



Ablating woven thermal protection system materials under high shear flow conditions

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Motivation



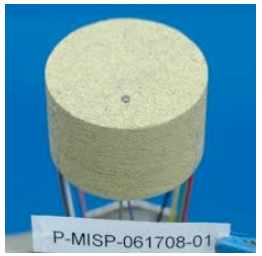


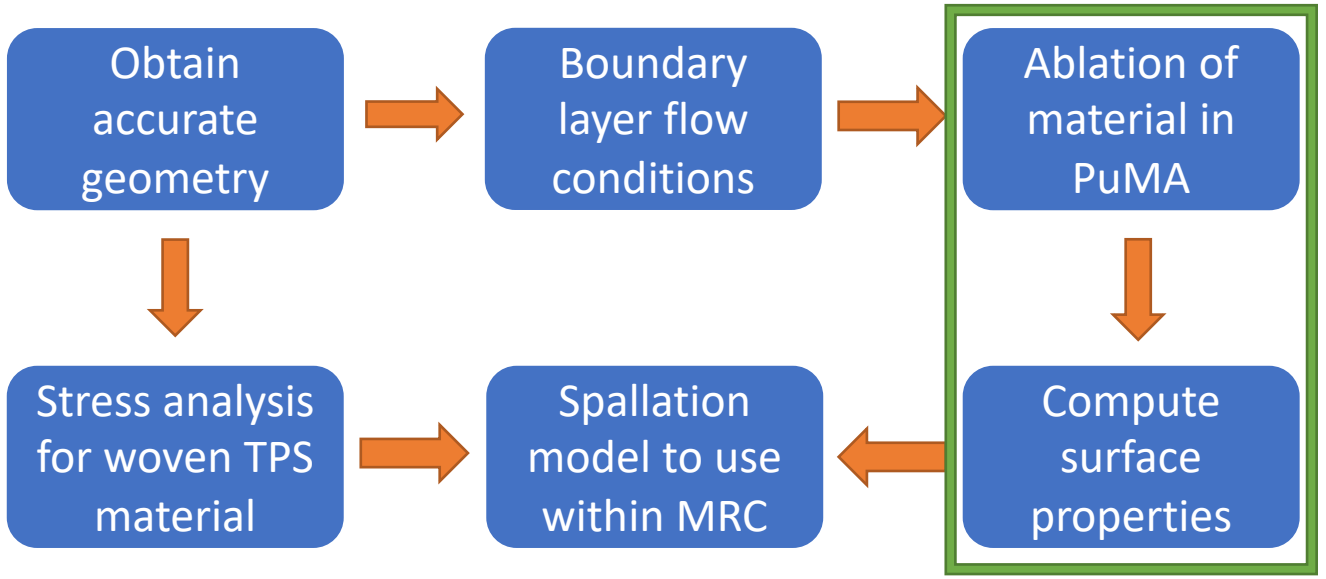


Image credit: NASA

Ablative TPS material considerations: recession, oxidation, pyrolysis



Overall Objective: Characterize and develop a spallation model for woven TPS material.

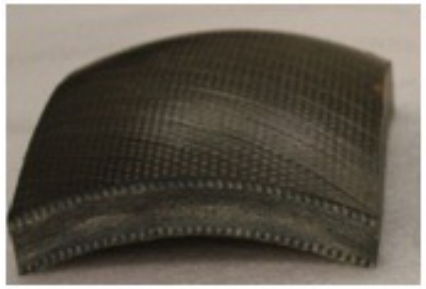


Current work objective: Compute surface properties such as heat flux, shear stress, pressure for boundary layer flow over woven TPS material.

Woven TPS materials

Heat Shield for Extreme Entry Environment Technology (HEEET)

Carbon weave



Phenolic Resin





Woven TPS

Image credit: NASA

Woven TPS:

- Woven TPS (WTPS) uses mature weaving technologies to vary material composition and properties while controlling placement of fibers within woven structure.
- The resulting WTPS can be designed and tailored to perform optimally for a wide range of entry environments without substantially changing the manufacturing process.

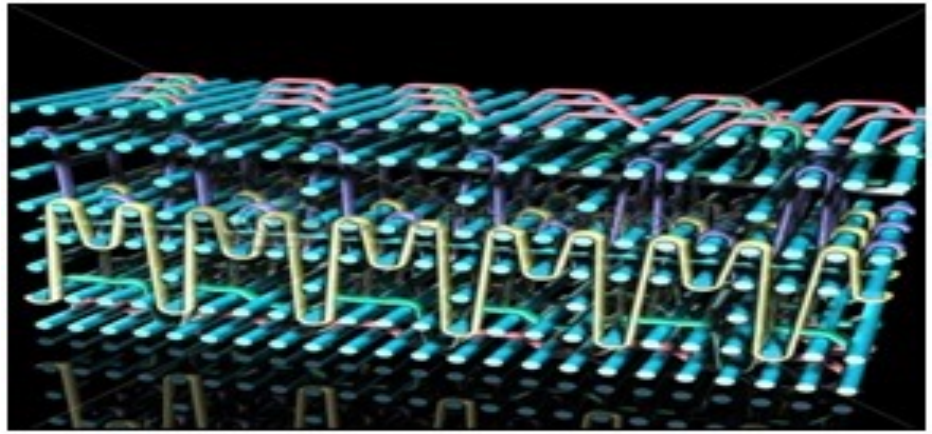
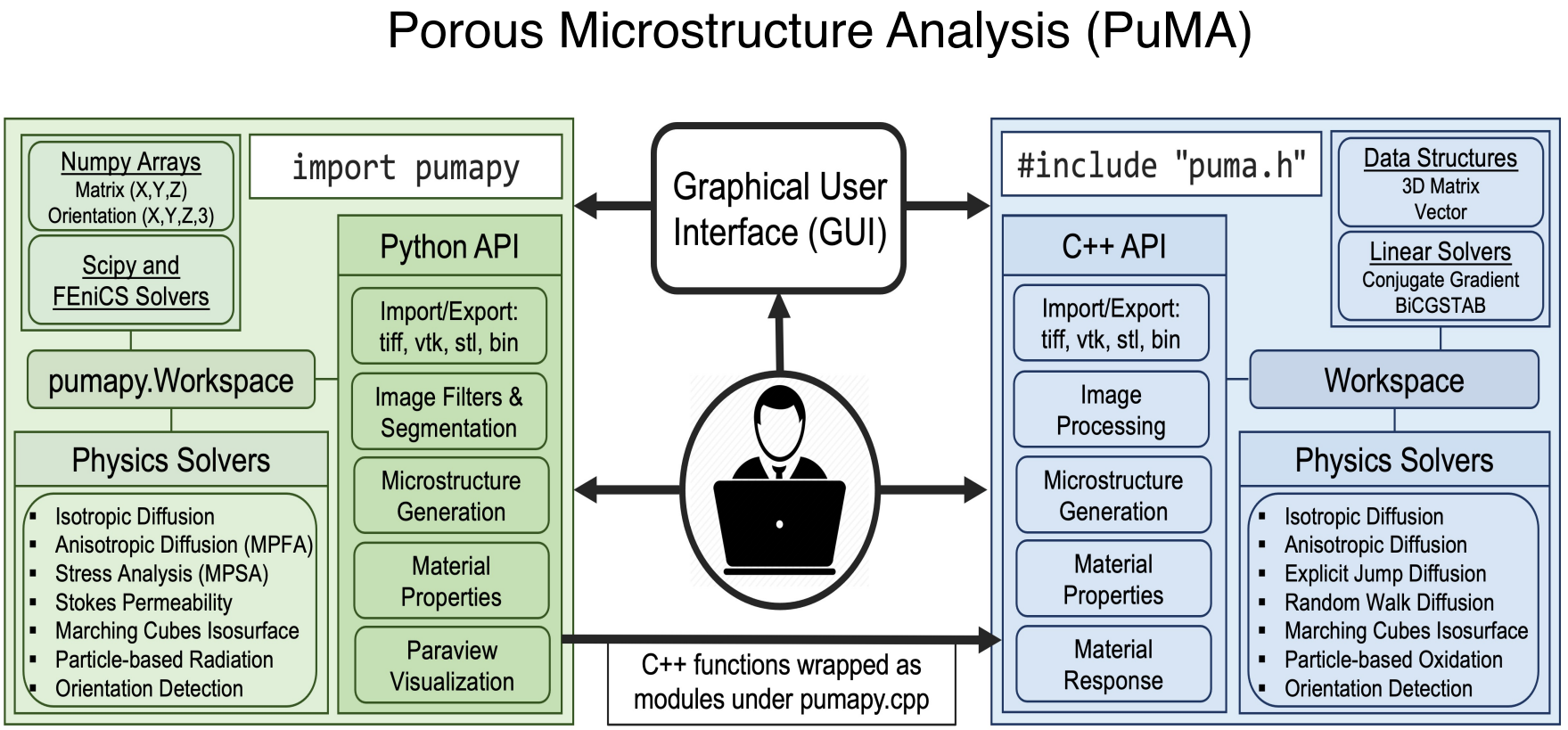
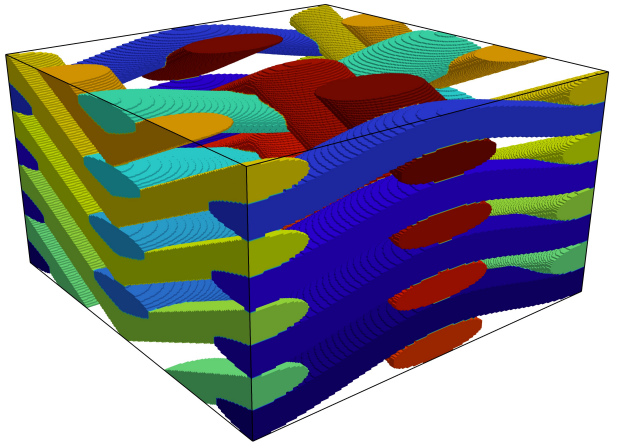
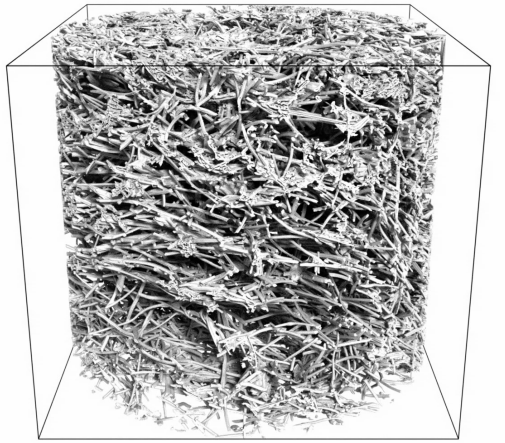


Image credit: NASA

Porous Microstructure Analysis (PuMA) [1]







[1] J. C. Ferguson, F. Panerai, A. Borner, N. N. Mansour, ***PuMA: the Porous Microstructure Analysis software***, SoftwareX 7 (2018) 81–87.

