technology

PATO is capable of massively parallel computing for material response

Outputs

- Monolithic & tiled
- Temperature 1D & 3D
- Recession 1D & 3D
- Internal velocity

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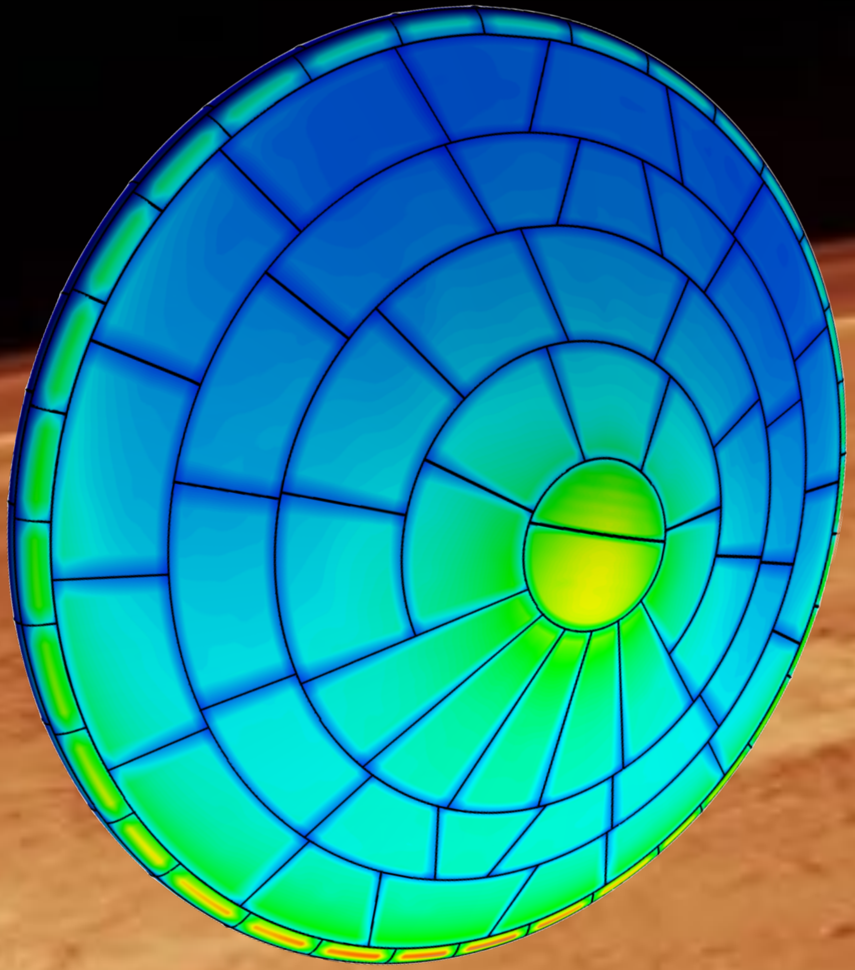

Questions ?

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