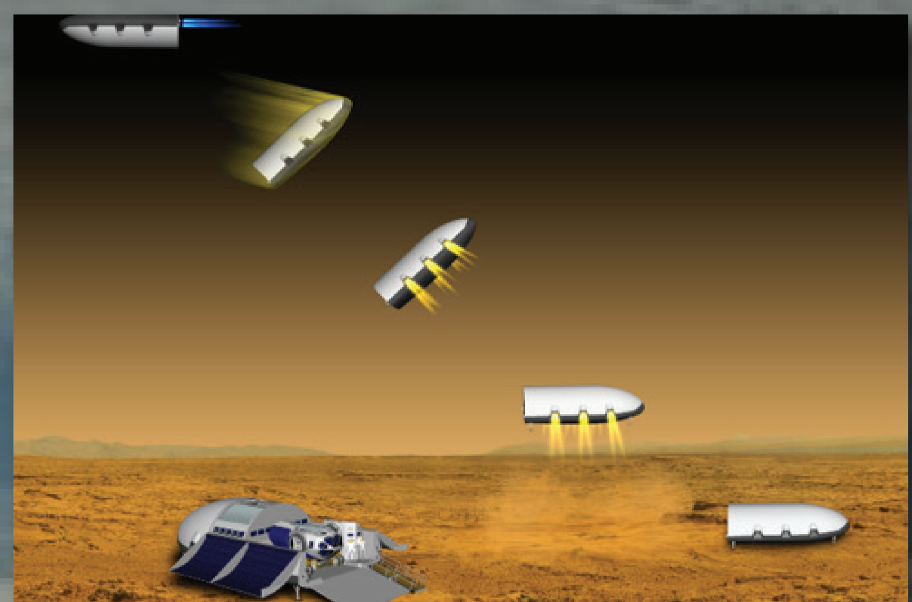
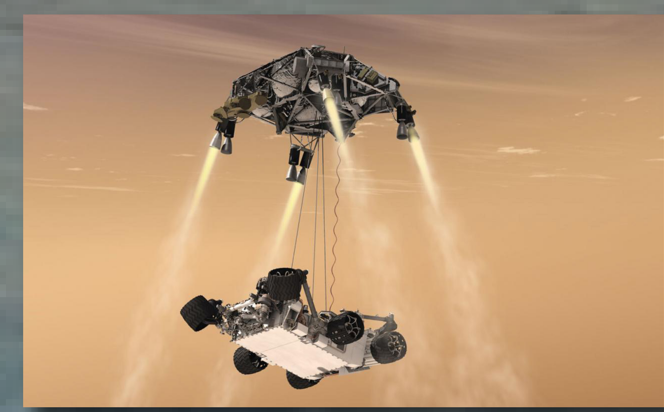
In-Space and Extra-Terrestrial Landing Plume Environments