DSMC – SPARTA [2]

Continuum breakdown

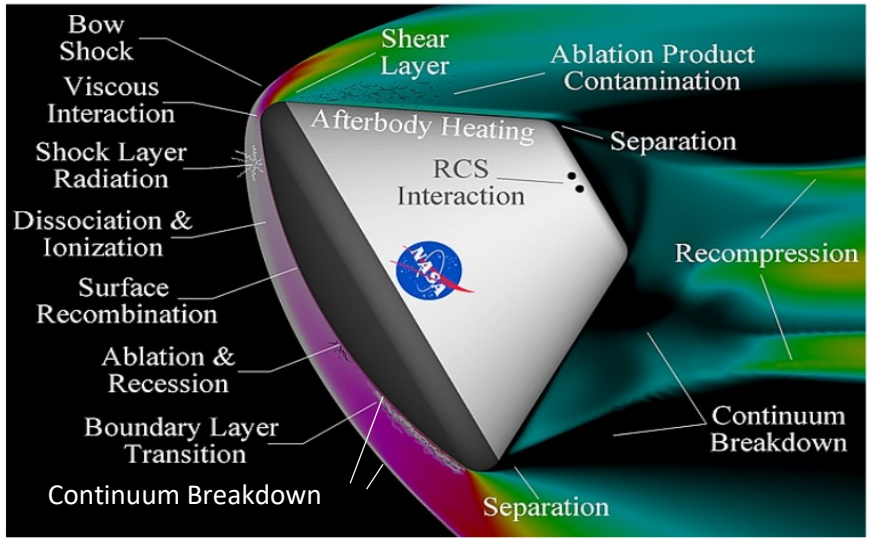


Image Credit: NASA

DSMC

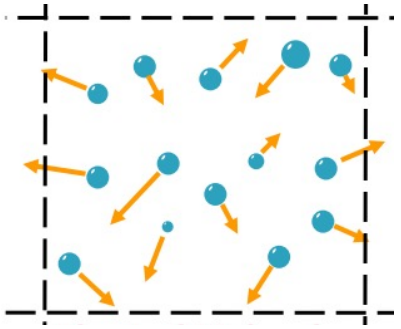
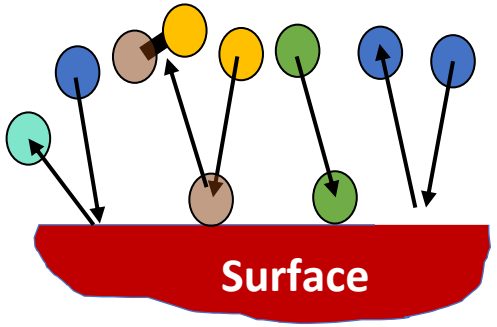


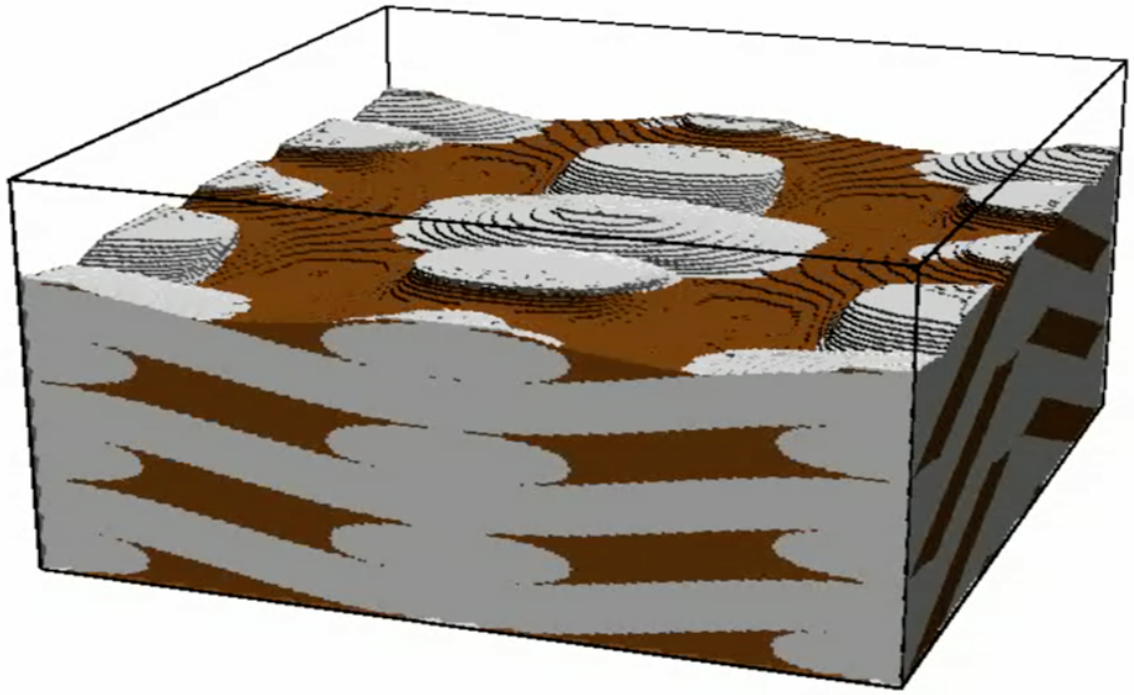
Image courtesy: https://prateekvjoshi.com/



[2] M. A. Gallis, J. R. Torczynski, S. J. Plimpton, D. J. Rader, T. Koehler, "Direct Simulation Monte Carlo: The Quest for Speed", 29th Intl Symposium on Rarefied Gas Dynamics in Xi'an, China, AIP Conf Proc, 1628, 27 (2014).

- CFD is not valid in regions of continuum breakdown.
- DSMC is a stochastic, particle-based method to solve the Boltzmann equation.
- DSMC is valid in all regimes: continuum, rarefied and transition (however computational cost increases with density).

