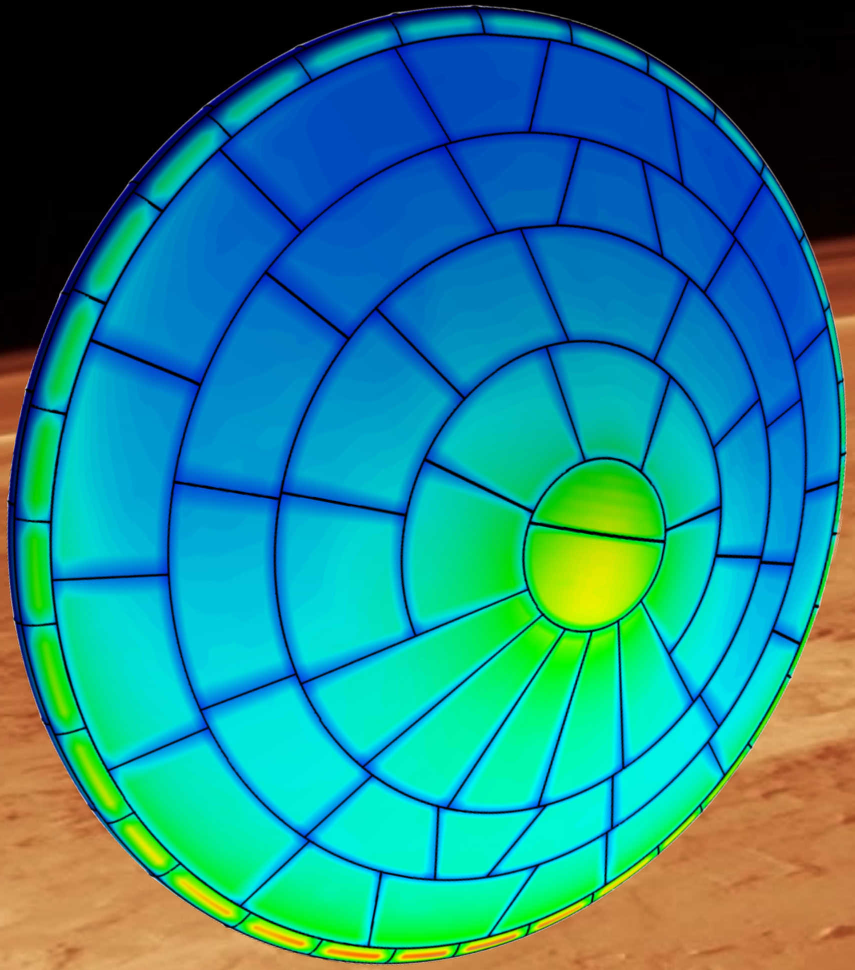

Full-scale Mars Science Laboratory Tiled Heatshield Material Response

9th Ablation Workshop

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

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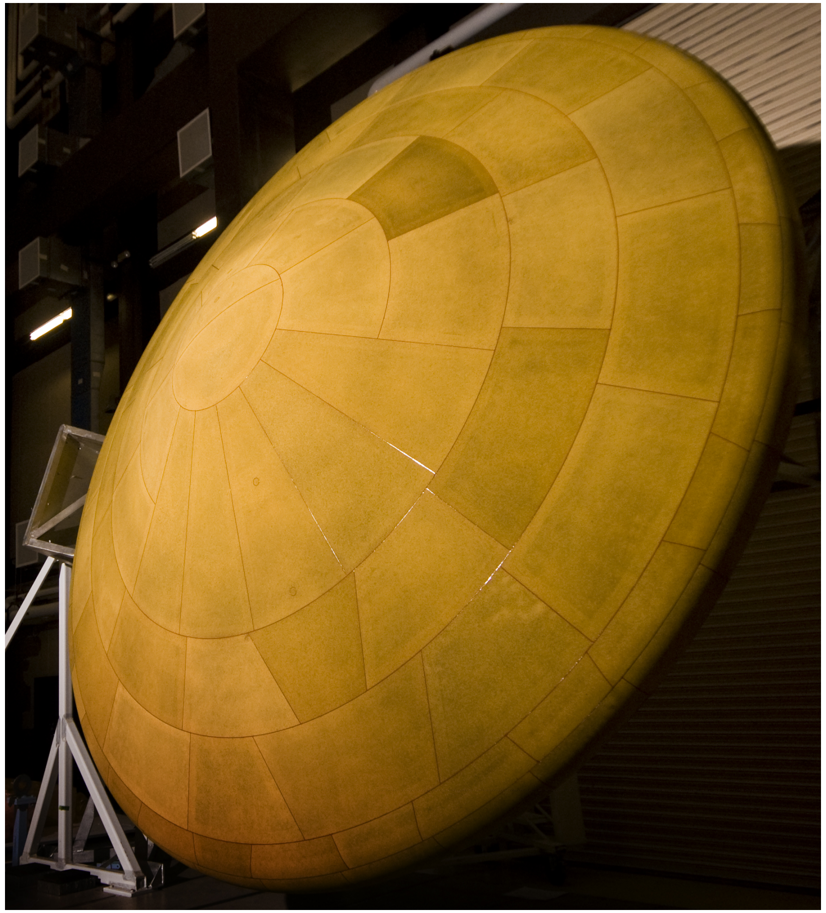
Mars Science Laboratory landed Curiosity in 2012



tiled MSL PICA heatshield
Lockheed Martin

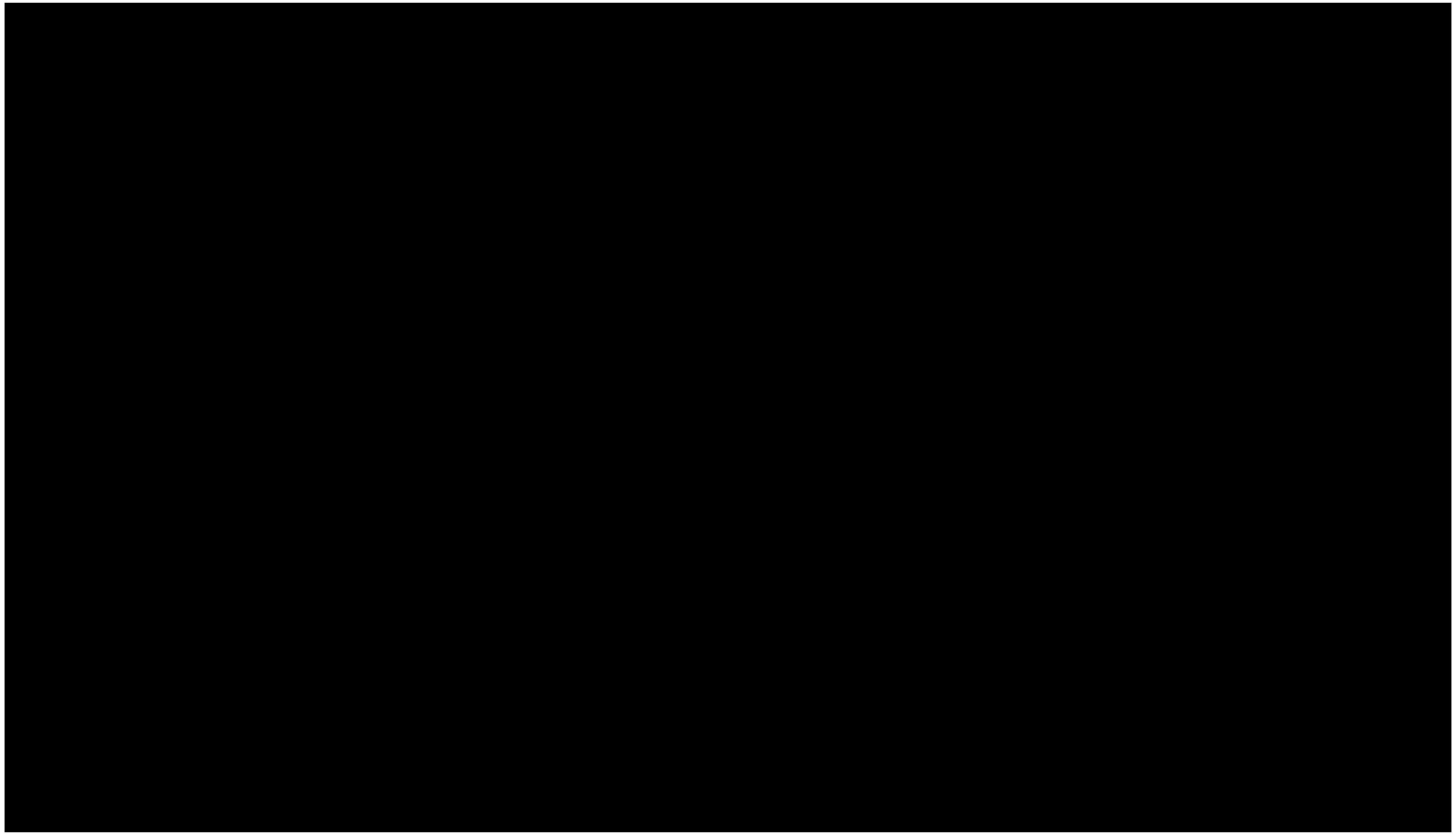
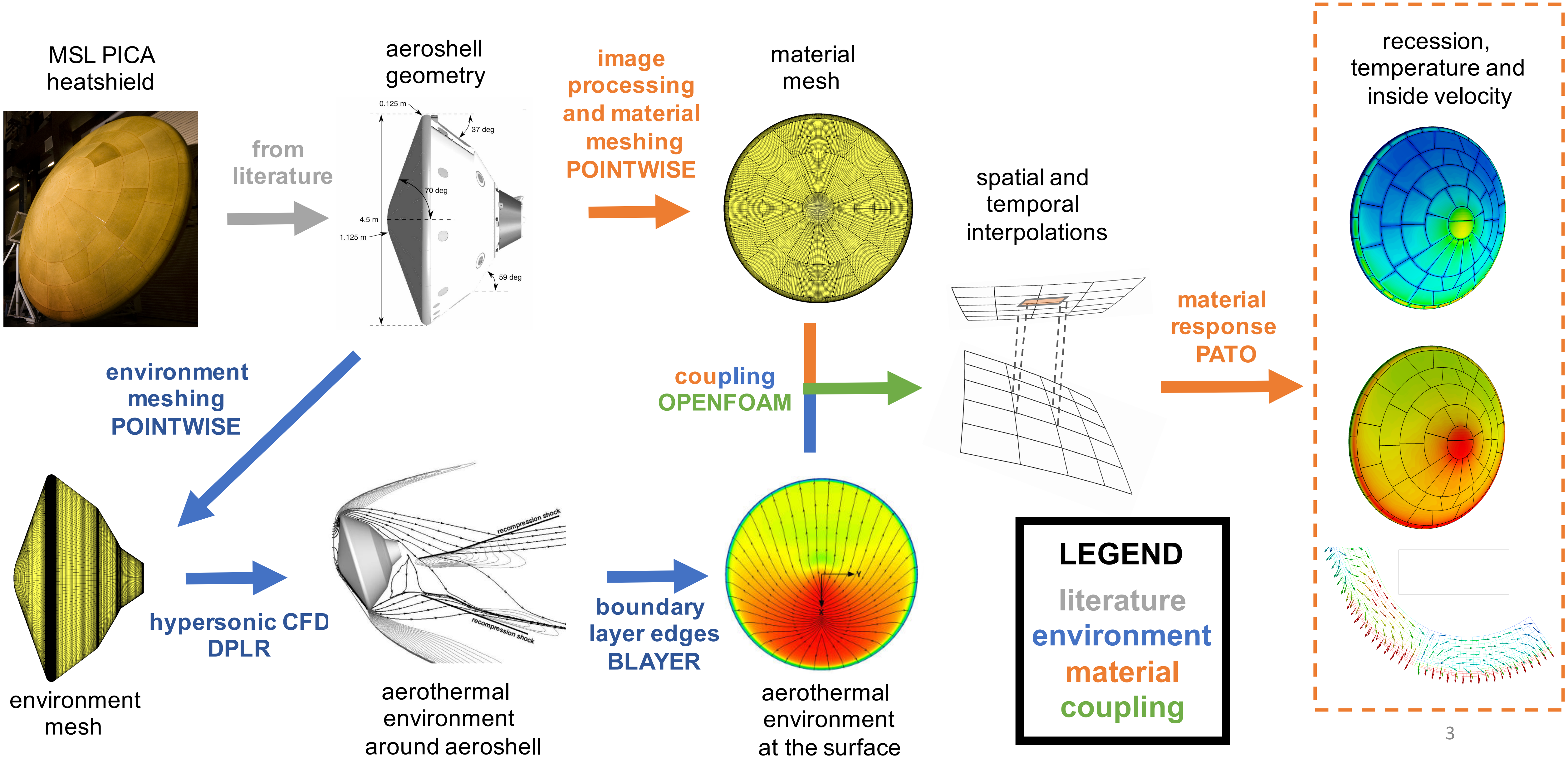
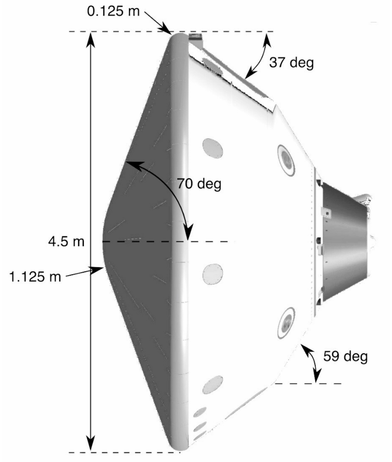