National Aeronautics and Space Administration

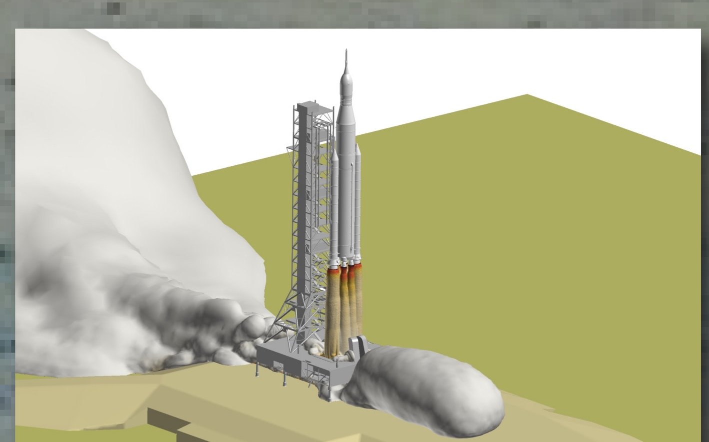


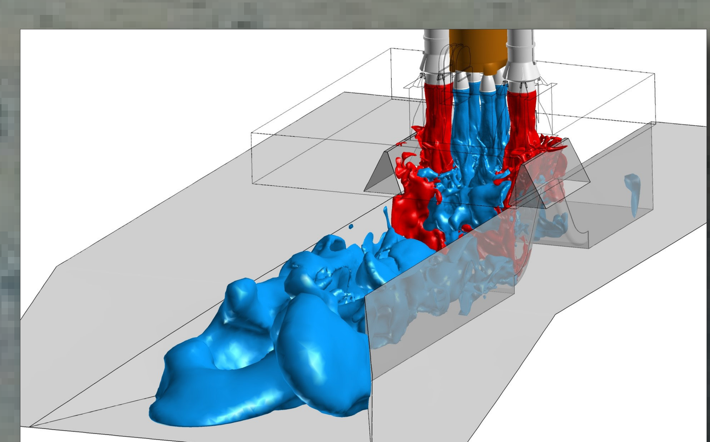


Proven High-Performance CFD Capability for Predicting Launch and Landing Plume Environments

Loci/CHEM Navier-Stokes solver, multi-species turbulent reacting flow, Overset 6-DOF moving body capability.

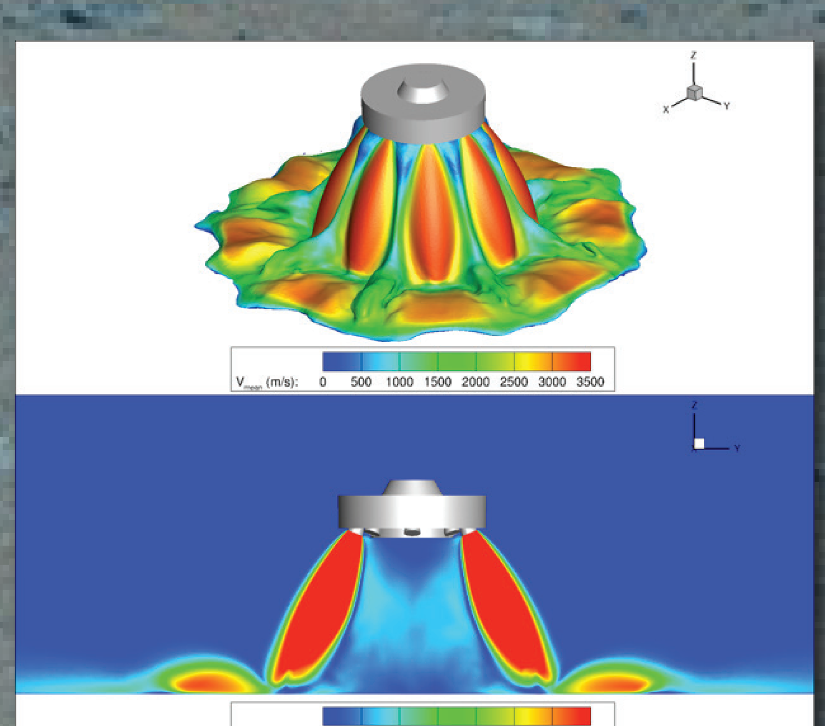
Decade-long validation history of liftoff and ascent plume effects for Shuttle, Constellation and SLS Programs. Products include Debris Transport Analysis (DTA) and Solid Rocket Motor Ignition Overpressure environments.