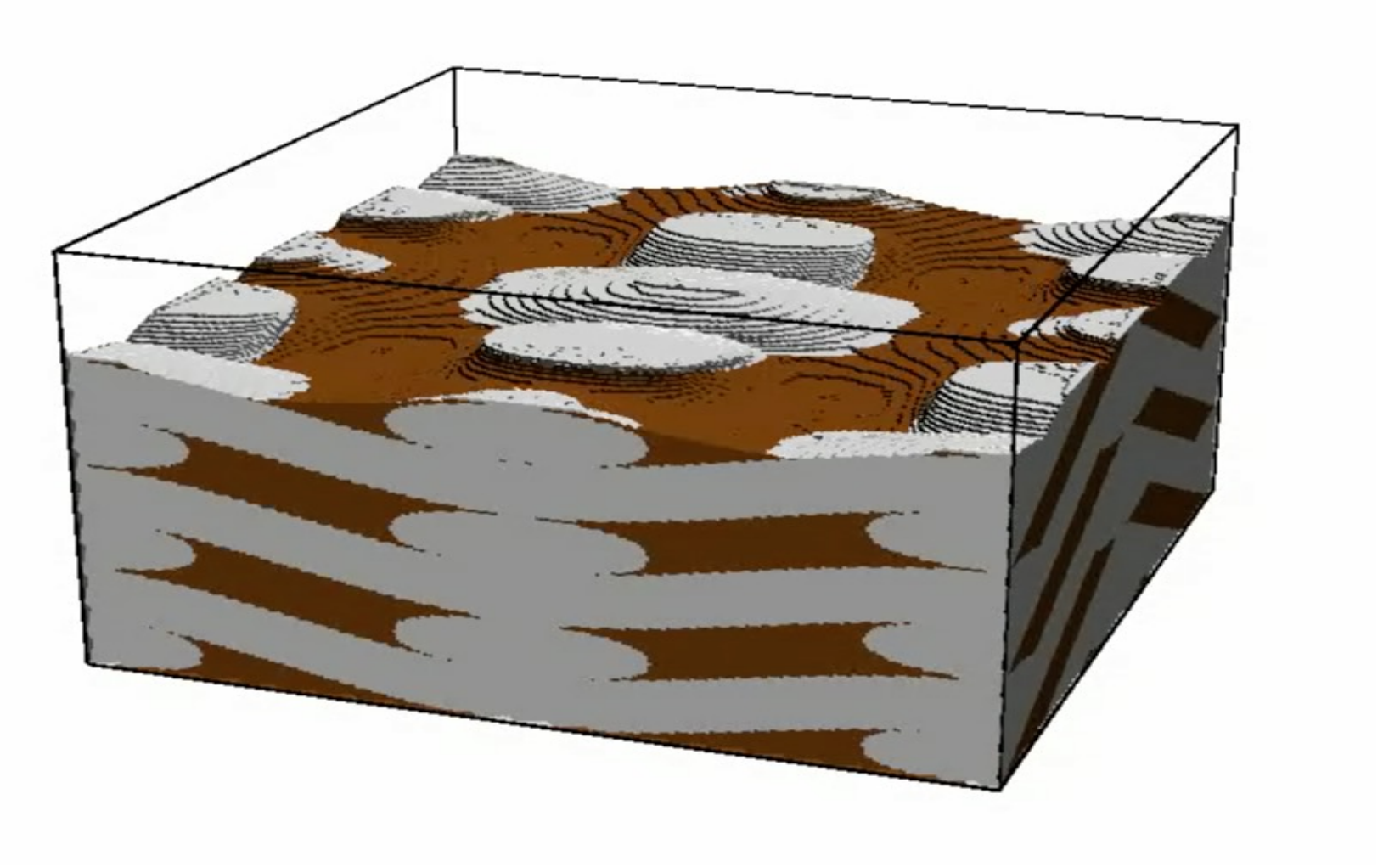
PuMA oxidation simulation



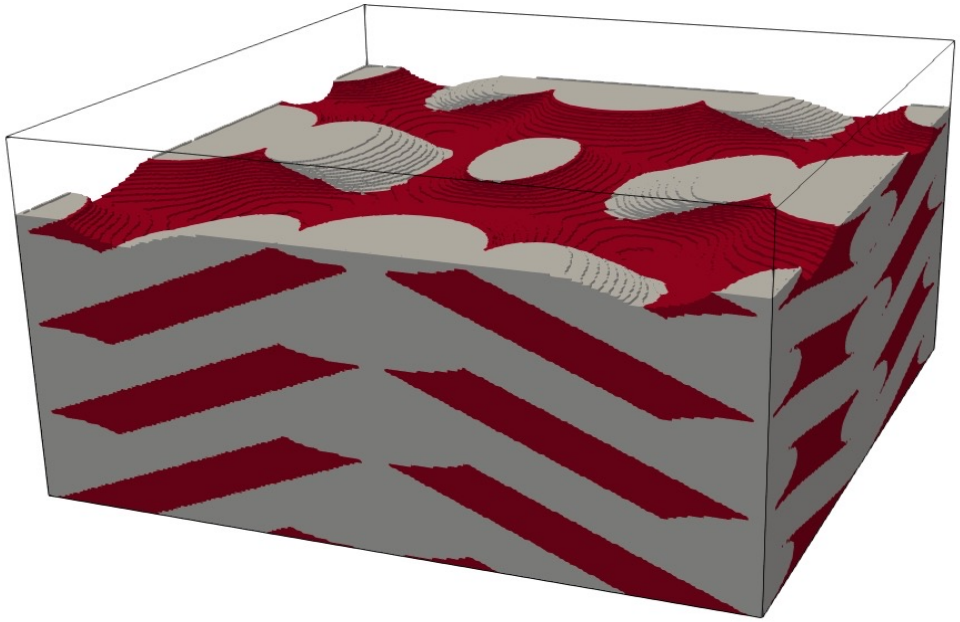
[3] Park, C. (1976). Effects of atomic oxygen on graphite ablation. *AIAA journal*, *14*(11), 1640-1642.

- We use a surrogate geometry similar to the MSR-EEV weave architecture
- Earth re-entry velocity = 10.3 km/s
- T_{gas} = 4000 K, P = 75 kPa.
- Dissociated air (N_2, N, O) with 24% O
- Only O is reactive – sublimation is neglected
- Oxidation rate from Park [3]
  k = 0.63 exp(-1160/T)
- Resin (brown) is assumed to be 5 times more reactive and 10 times less dense than fibers (grey)