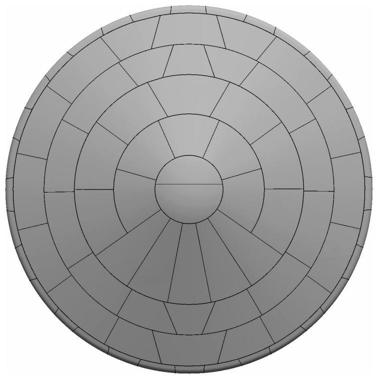
illustration of MSL Mars entry on August 2012
credit: NASA JPL

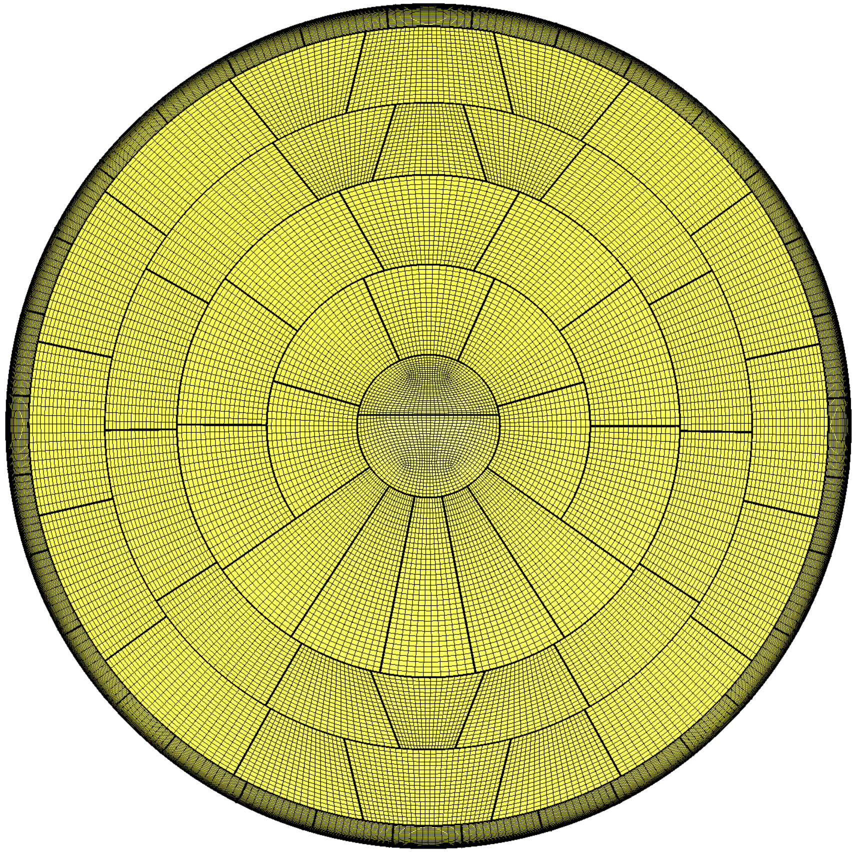
Overview – coupling aerothermal environment and material response

