Entry Systems and Technology Division
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# Dust Particle Aeroheating Calculations for Mars Entry Hypersonic Flows

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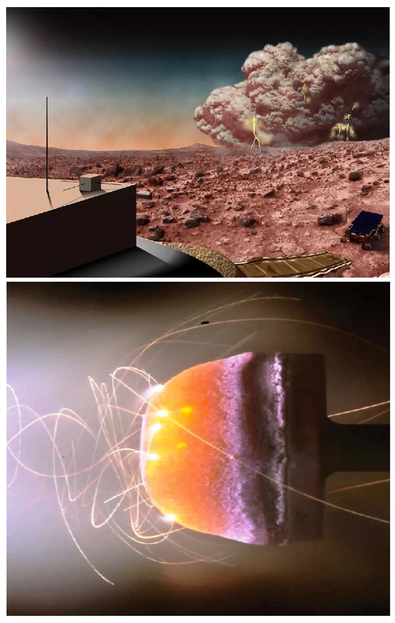
## Introduction

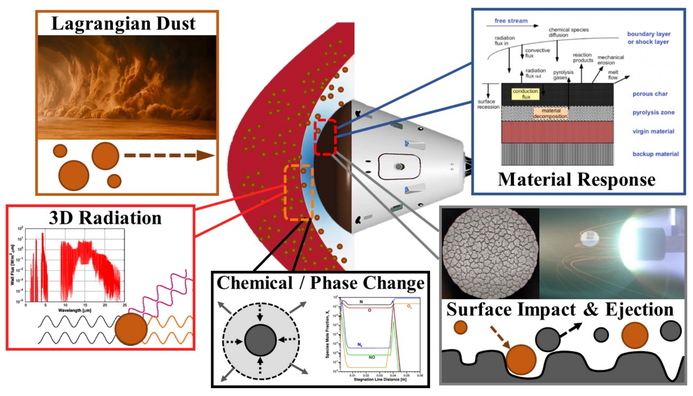
- Spacecrafts may encounter regional / global dust storms during Martian planetary entry.
- Accounting for increased degradation due to dust particle impacts imperative for safe TPS designs.
- Modeling approaches with differing levels of fidelity possible:
  - 1-way (Fluid affects particles)
  - 2-way (Fluid/particles affect each other)
  - 4-way (2-way + particle-particle interaction)



Source: NASA

## Objective

**"Simulate dust particle dynamics and increased heat transfer to spacecraft during hypersonic entry with physical models of varying fidelity."**




**"Development pathway targets interfacing with existing NASA software to realize truly multi-physics simulations."**

## DUst Simulation & Tracking (DUST) Solver

**DUst Simulation & Tracking (DUST) is a new unstructured Lagrangian particle solver that works in conjunction with the US3D CFD flow solver to model particle-flow and particle-particle interactions.**

### Assumptions

- Lagrangian point-particle method.
- Particles are smooth non-rotating spheres + uniform properties.
- Exchange momentum/energy with fluid.
- Particle collisions based on hard sphere model.

### Governing Equations / Model Details

- System of 8 ODE's solved for each particle:
  - Position
  - Velocity
  - Temperature
  - Diameter
- Henderson drag model; Fox Nusselt number correlation.
- Particle sublimates after reaching vaporization temperature.

### Key Features Ensuring Numerical Efficiency

- Low-cost mesh localization for mapping between Eulerian and Lagrangian frames.
- Particle collisions evaluated using time-driven hard sphere model.
- Coarse-graining using computational parcels.
- Adams-Bashforth time stepping and point-to-point MPI exchanges.

**Acknowledgements**

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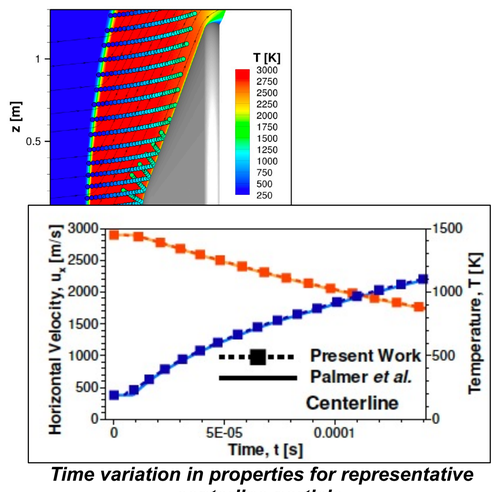
## Results: Verification and Validation