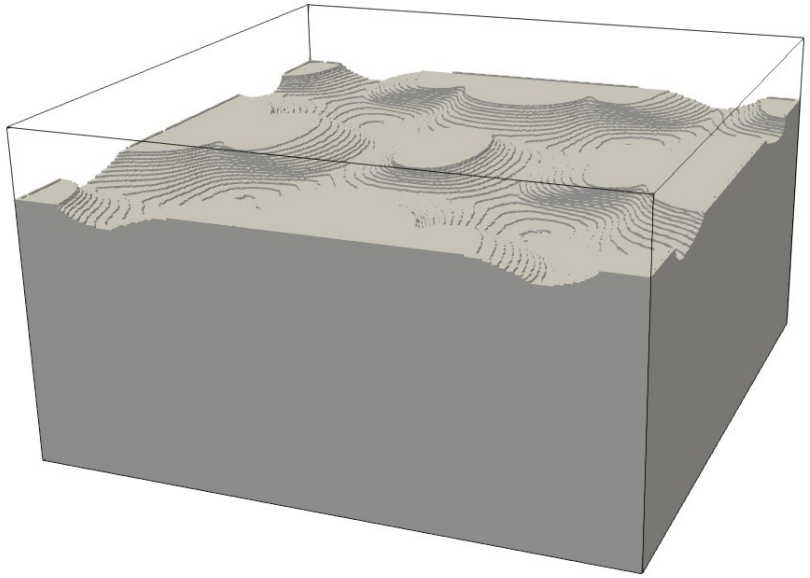
PuMA oxidation simulation



Resin vs No resin



Geometry from PuMA simulation

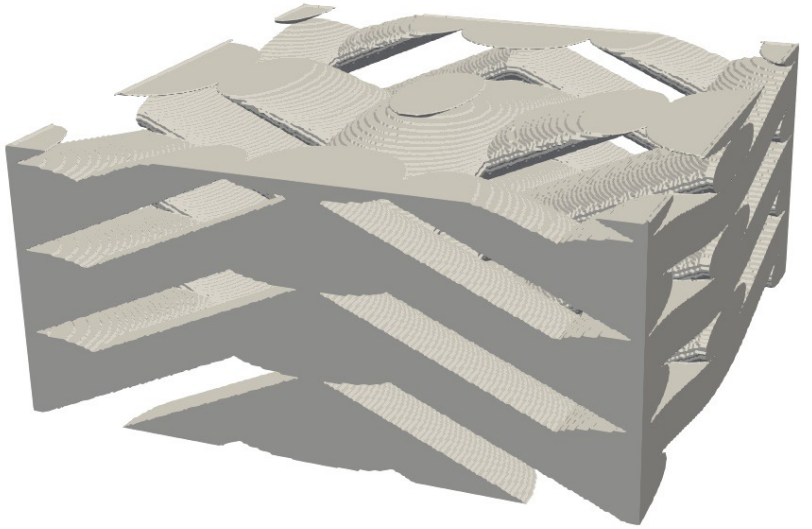


With Resin

- Resin is treated same as the carbon weaves.
- Diffusion limited regime

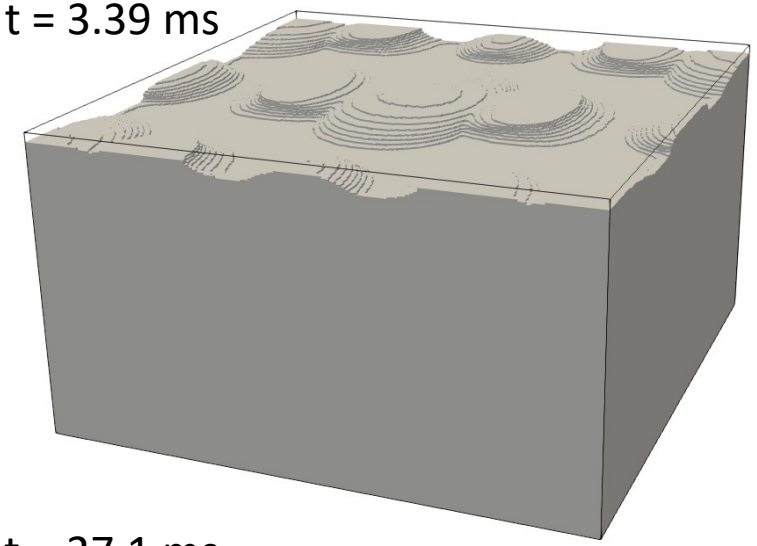
Without Resin

- Resin is completely removed from the top layers
- Reaction limited regime

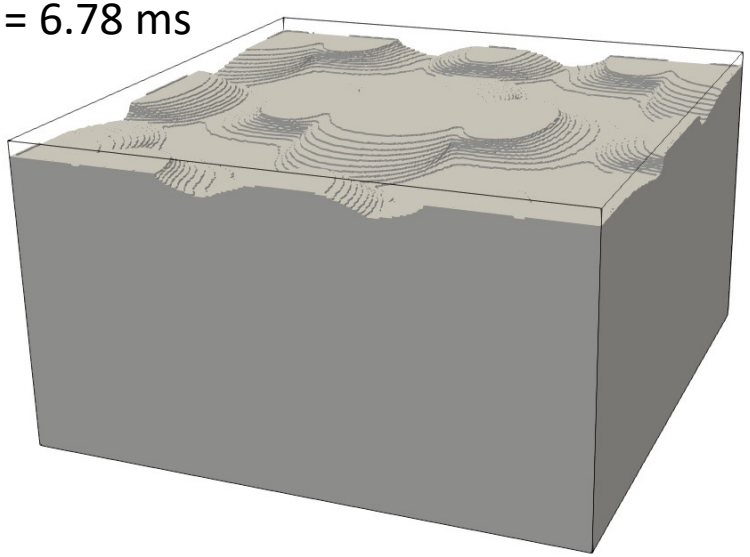


With Resin

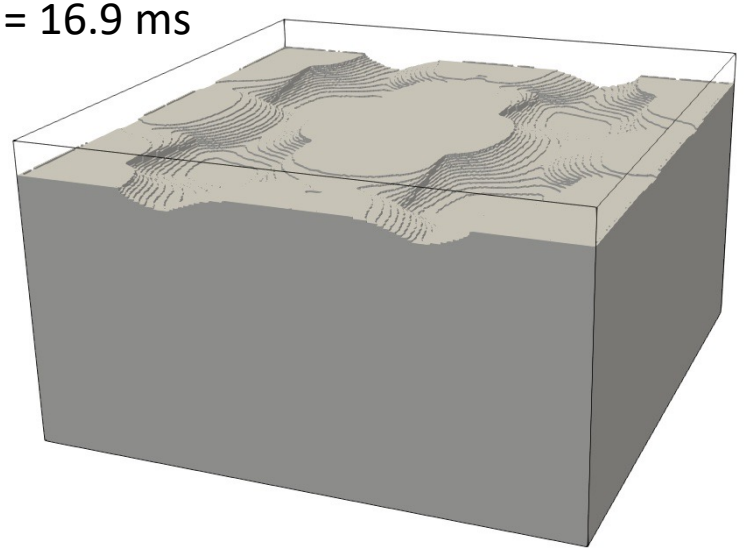
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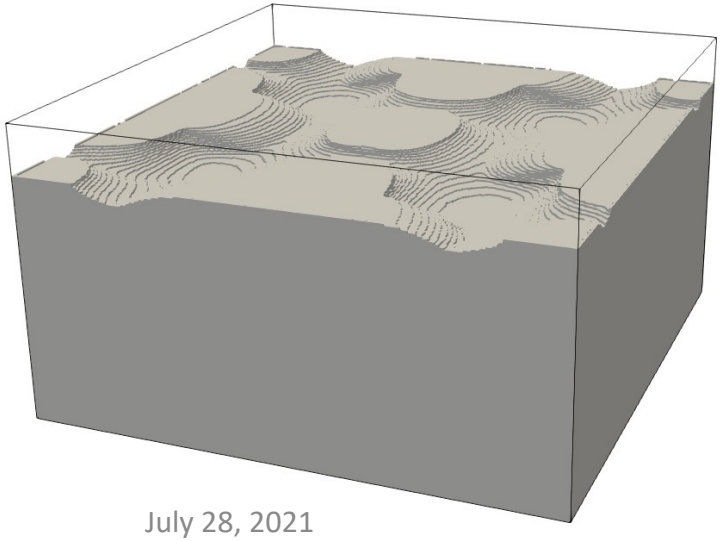
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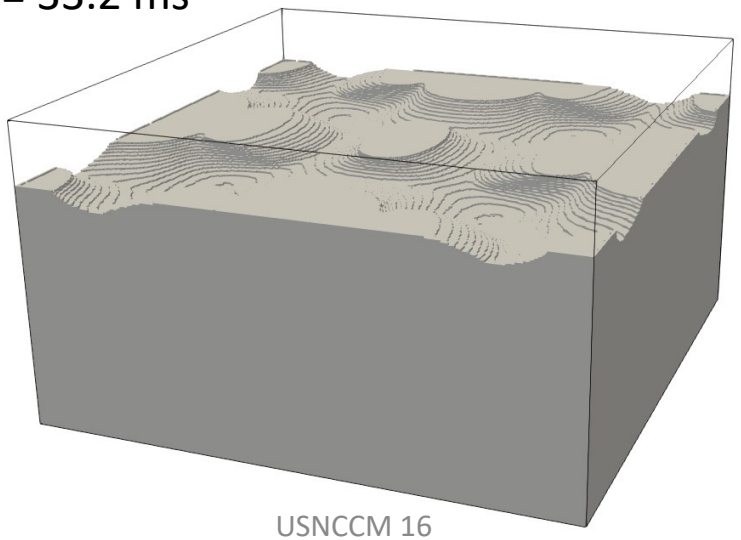
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t = 27.1 ms



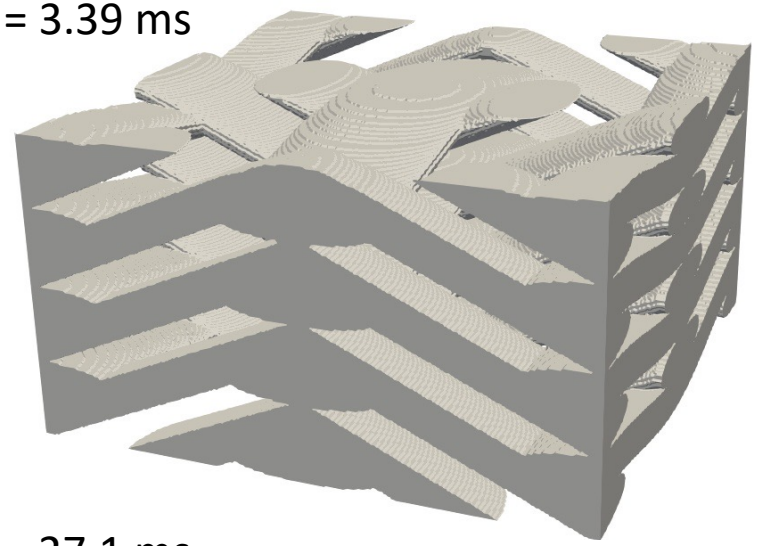
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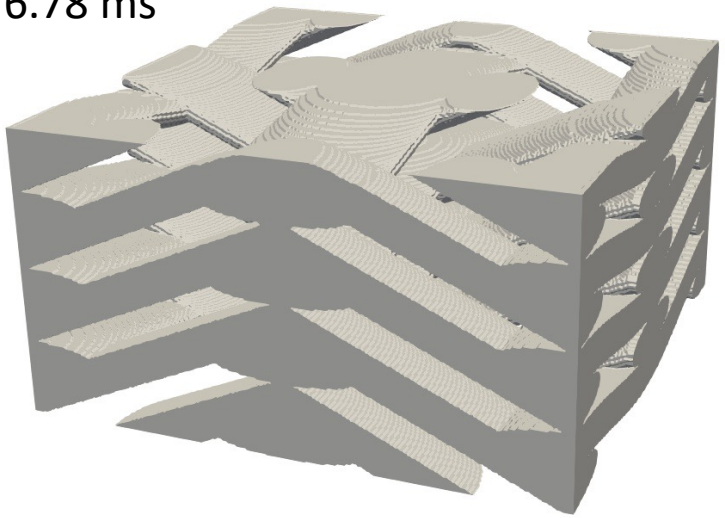
Woven TPS geometries with resin at various stages of oxidation

Without Resin

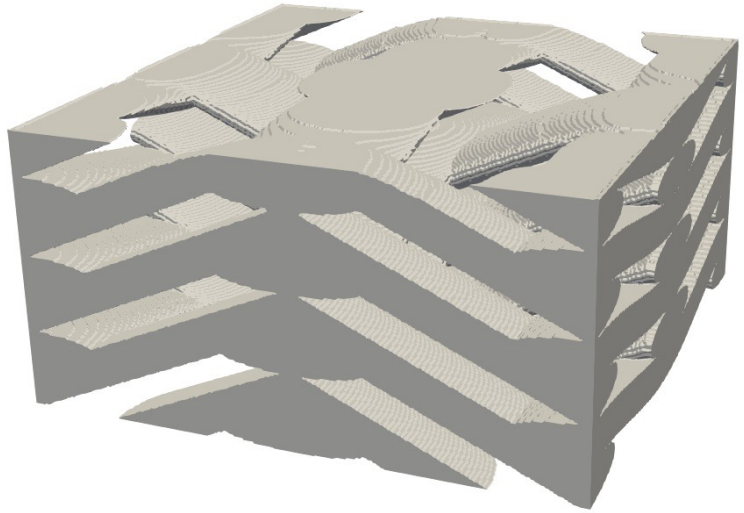
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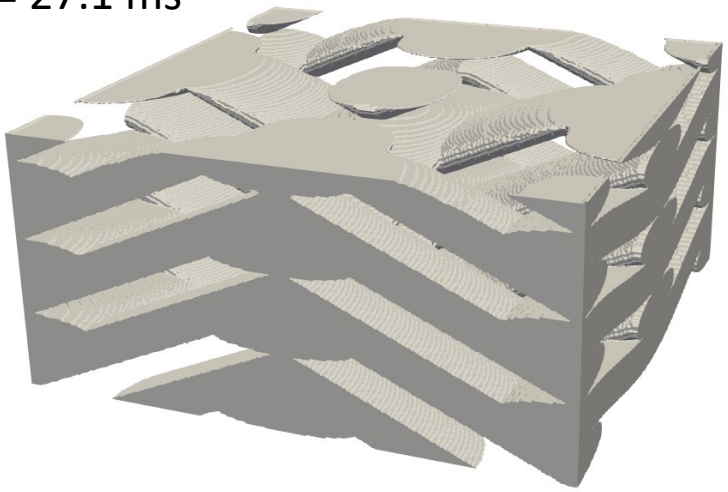
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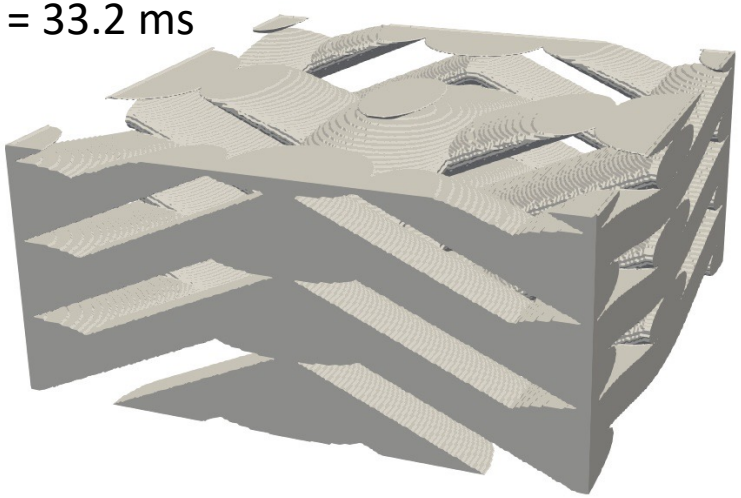
t = 16.9 ms