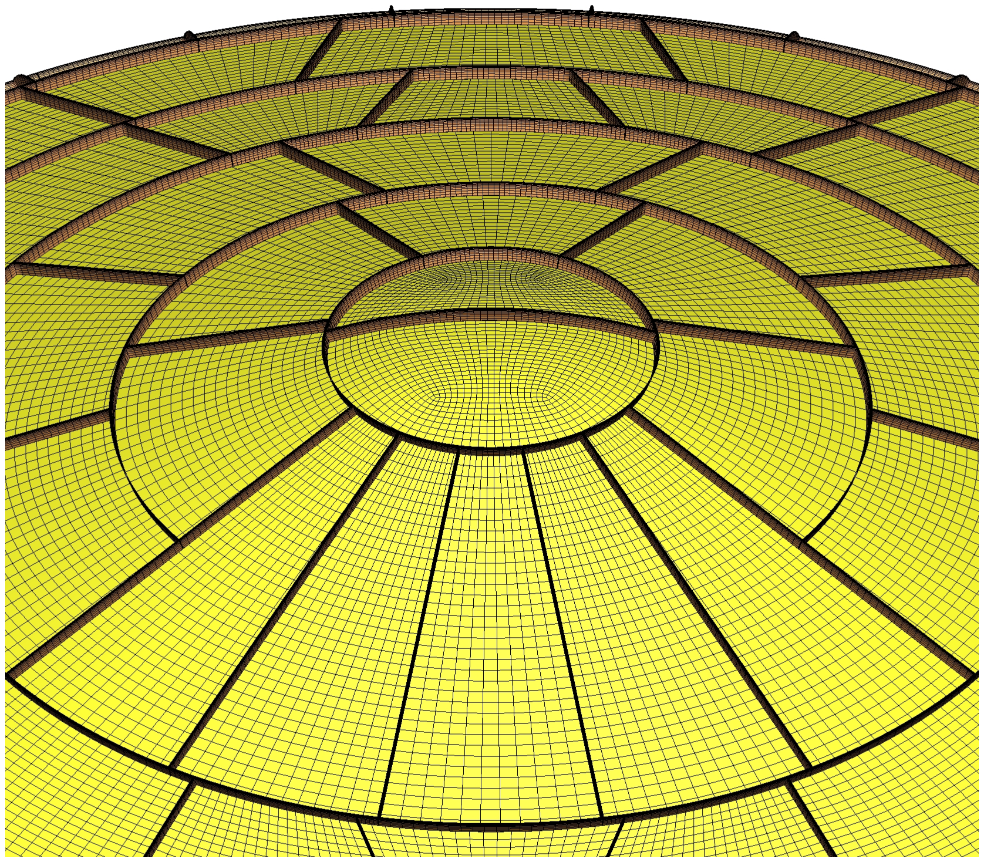


Computational domain of the entire MSL heatshield









aeroshell geometry with 113 PICA heatshied tiles

2 million cells mesh of the tiled heatshield

heatshield material in 2 regions
bounding agent + porous tiles

PATO* is used for the material response model

Pyrolysis

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

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

Mass and momentum conservation

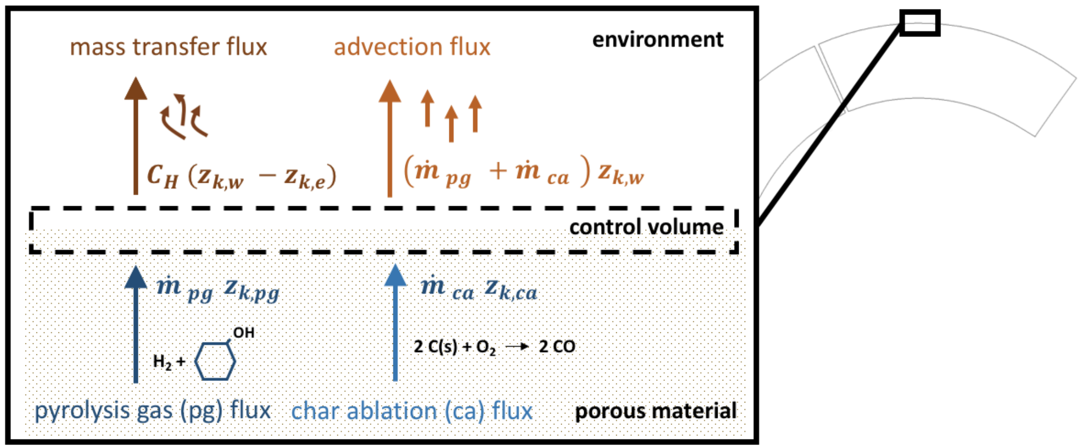
$$\partial_t \left(\frac{\epsilon_g M}{RT} p\right) - \partial_x \cdot \left(\frac{pM}{RT}\left[\frac{1}{\mu} \overline{\overline{K}} + \frac{1}{p} \overline{\overline{\beta}}\right]\right) = \Pi$$

Energy conservation

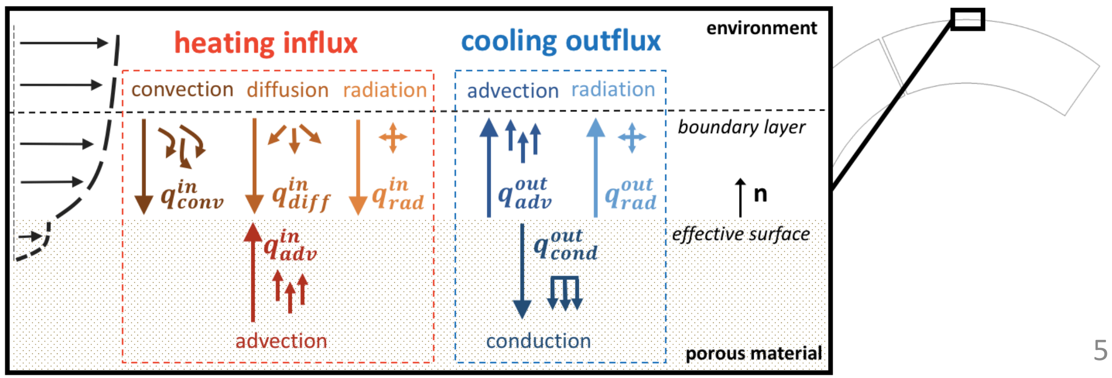
$$\sum_{i=1}^{N_p} [(\epsilon_i \rho_i c_{p,i})\, \partial_t T] - \partial_x \cdot (\overline{\overline{k}} \cdot \partial_x T)$$

$$= \sum_{i=1}^{N_p} [\, h_i\, \partial_t(\epsilon_i \rho_i)\,] - \partial_t(\epsilon_g \rho_g h_g - \epsilon_g\, p) + \partial_x \cdot (\epsilon_g \rho_g h_g v_g)$$

Surface mass balance $\longrightarrow$ h_w $\dot{m}_{ca}$

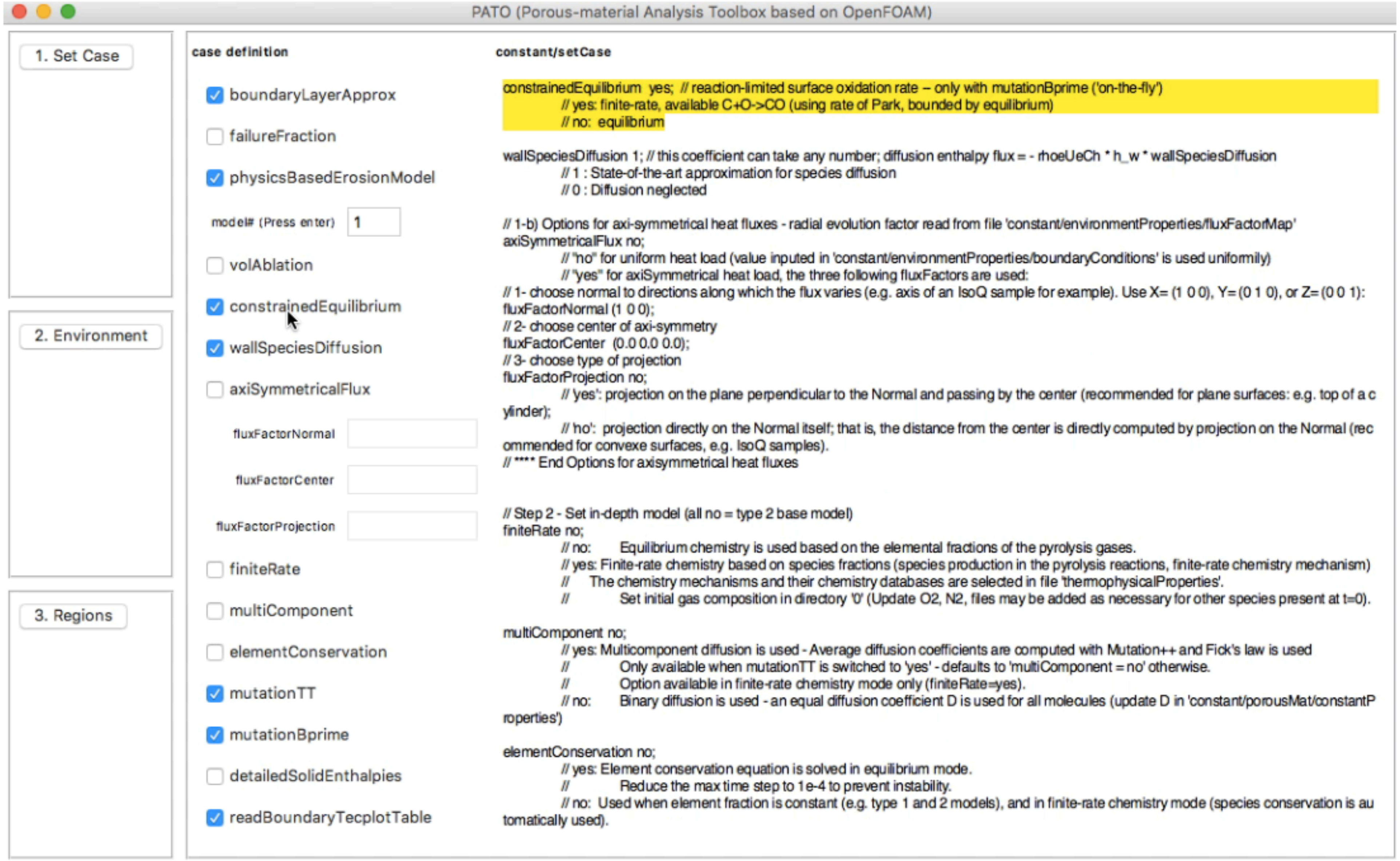


Surface energy balance $\longrightarrow$ T_w



* PATO = Porous-material Analysis Toolbox based on OpenFOAM

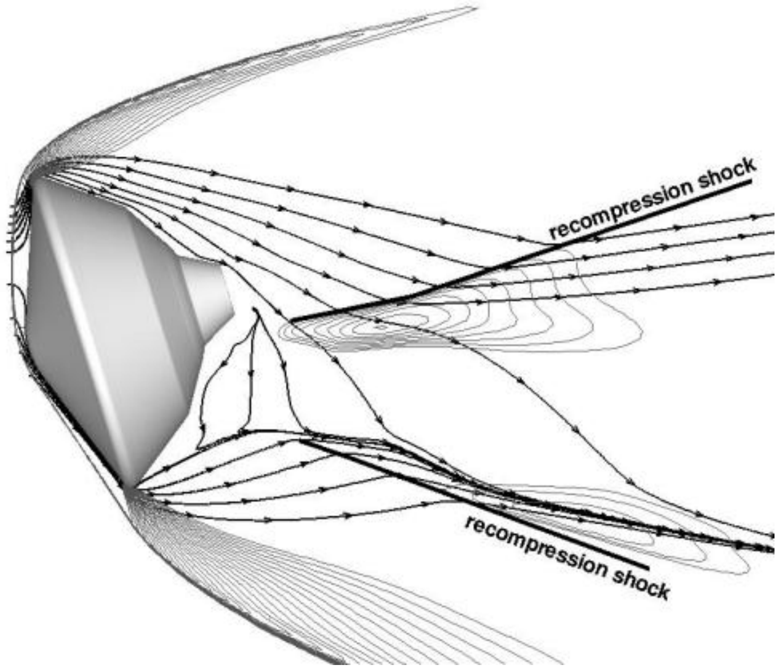
A new GUI implemented in PATO



Aerothermal environment computed from DPLR*

DPLR assumptions

- laminar boundary layer
- chemical and thermal non-equilibrium
- radiative equilibrium
- super-catalytic wall
- non-blowing & smooth wall
- 12 reactions & 8 species
- Mars atmosphere: y_{CO2} = 0.97, y_{N2} = 0.03