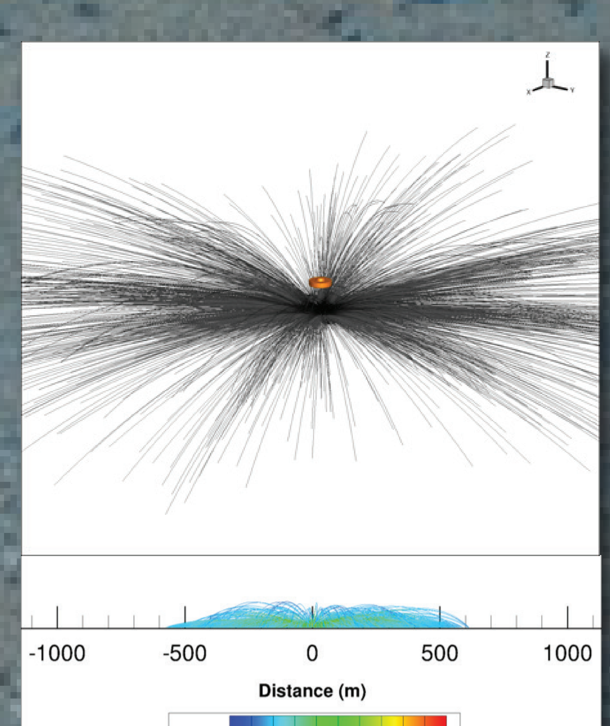




Plume Driven Debris Transport Analysis (DTA)

Recently applied this capability to Mars landing plume driven regolith/rock debris transport during lander concept design to the prediction of keep-out zones for habitats and other vehicles.





Mars Human Lander Concept Plume Surface Impingement
Farfield Debris Transport Defines Stay-out Zone

Extra-Terrestrial Rocket Plume Environments Present New Challenge

Future propulsive landings require multiple large engines. Plume impingement damage of unprepared landing surface results in erosion and cratering of regolith layer and rock leading to debris transport.

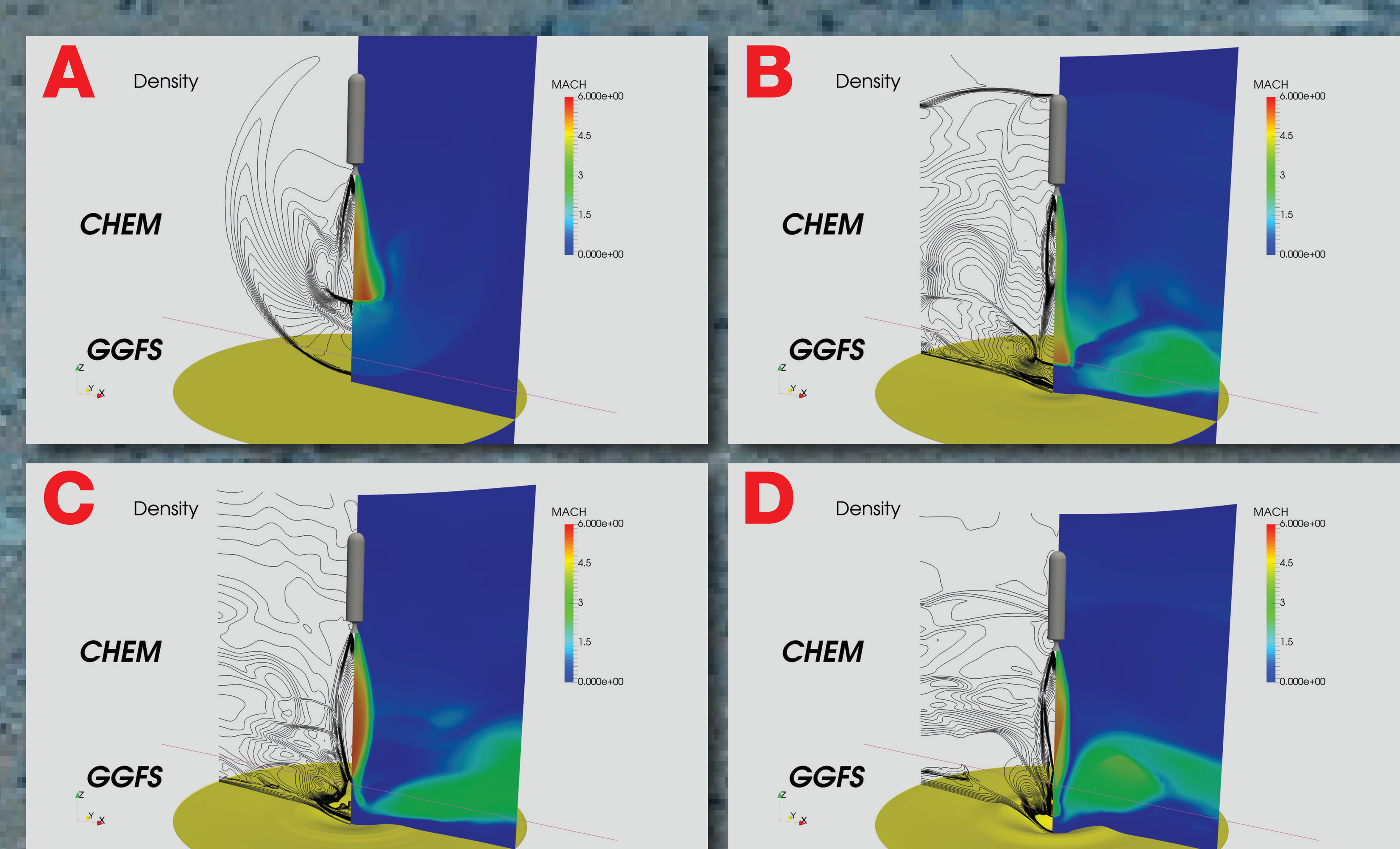
NASA/MSFC's Fluid Dynamics Branch has led the development of predictive plume-ground interactions for launch vehicles and is now applying and augmenting these capabilities to meet the new challenge.