t = 27.1 ms

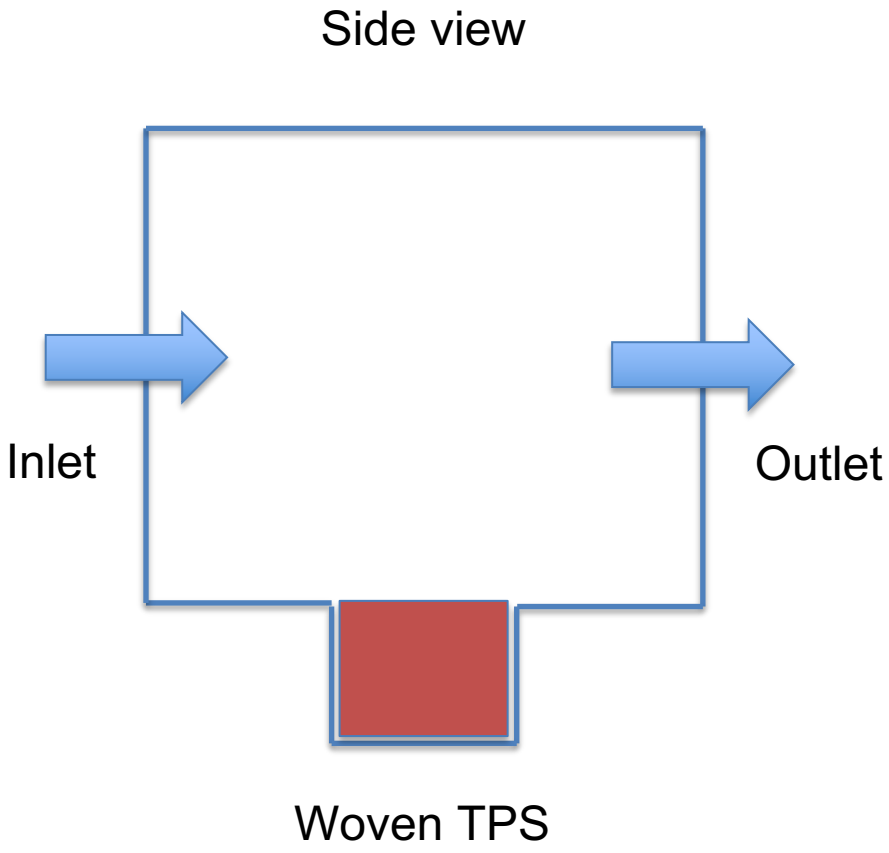


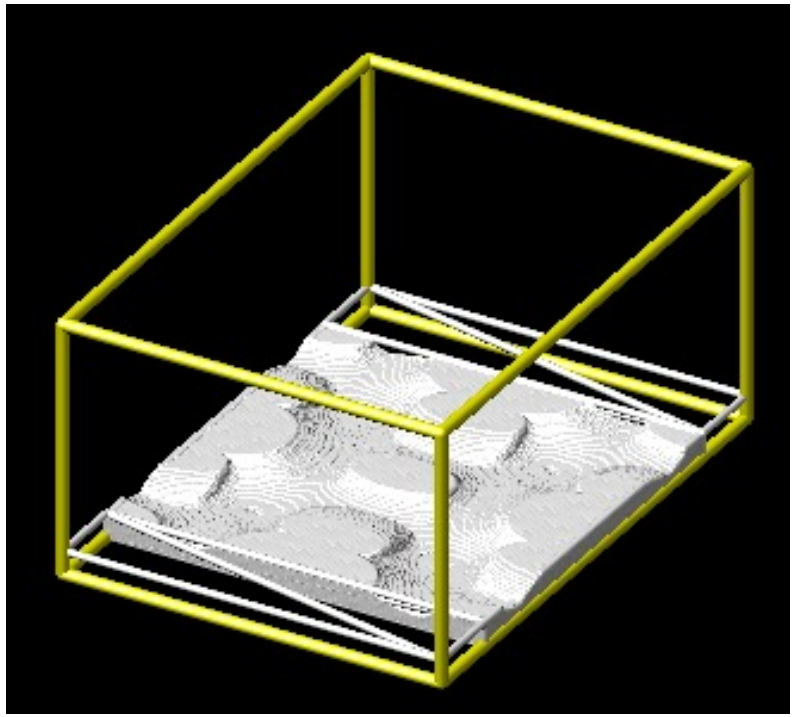
t = 33.2 ms



Woven TPS geometries without resin at various stages of oxidation

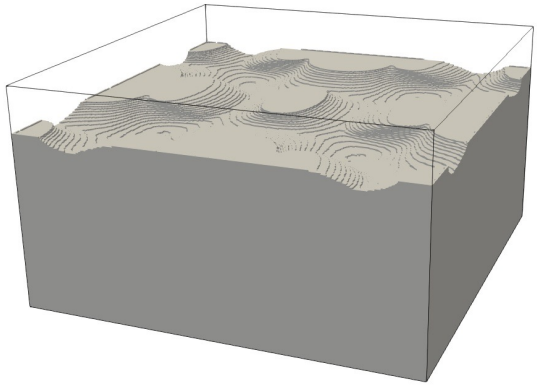
SPARTA DSMC simulation domain



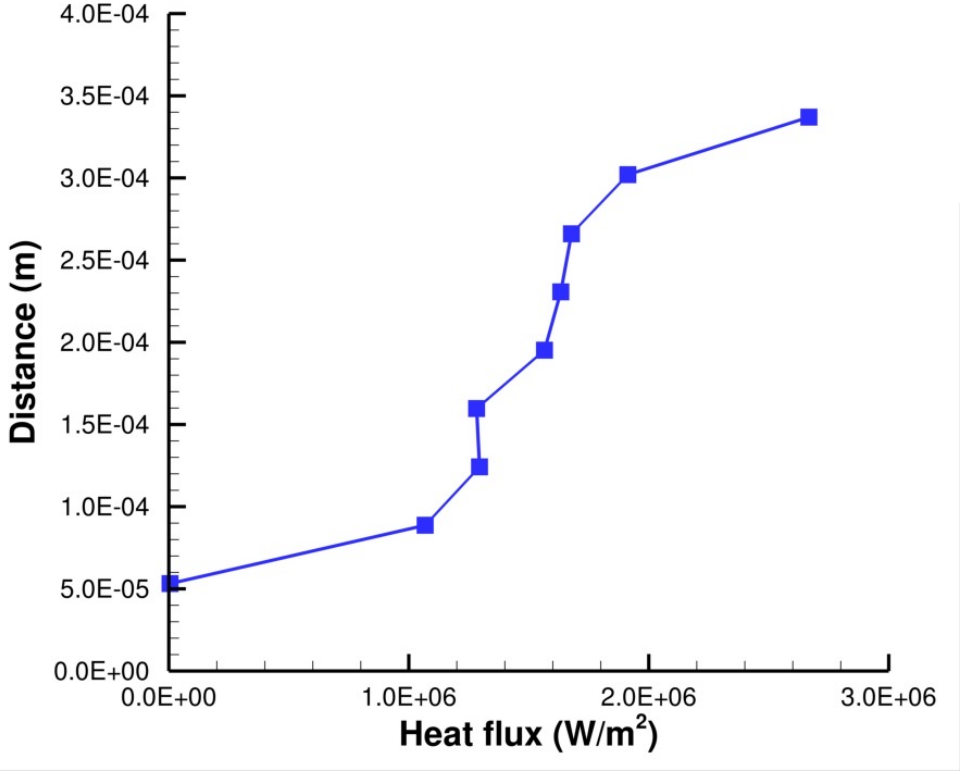


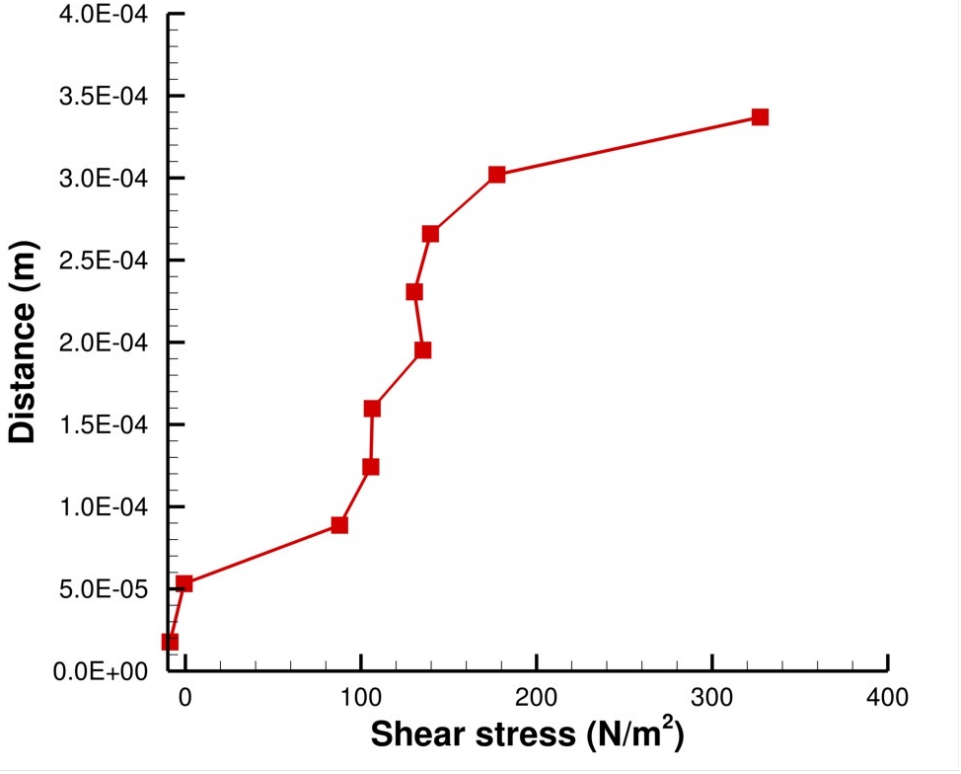
- Fully dissociated gas - O(21%), N(79%)
- T_{surf} = 3250 K
- Fully diffuse scattering
- ~ 13 million particles in the domain
- After steady state is reached, the final data is averaged over 100,000 timesteps