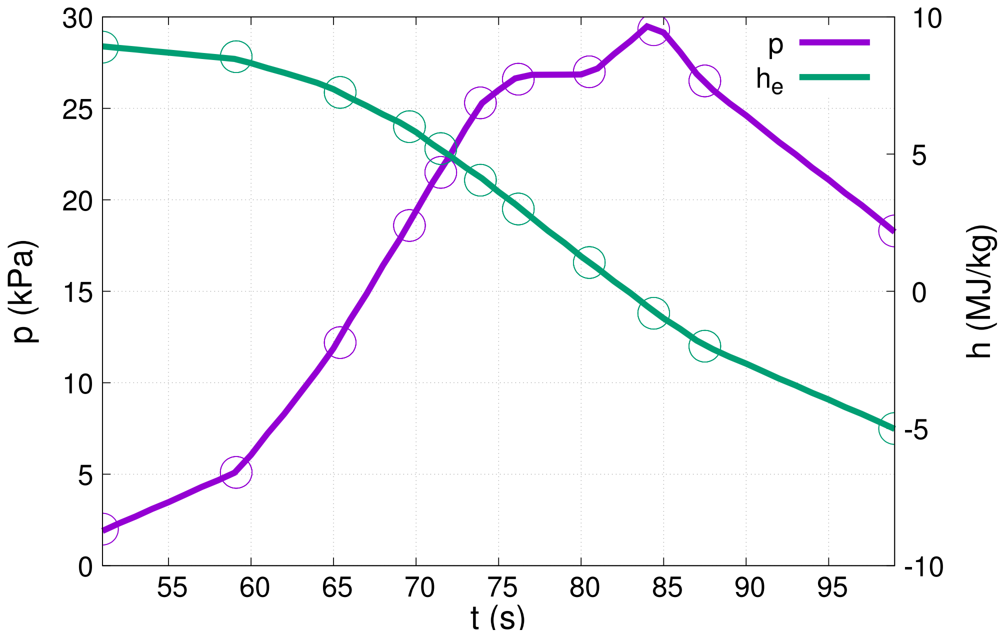
BLAYER calculates the **boundary layer edges** using a curvature-based method

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

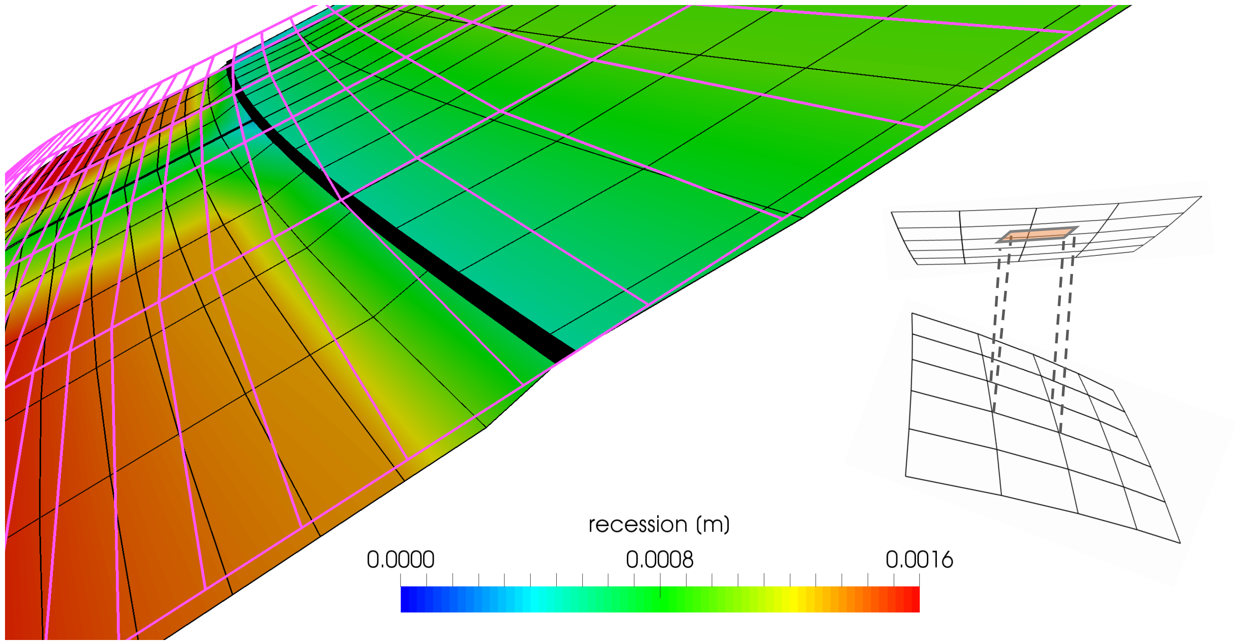
Temporal and spatial interpolations

temporal interpolation



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

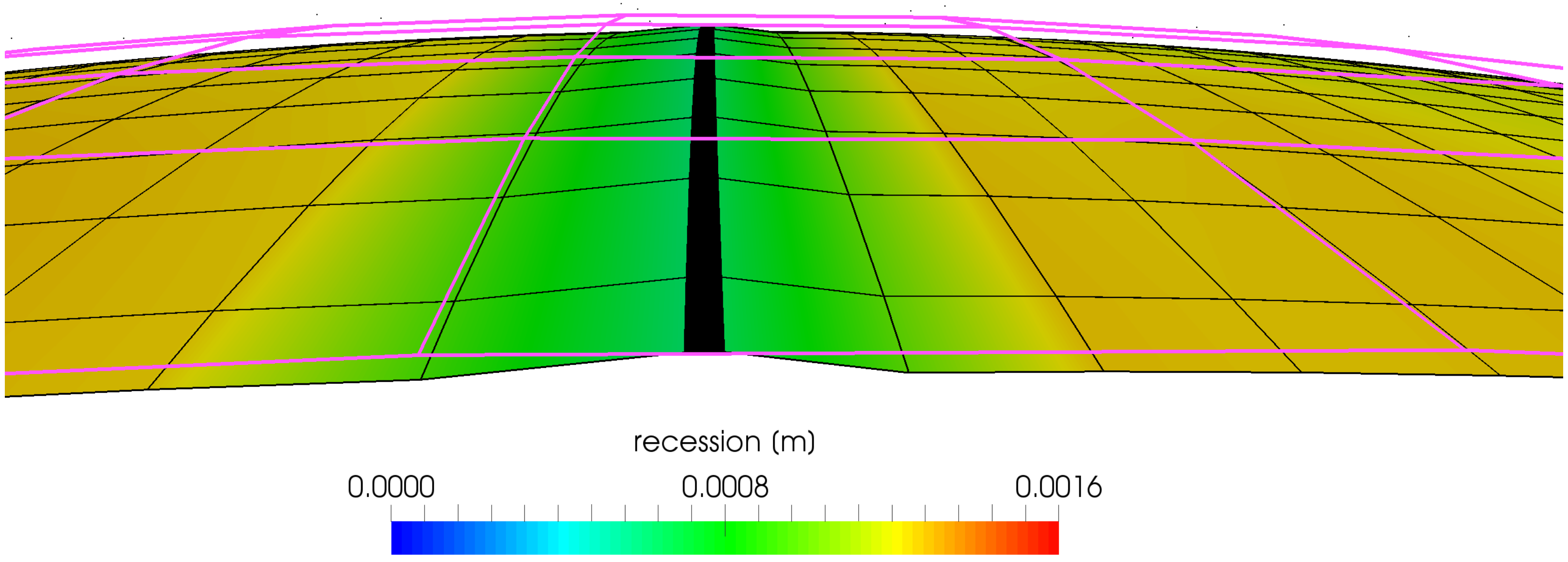
spatial interpolation



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

“Fencing” effect at tiles interfaces

MSL heatshield front surface at the nose



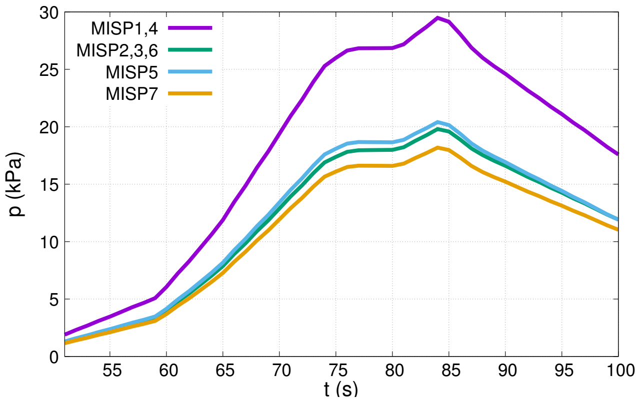
Post-test arcjet coupons

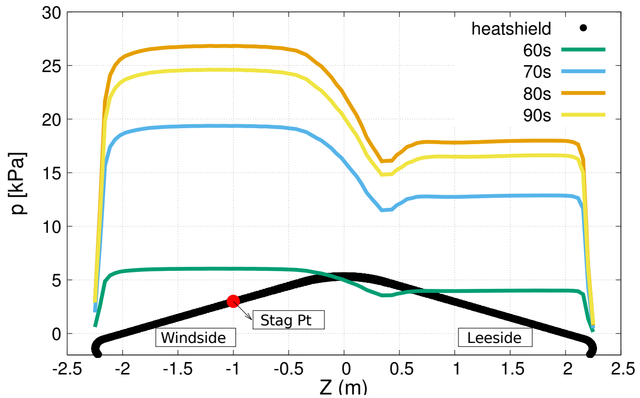
Pre Test Sample | 85 W/cm², 0.33 atm | 175 W/cm², 0.28 atm | 270 W/cm², 0.27 atm

