Entry Systems and
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Dust Particle Aeroheating Calculations for Mars Entry Hypersonic Flows

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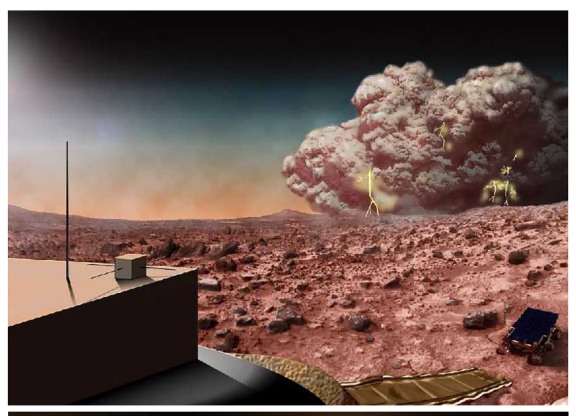
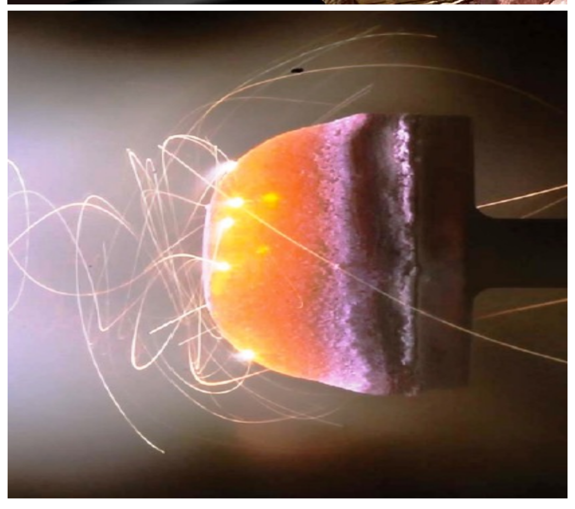
Introduction

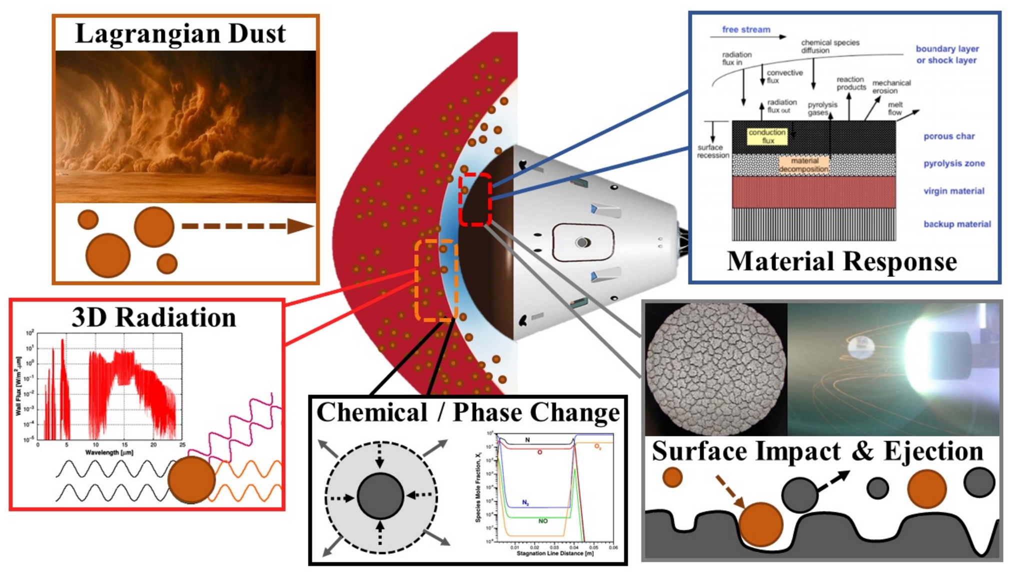
- Spacecraft may encounter regional / global dust storms during Martian planetary entry.
- Accounting for increased degradation due to dust particle impacts imperative for safe TPS designs.
- Modeling approaches with differing levels of fidelity possible:
  - 1-way (Fluid affects particles)
  - 2-way (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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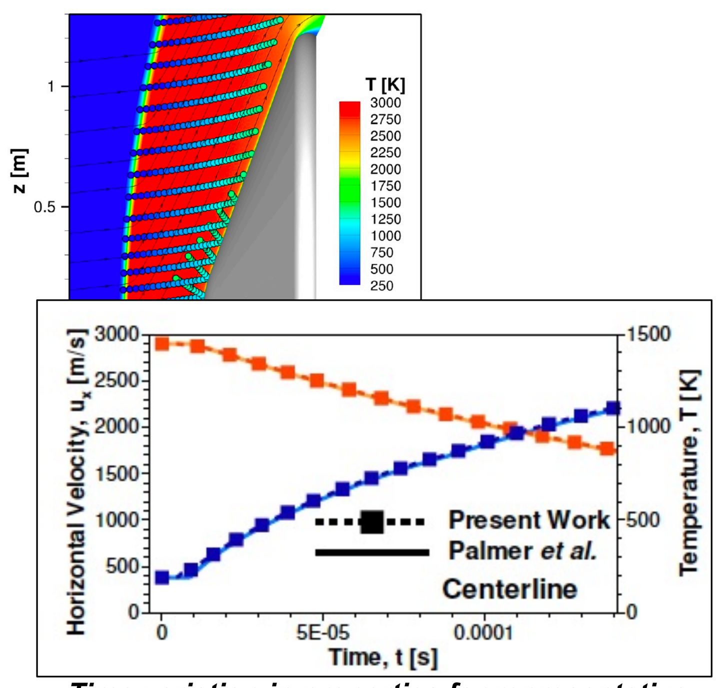
Results: Verification and Validation