With Resin
t=33.2 ms geometry



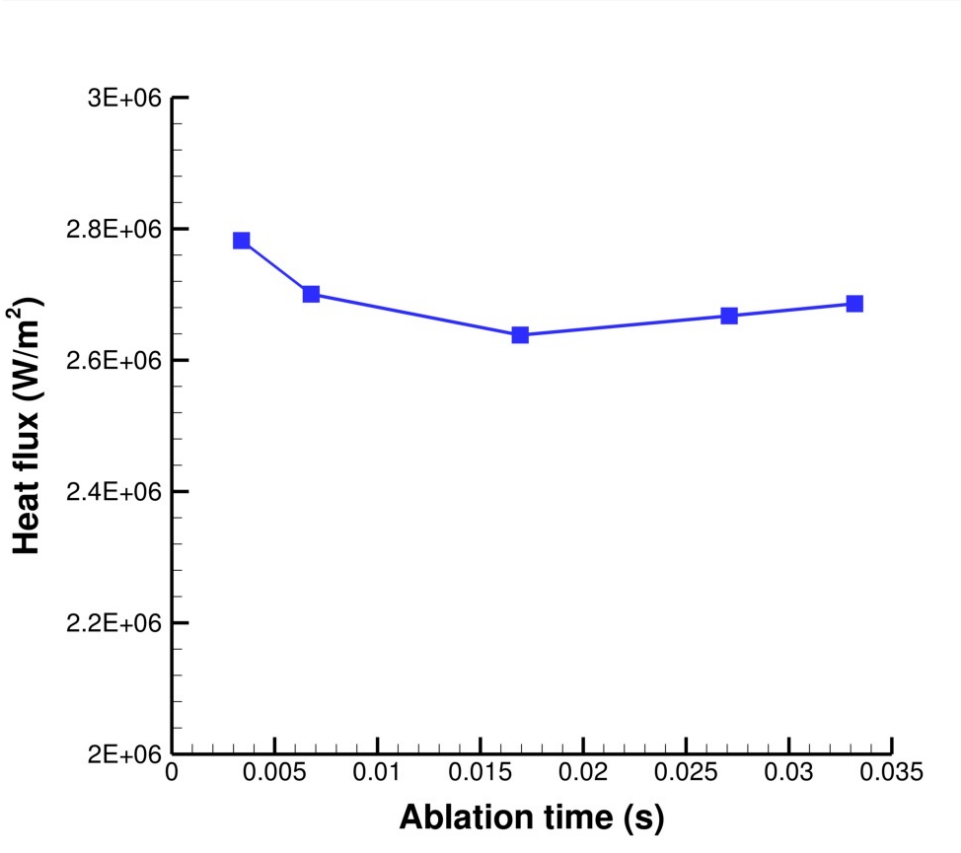
t = 33.2 ms



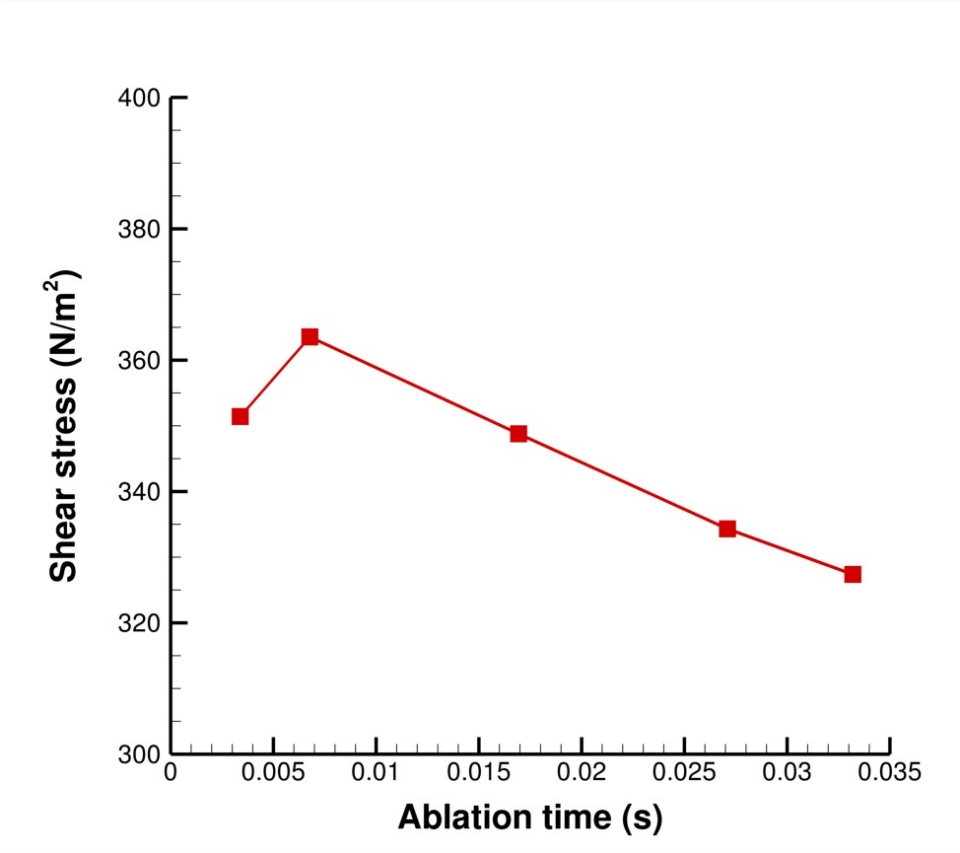


With Resin
Variation with different geometries

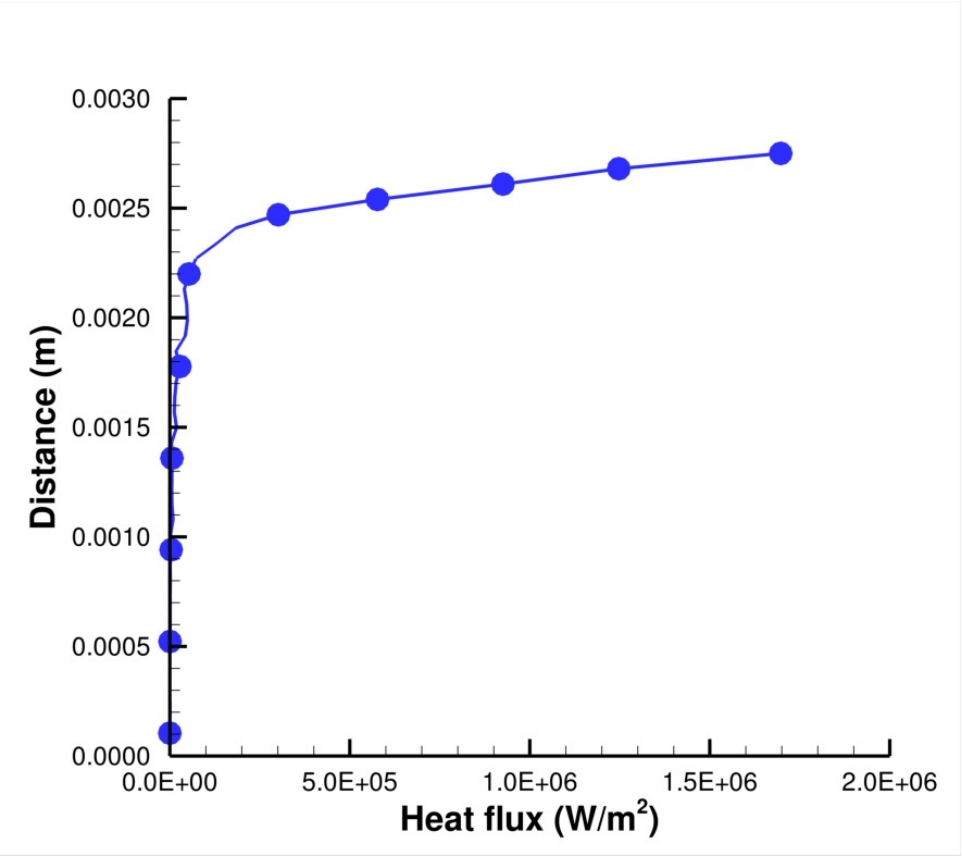
Maximum heat flux from all geometries