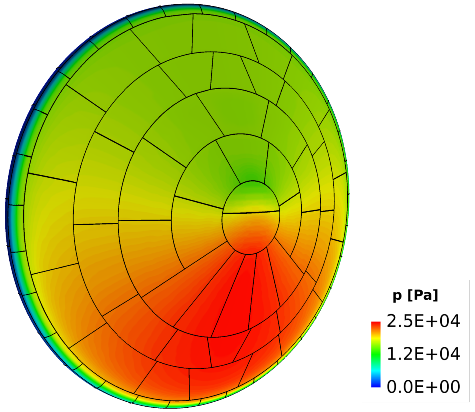
Interpolated inputs from BLAYER to PATO

surface pressure

p_w

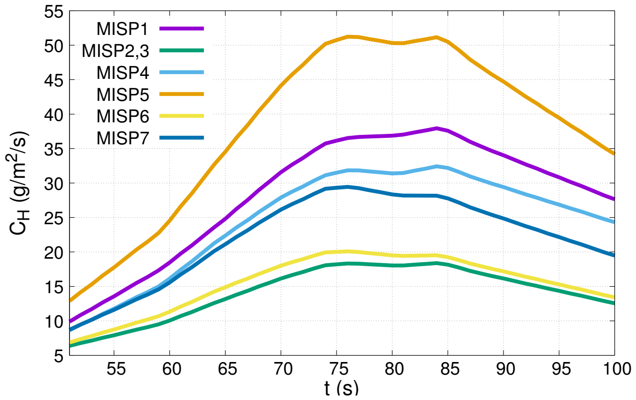


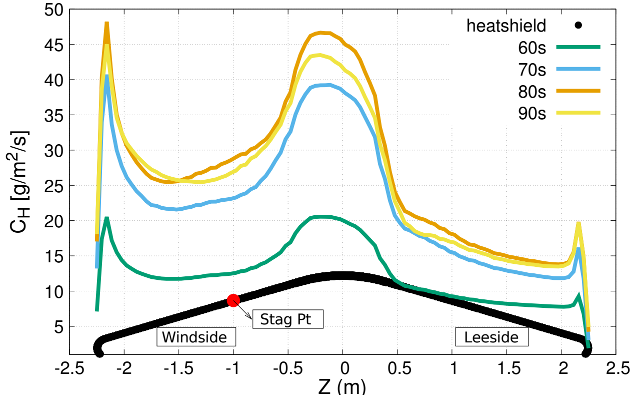


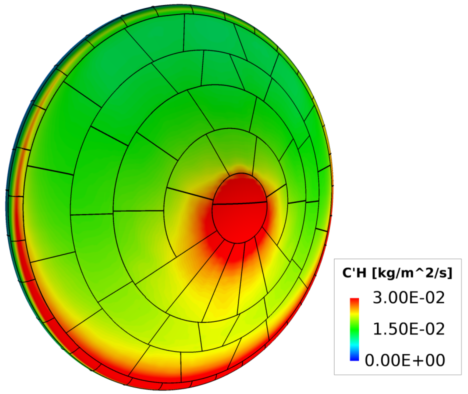


heat transfer coefficient

C_H

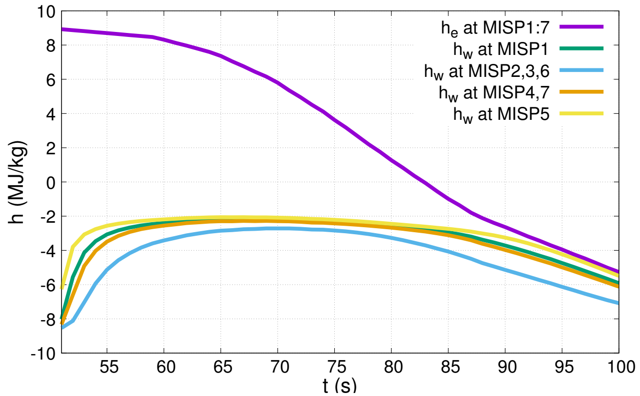


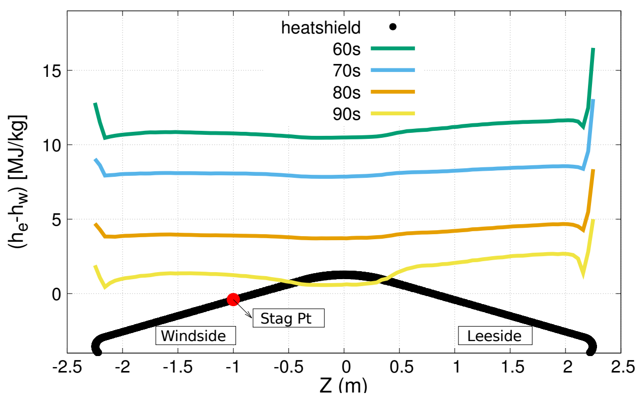


