Mesoscopic Modeling of Thermal Protection Systems Using the Lattice Boltzmann Method

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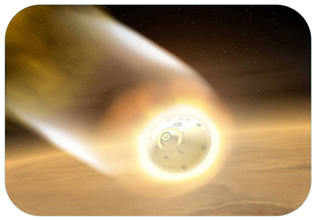
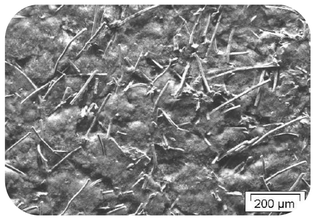
Atmospheric reentry



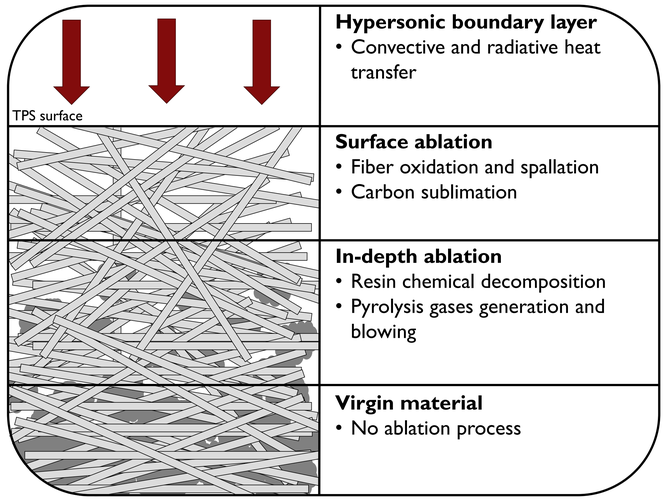
Atmospheric reentry stage [1]

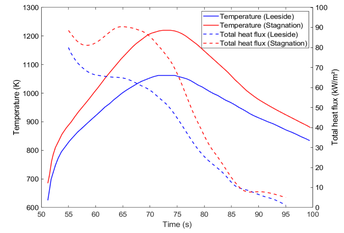


Microscopic view of a virgin TPS [2]

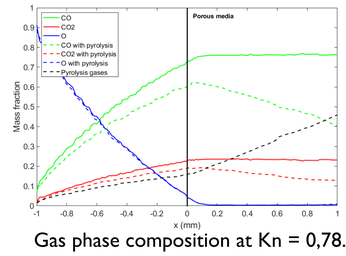
- **Significant heat** is generated at the surface through **atmosphere friction** at reentry stage.
- Without proper thermal protection, the spacecraft can be **severely damaged**.
- **Thermal protection systems (TPS)** are composed of carbon fibers impregnated with a resin matrix, giving them **porous properties**.
- **Heat dissipation** through TPS occurs through different physicochemical processes defined as **ablation**.

Ablation process





Temperature and heat flux profiles during MSL reentry. Adapted from [3].

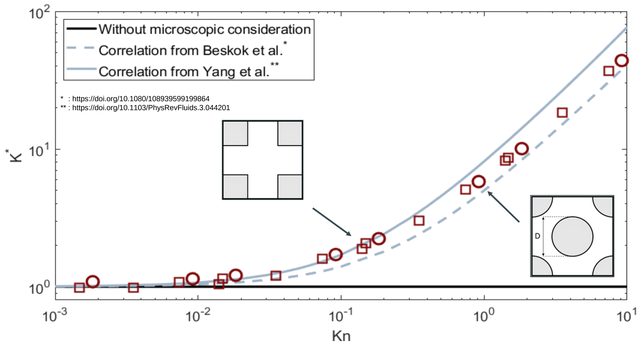


Gas phase composition at Kn = 0,78. Adapted from [4].

Objective

Develop a numerical **ablation model** at a **mesoscopic scale** to better **predict the macroscopic evolution** of TPS by simulating in-depth and pore scale flows through porous structures.

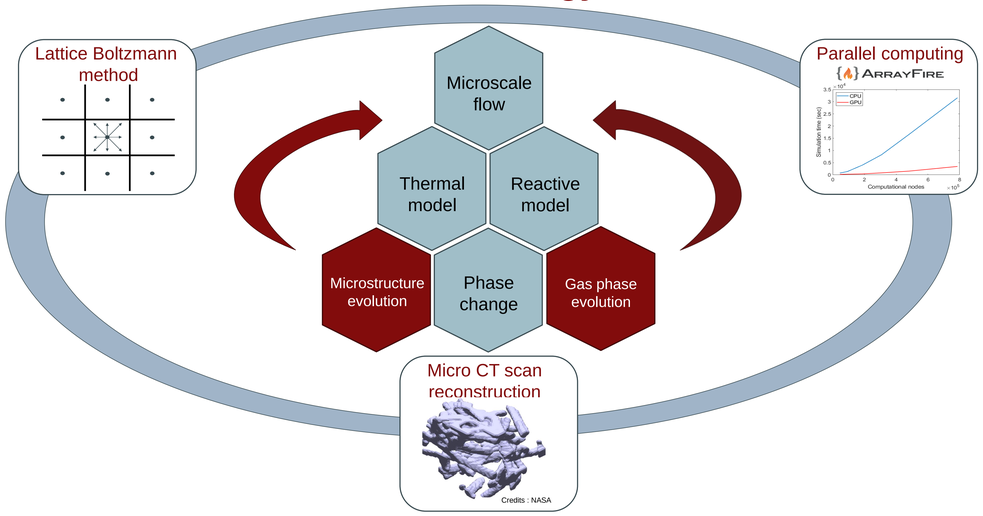
Preliminary results



Normalized permeability against rarefaction rate

- Non-continuum theory predicts **slippage effects** at fluid-solid interfaces at a **microscopic scale**.
- **Rarefaction influence** on **gas permeability** changes **local** ablation rate**.**

Methodology



Nomenclature

D : Diameter of the fiber
Kn : Knudsen number
K* : Normalized permeability

CPU : Central Processing Unit
GPU : Graphics Processing Unit

Acknowledgments

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Future work

- **Develop** and **validate** the thermal and reactive models separately
- **Couple** thermal and reactive model to **predict phase change rates** under re-entry conditions
- **Add microscale flow model** to permeability and gas phase composition calculations
- **Integrate** the mesoscopic model to current models for **multiscale simulations**

References

[1] : Retrieved from *http://mars.nasa.gov/mer/gallery/artwork/hires/entry.jpg*, 2004.
[2] : Lawson et al. (2010). Examination of Scanning Electron Microscope and Computed Tomography Images of PICA.
[3] : Meurisse et al. (2018). Multidimensional material response simulations of a full-scale tiled ablative heatshield. *Aerospace Science and Technology*, 76, 497-511.
[4] : Poovathingal et al. (2018). Nonequilibrium flow through porous thermal protection materials, Part II: Oxidation and pyrolysis. *Journal of Computational Physics*.