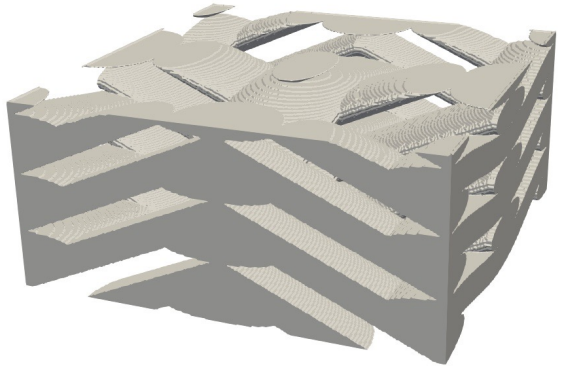


Maximum shear stress from all geometries

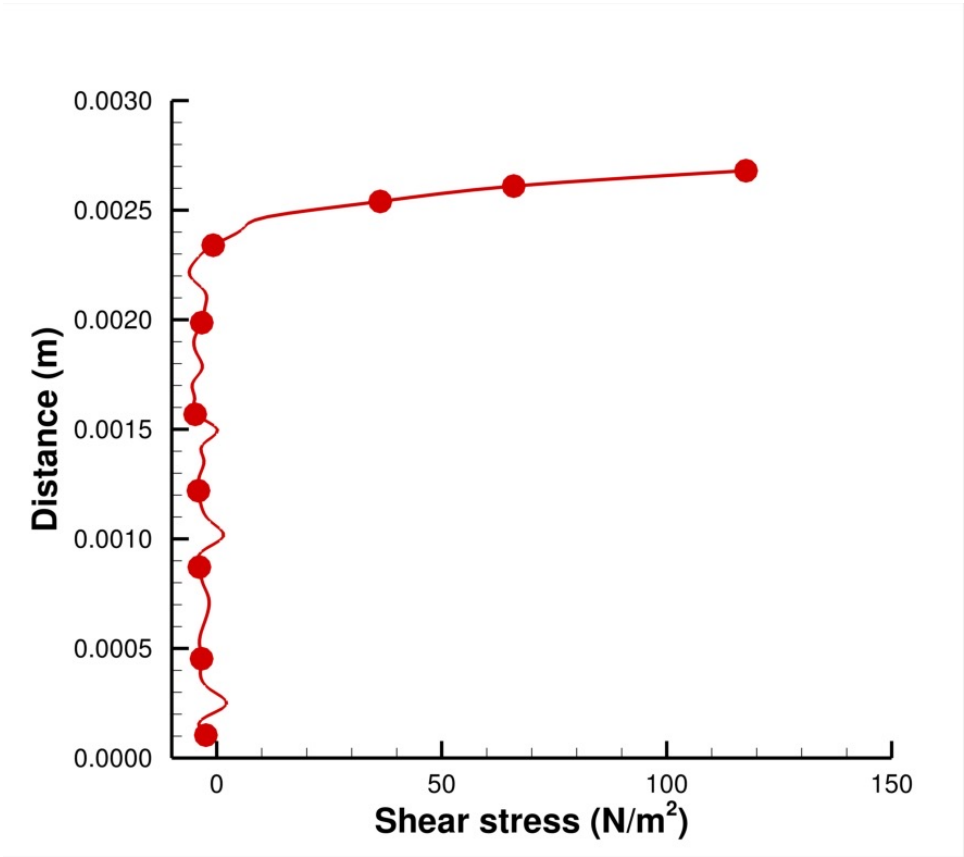


Without Resin
t=33.2 ms geometry



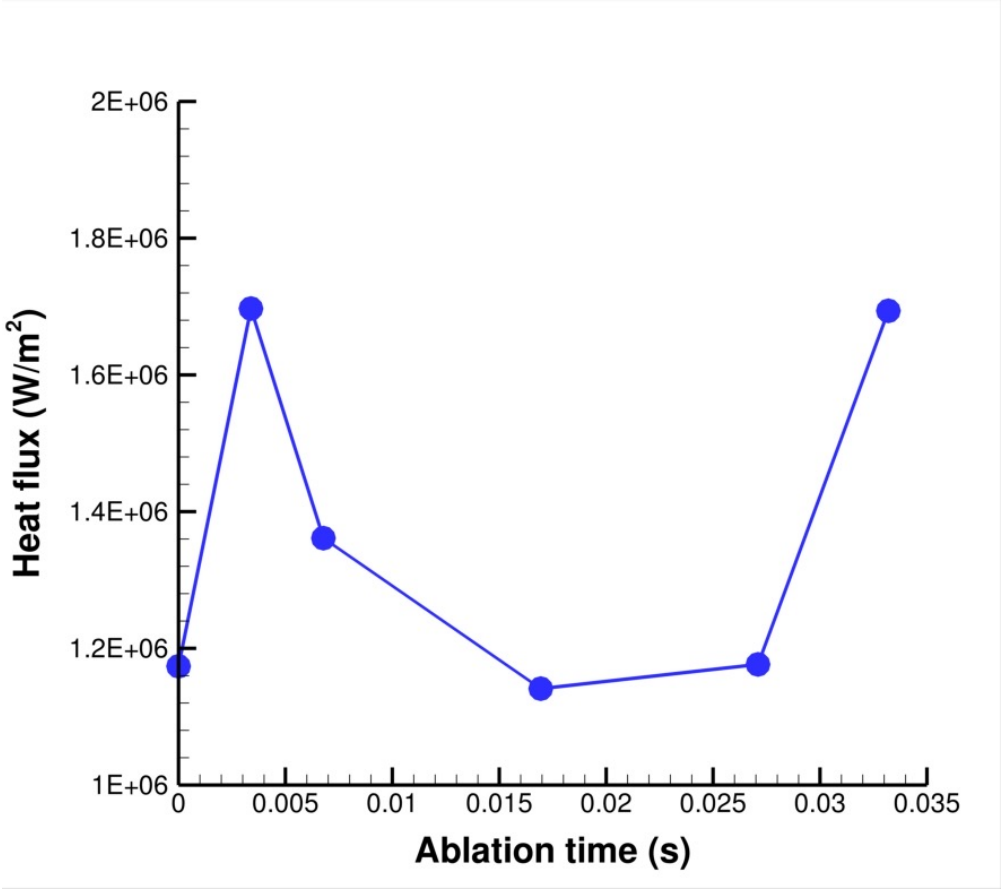


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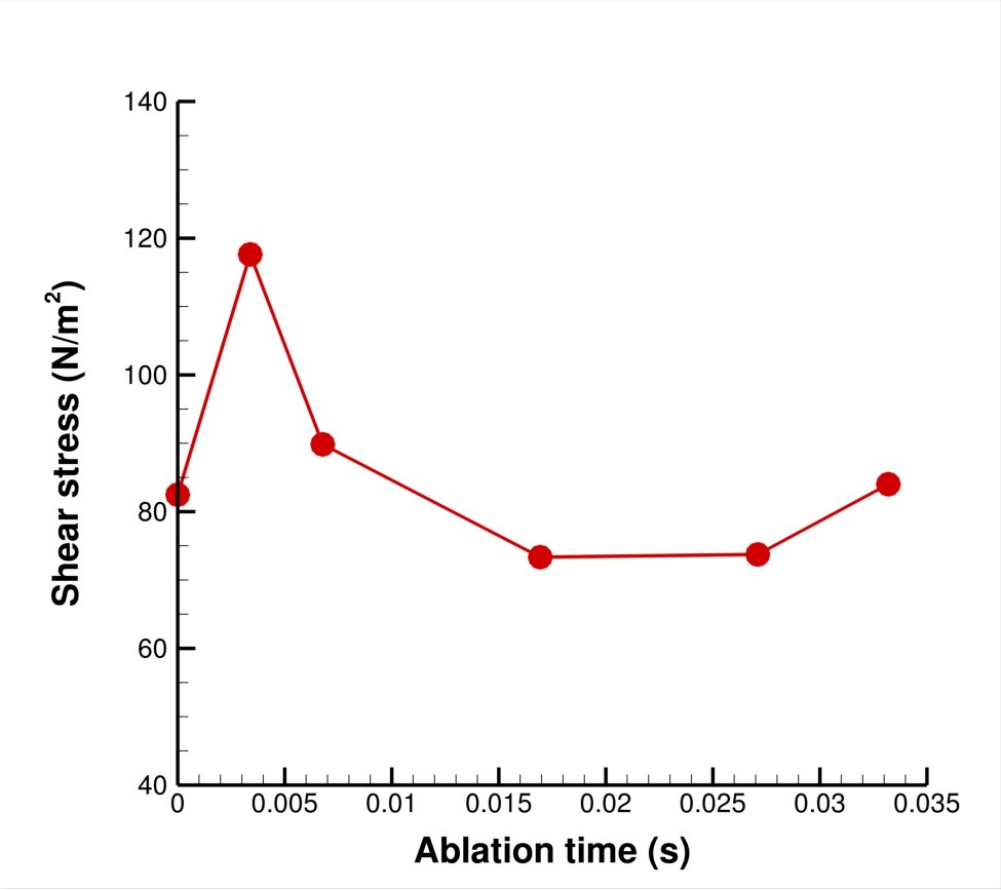