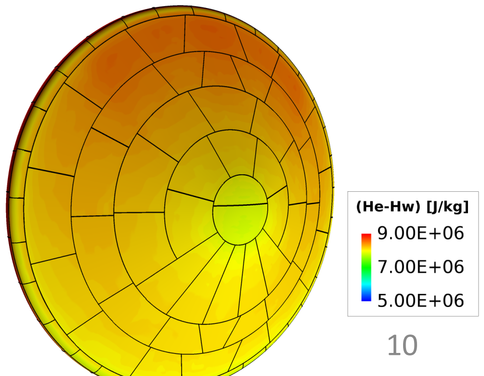


edge enthalpy

h_e

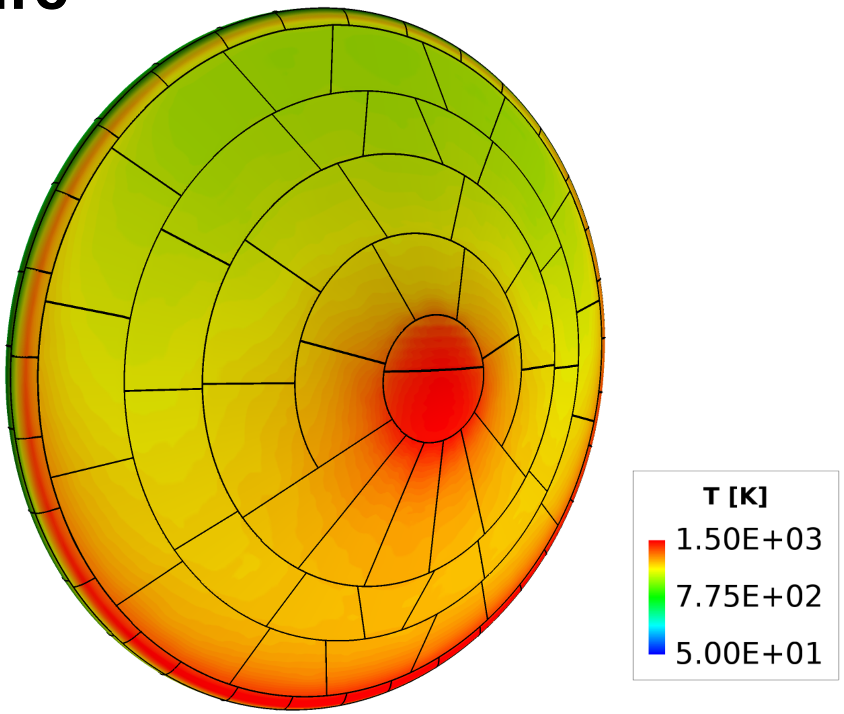


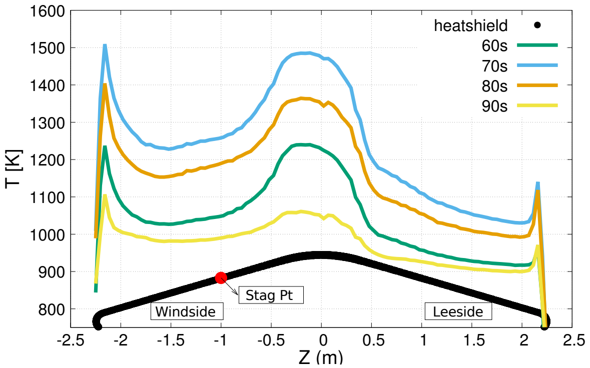


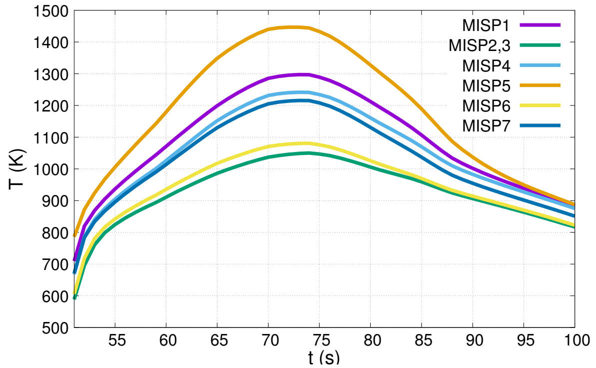


Temperature and recession from PATO

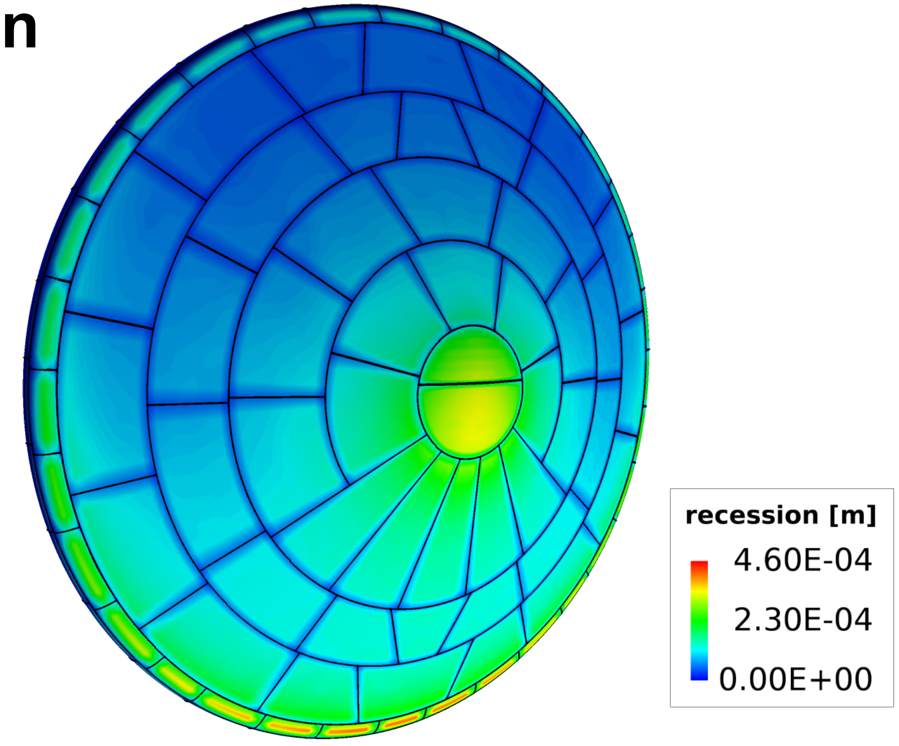
temperature

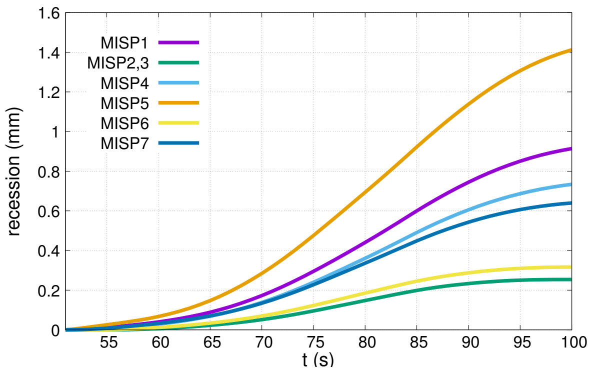