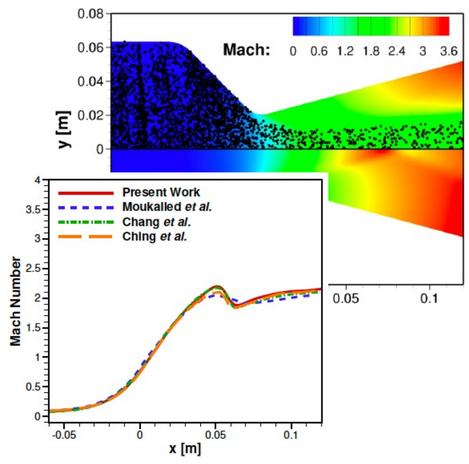
**Rigorous V&V testing covering 1-, 2-, 4-way coupling**

*1-Way: Schiaparelli*

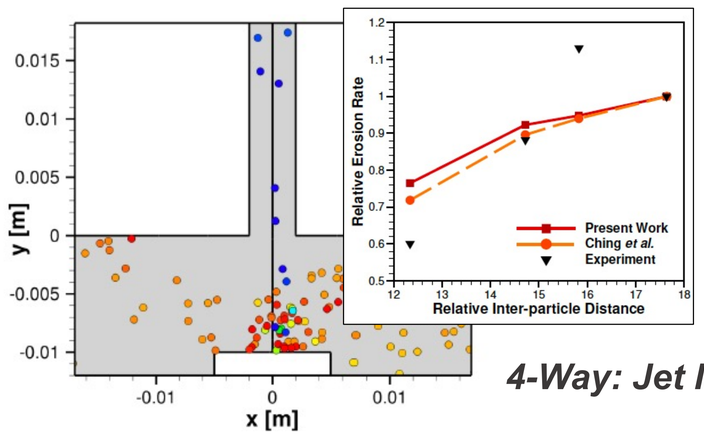



*Time variation in properties for representative centerline particle.*

*2-Way: Caltech Nozzle*




*Mach number along nozzle centerline for dust-laden flow*

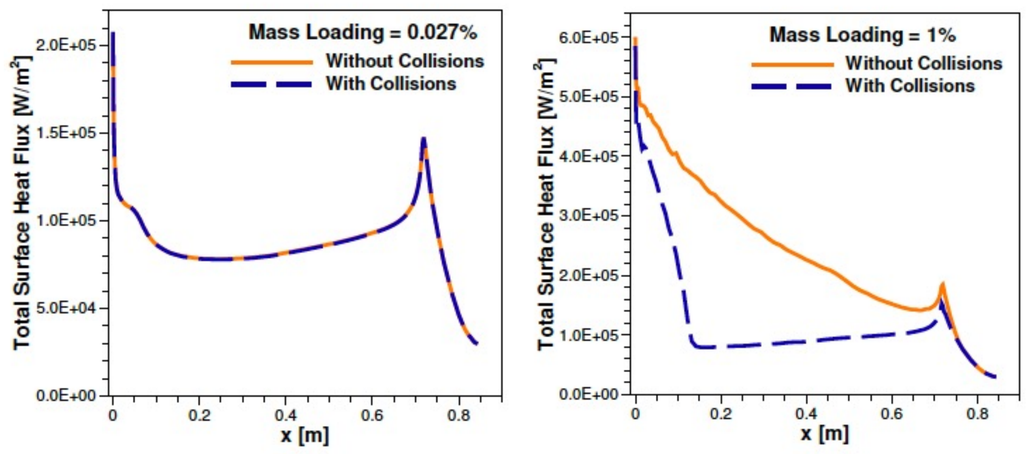



*Change in surface erosion rate with decreasing particle loading (increasing inter-particle distance)*

*4-Way: Jet Impingement*

## Results: Mars 2020

- Freestream conditions correspond to trajectory point of peak dynamic pressure. Particles with D = 4.4 $\mu m$ (effective particle diameter from Mars atmospheric data) continuously injected till steady state achieved.
- Two mass loadings considered: a) *0.027% (July 2007 global dust storm)* b) *1%.* Low enough that 2-way coupling between fluid and particle can be ignored.
- Impact of particle-particle collisions on surface heat flux becomes pronounced as particle concentration increases.




- Particles undergo inelastic collisions with the wall and accrue in the boundary layer.
- Fresh particles collide with previously impacted particles, shielding the spacecraft surface (lowered heat flux).

## Conclusions

- Developed framework for parallel, coupled Lagrangian particle calculations on unstructured meshes which has been subjected to rigorous V&V testing.
- Particle dynamics around the Mars 2020 spacecraft studied with and without particle-particle collisions.
- Particles accumulate in the boundary layer and shield spacecraft surface; lower heat flux compared to 1-way coupled predictions.

## Future Work

- Incorporate additional physical models and boundary conditions to tackle a wider variety of problems.
- Establish linkages with material response code (*Icharus*) and radiation solver (*NERO*).