MSFC Fluid Dynamics Branch and CFDRC assembled comprehensive plume driven debris transport analysis framework

- **Loci/CHEM and Loci/Boltzmann** CFD for transient plume impingement in mixed rarefied-continuum environments.
- **Gas-Granular Flow Solver (GGFS)** for surface cratering effects
- **Debris Transport Analysis (DTA)** toolset for post-processing of regolith and rock debris particle transport

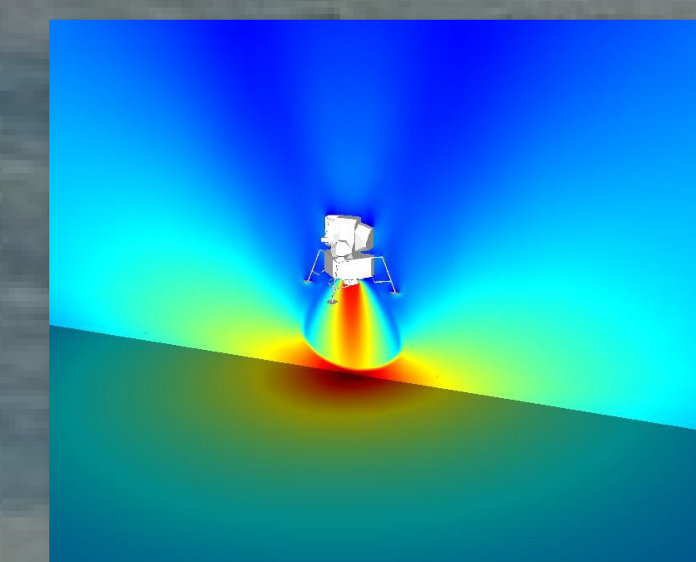
Fully coupled moving vehicle descent trajectory and/or 6-DOF Loci/CHEM simulation combined with GGFS plume-induced surface cratering.

Captures descent profile plume impingement flow dynamics and reverse flow amplification effects resulting from crater formation.