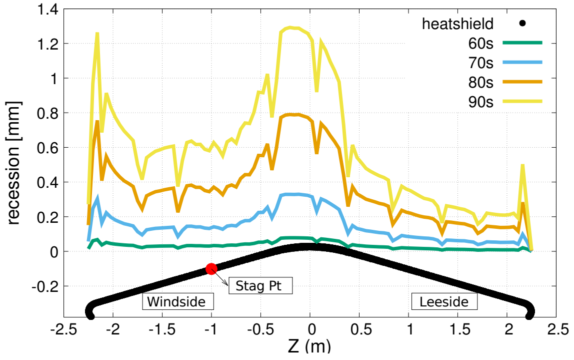




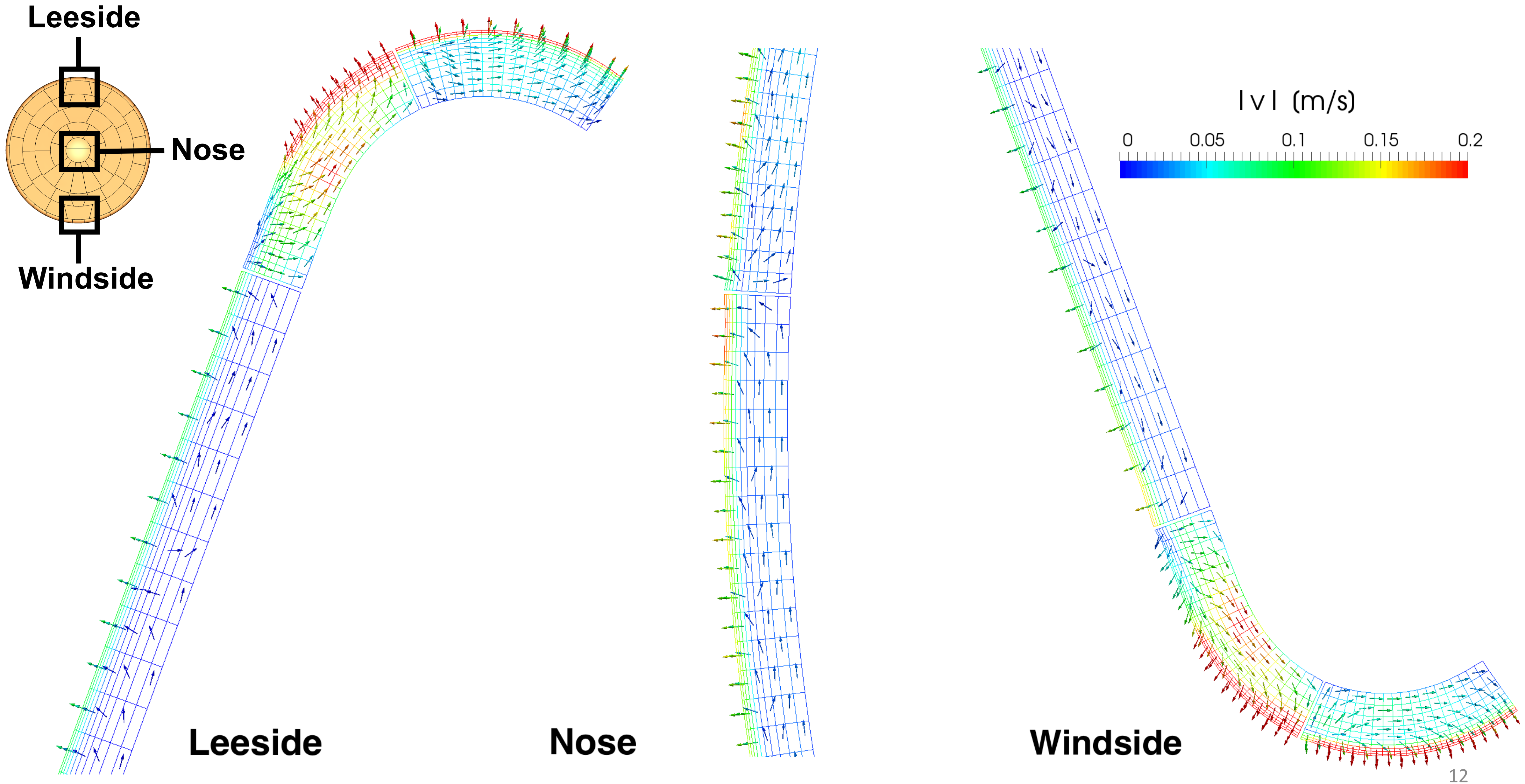
recession





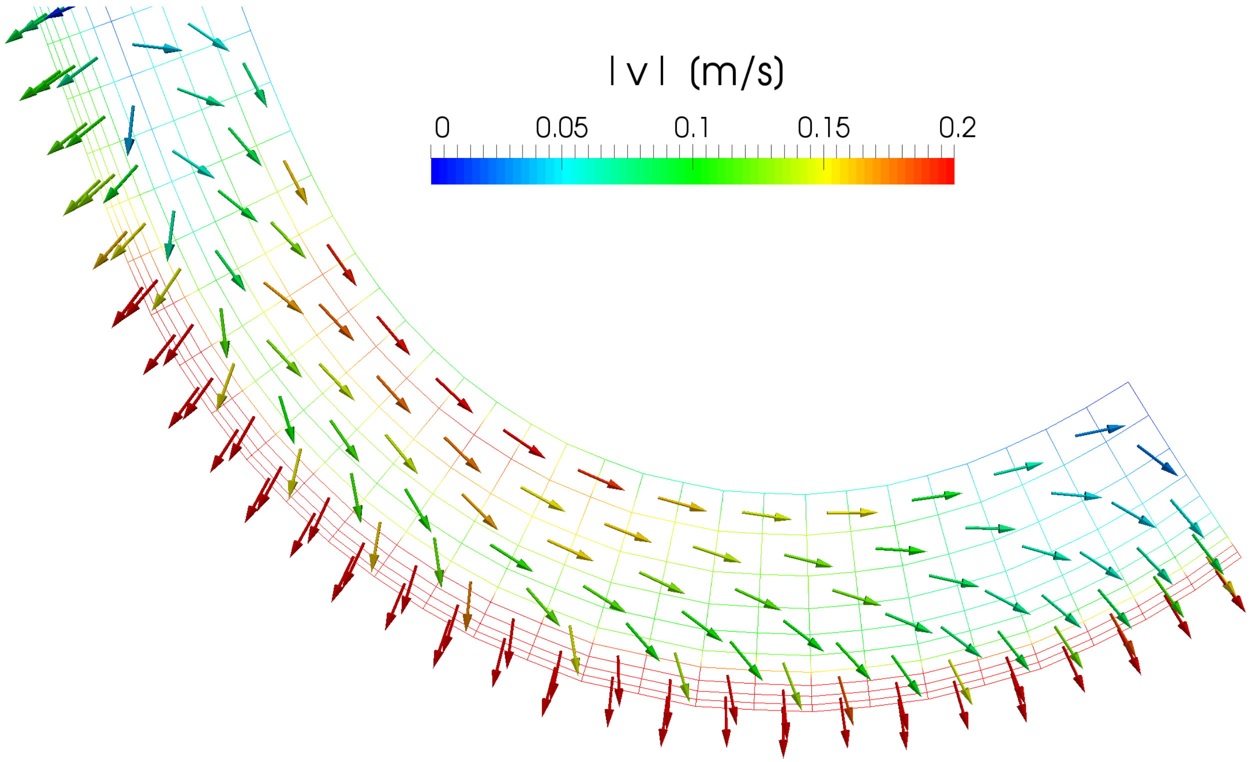


Velocity inside the porous material

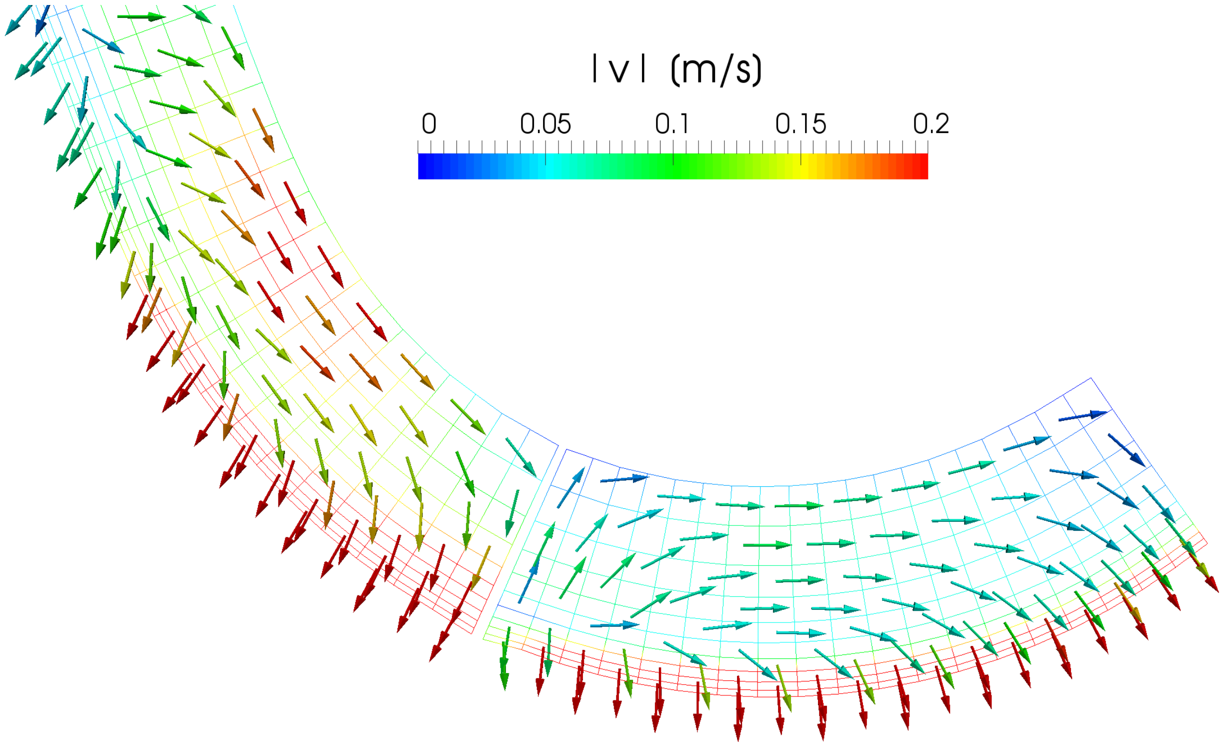


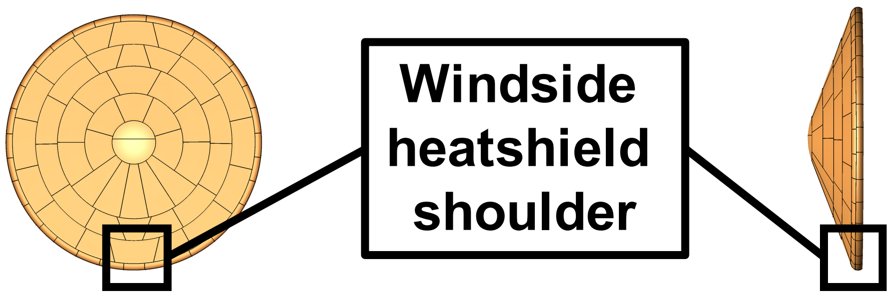
Tiled configuration changes the flow inside the material