Without Resin
Variation with different geometries

Maximum heat flux from all geometries



Maximum shear stress from all geometries

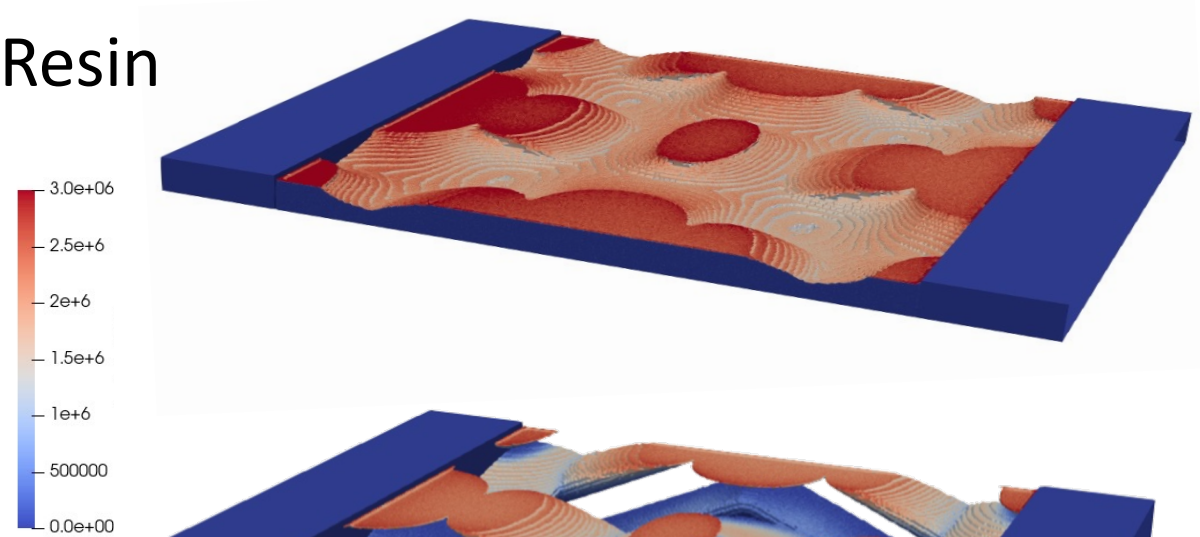


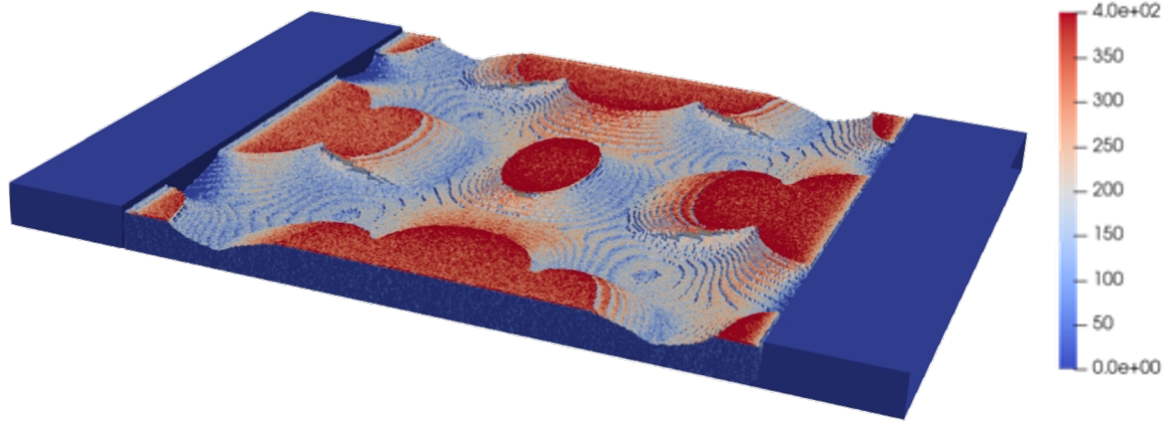
Comparison of with and without resin

Heat flux (W/m^2)

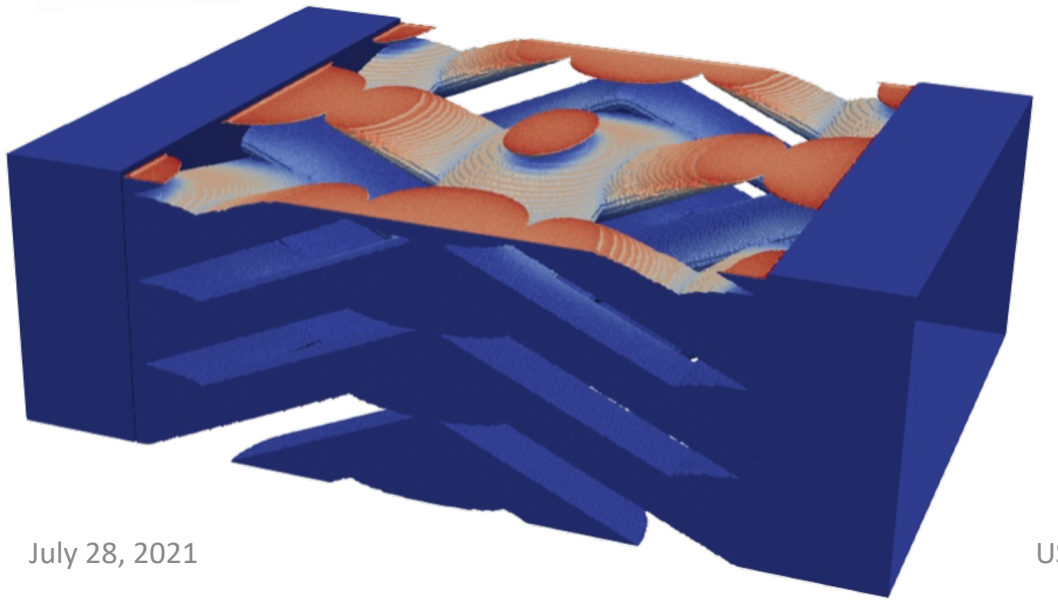
Shear stress (N/m^2)

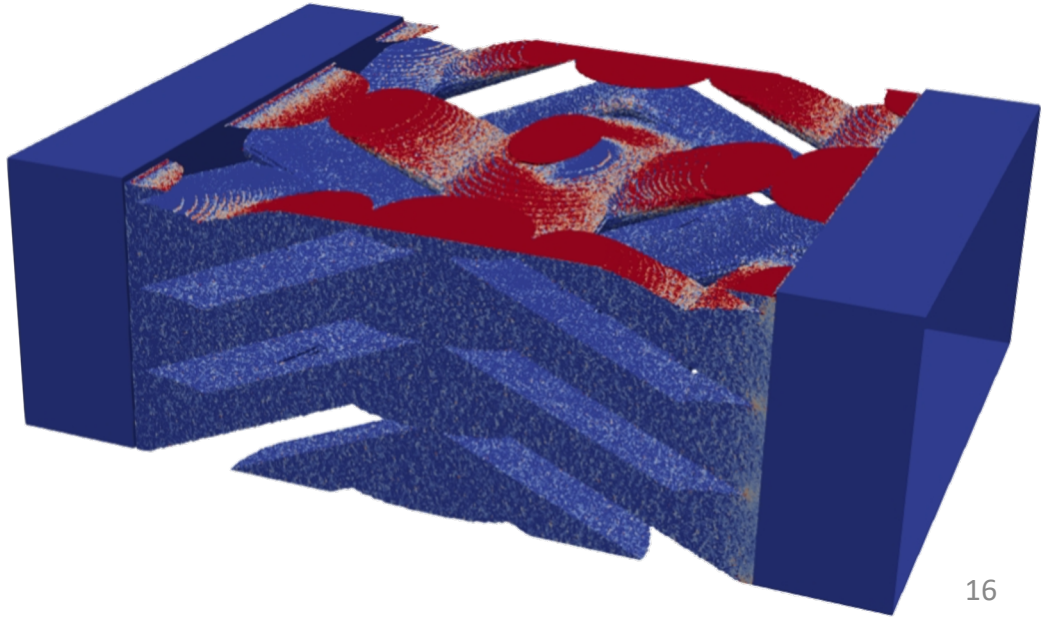
Resin





No Resin





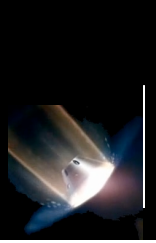
Summary and Future Work

Summary

- Oxidation simulations of woven TPS material were performed in PuMA.
- Boundary layer flow simulations were carried out in SPARTA for geometries at various stages of chemical degradation.
- Woven TPS geometries with and without the resin were considered. The case with resin had greater heat flux (1.5x) and shear stress (4x) compared to the case without resin and therefore more susceptible to mass loss due to spallation.
- Various surface properties such as heat flux and shear stress were computed and analyzed for all the geometries.

Future Work

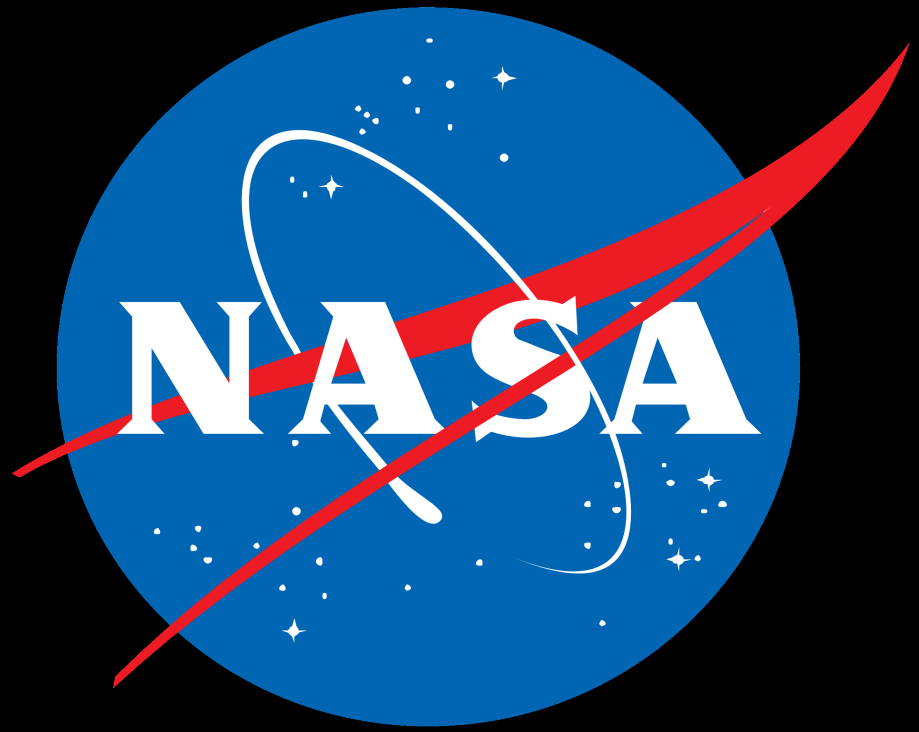
- Analyze and establish trends between the surface properties and geometric properties such as exposed surface area at top.
- Use this information to develop a Spallation model for woven TPS material.





Questions?

National Aeronautics and Space Administration



Ames Research Center
Entry Systems and Technology Division