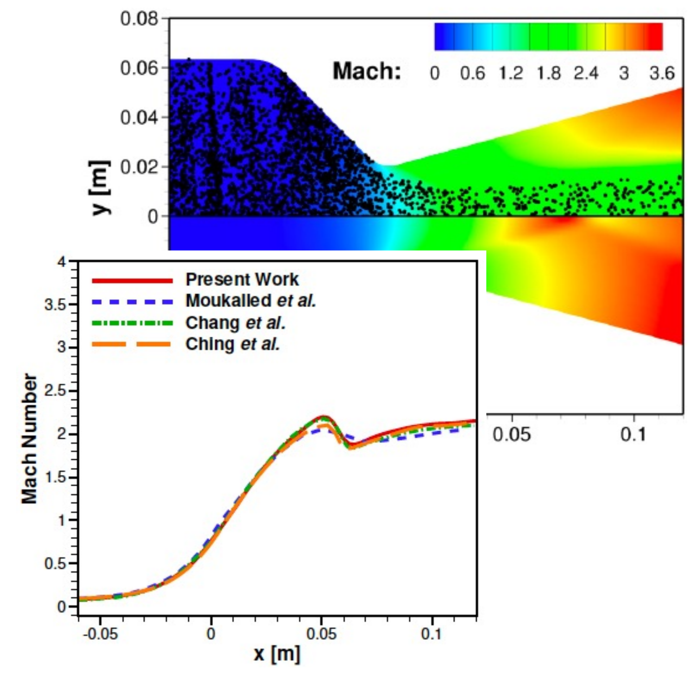
Rigorous V&V testing covering 1-, 2-, 4-way coupling