non-tiled configuration

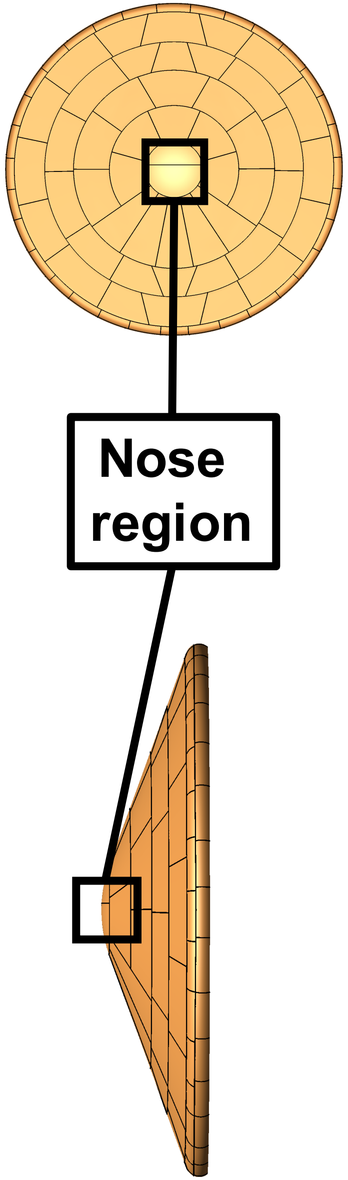


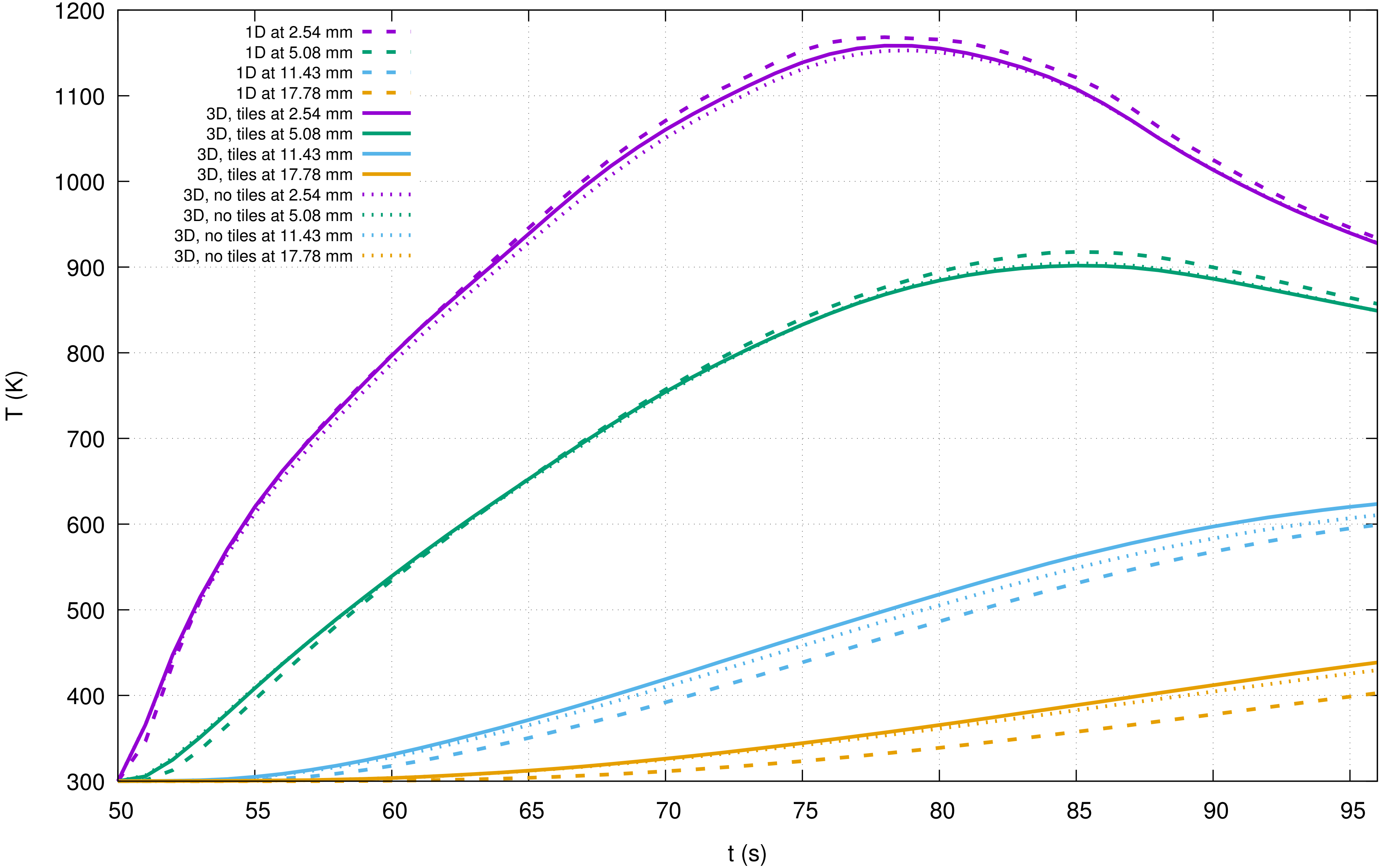
tiled configuration



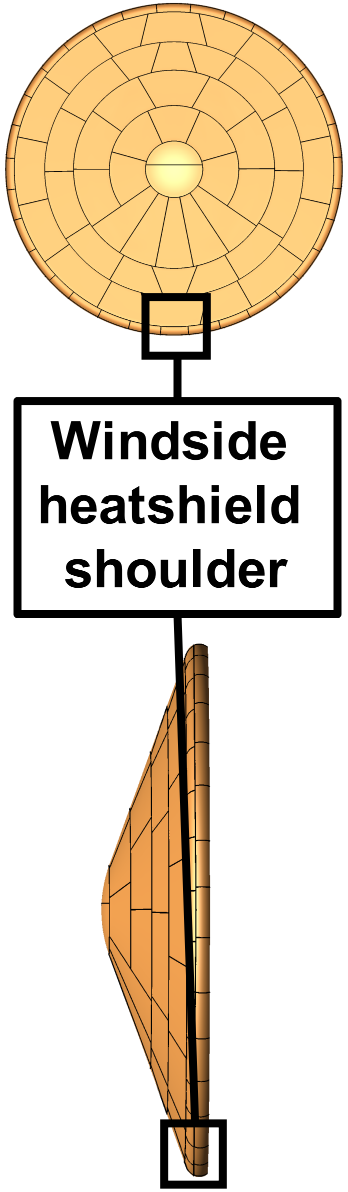


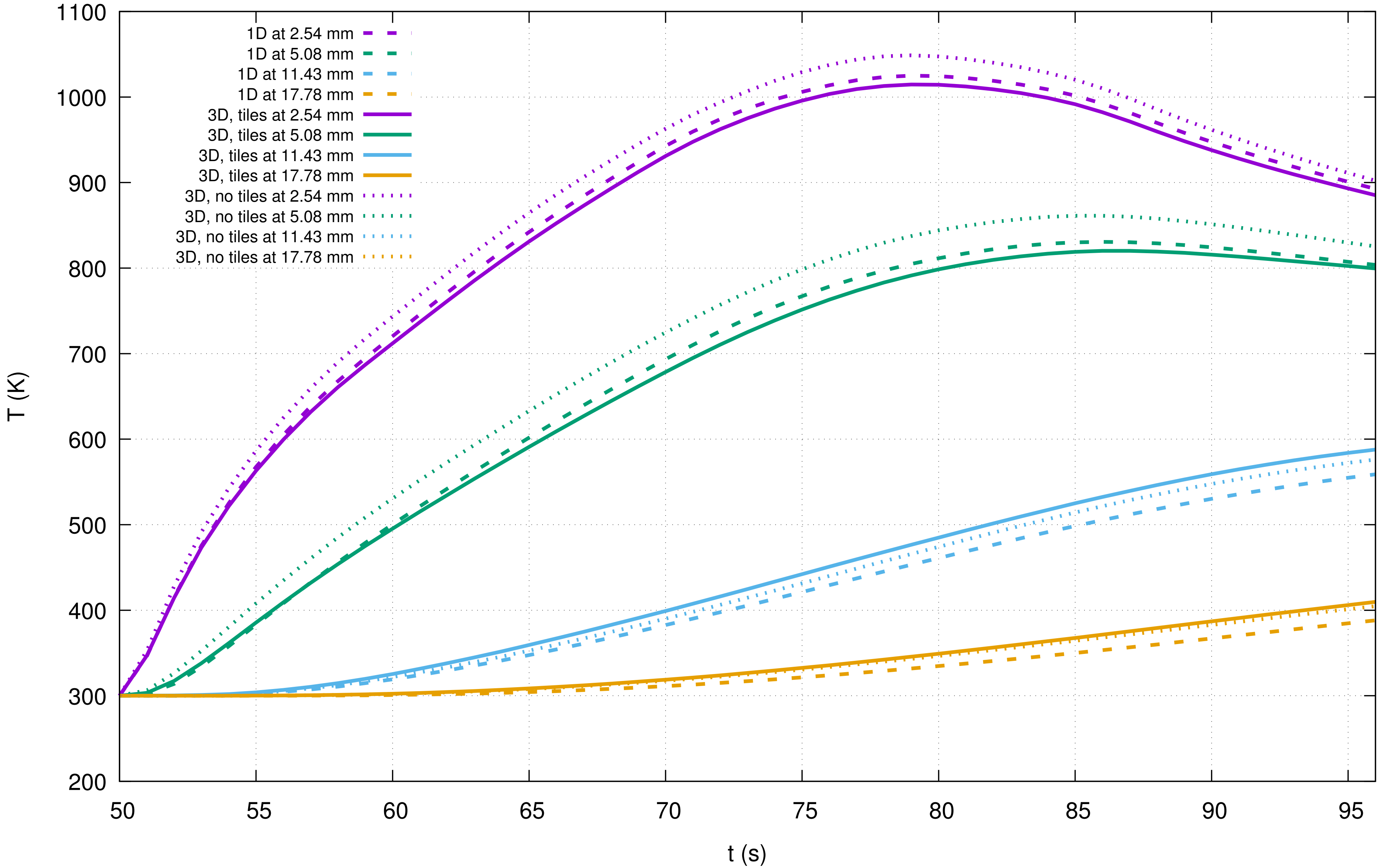
1D and 3D material response comparison – nose





1D and 3D material response comparison – shoulder





Conclusion and future work

hypersonic environment (DPLR)

- laminar
- super-catalytic wall
- non-blowing
- 8 species & 12 reactions

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)

- equilibrium
- pyrolysis
- CMA-type BL approx.
- no finite-rate, no oxidation

impacts

- 2020 mission
- MISP locations
- "fencing" effect
- tiled configuration

outputs

- temperature
- recession
- heat fluxes
- inside velocity

impacts

PATO is a useful tool to predict material response for future entry missions

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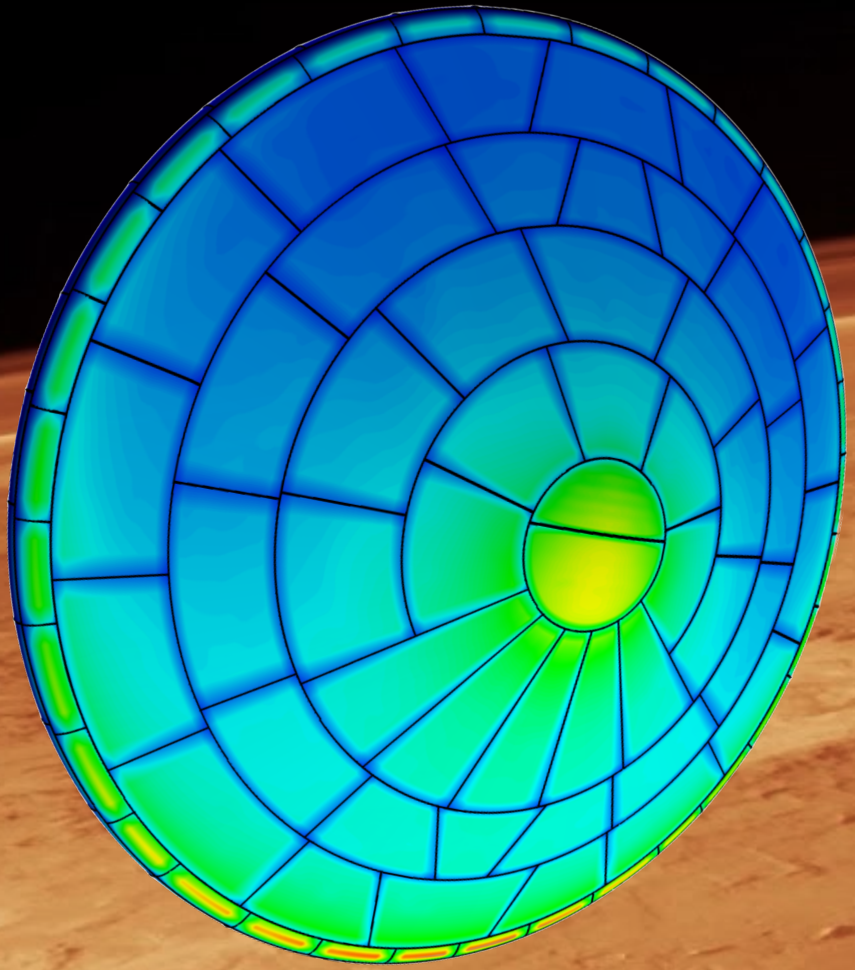

Questions ?

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