1-Way: Schiaparelli

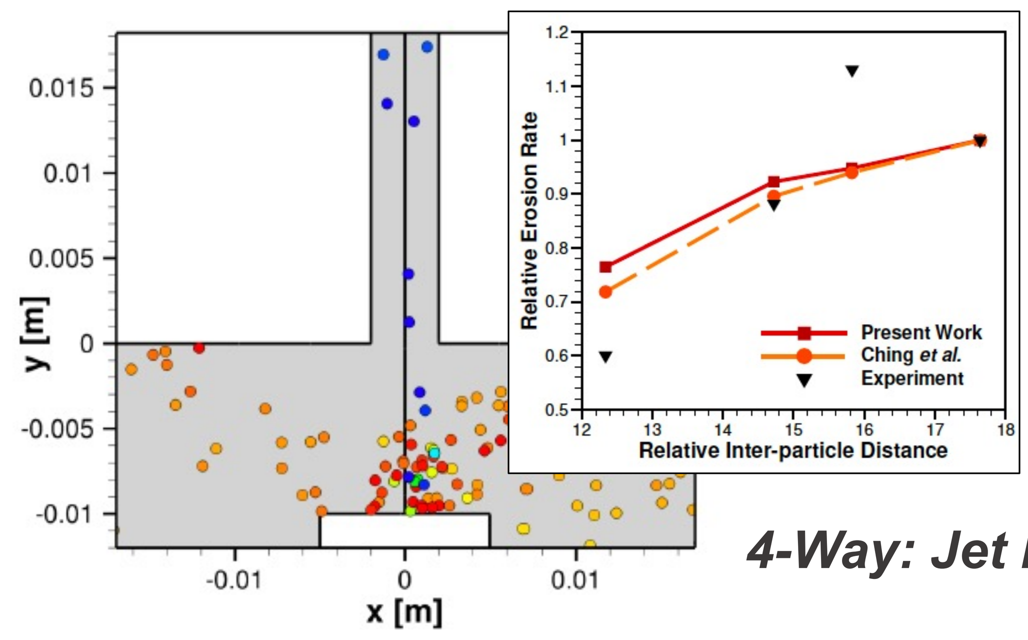


Time variation in properties for representative centerline particle.

2-Way: Caltech Nozzle



Mach number along nozzle centerline for dust-laden flow

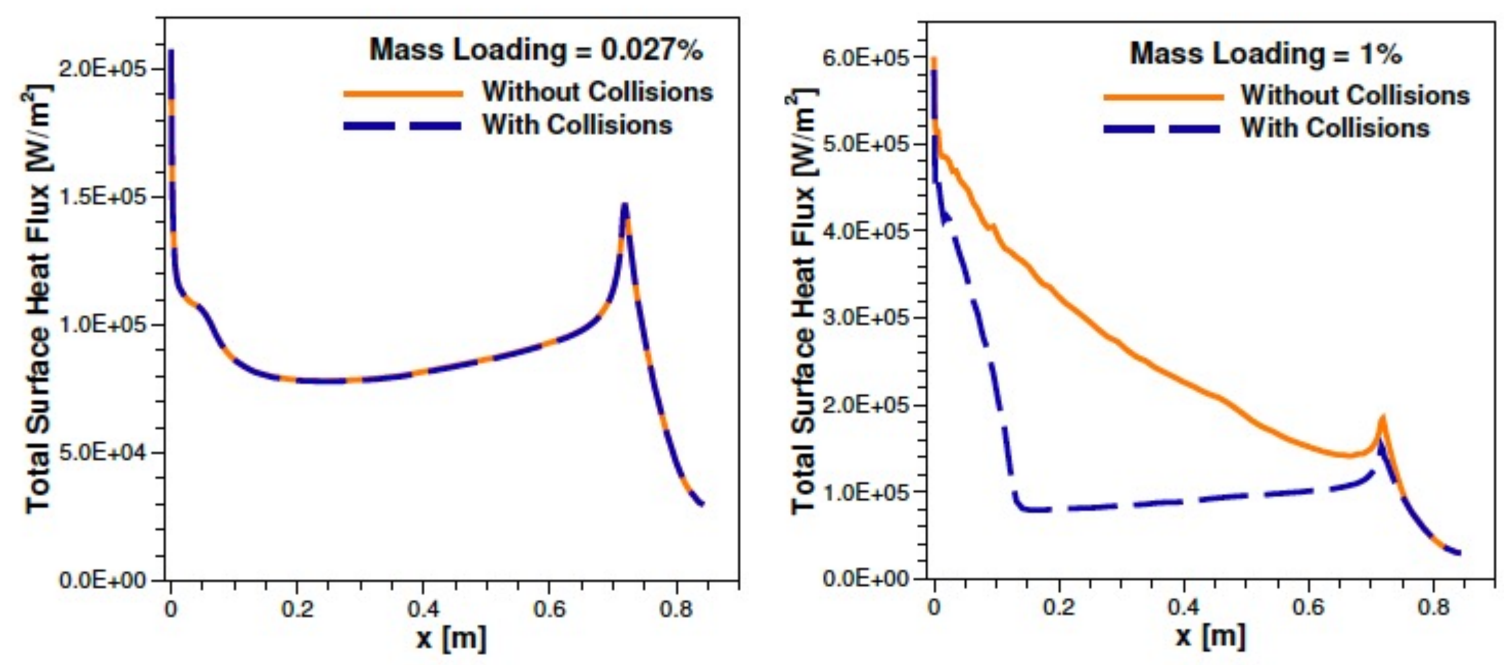


Change in surface erosion rate with decreasing particle loading (increasing inter-particle distance)

4-Way: Jet Impingement

Results: Mars 2020

- Freestream conditions correspond to trajectory point of peak dynamic pressure. Particles with D = 4.4 μm (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 (*Icarus*) and radiation solver (*NERO*).