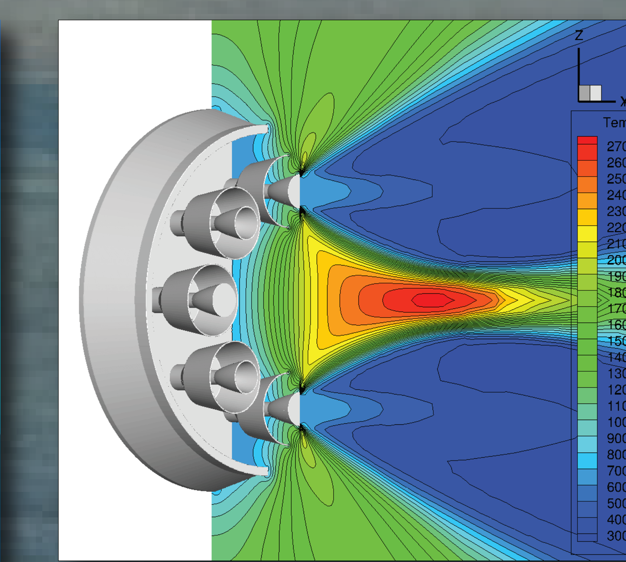


Rocket Plume Flow in mixed Continuum-Rarefied Environment

For bodies with no atmosphere a mixed rarefied-continuum flow must be predicted. Coordinated Boltzmann/Navier-Stokes CFD tool developed by CFDRC and implemented as Loci/Boltzmann.



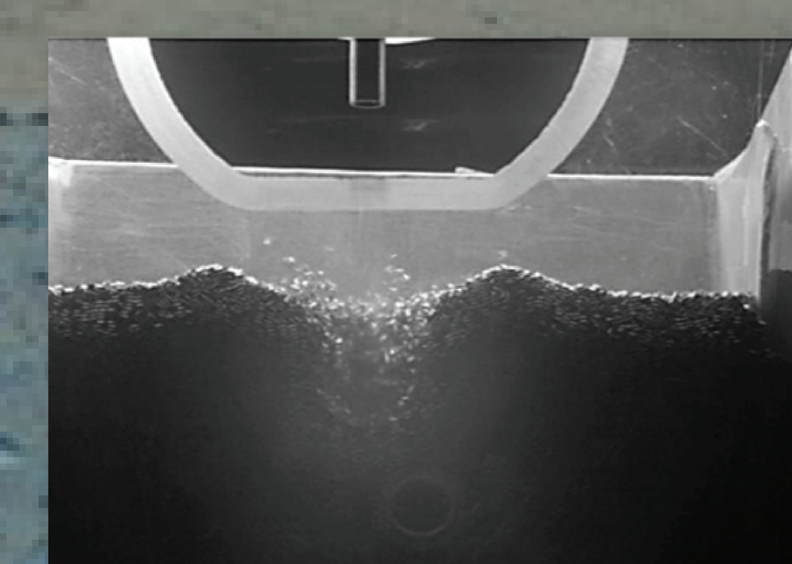
Apollo LEM Plume in Lunar Vacuum

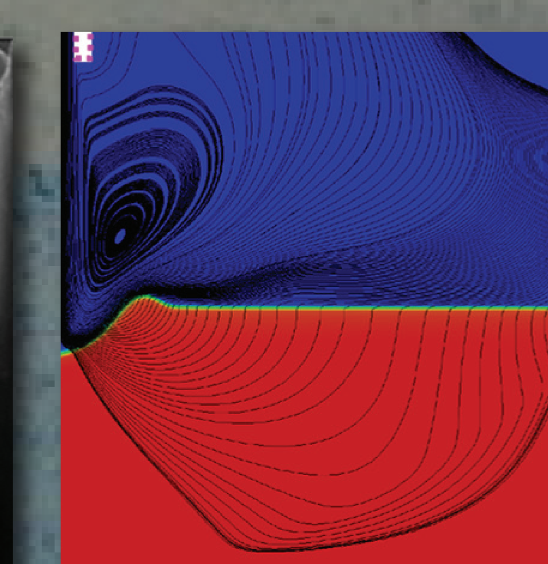


Europa Clipper Plume Interaction

Surface Cratering Prediction: Gas-Granular Flow Solver (GGFS)

Gas-Granular Flow Solver (GGFS), developed by CFDRC offers modeling capability for surface regolith particle flow and resulting plume impingement cratering





Gas-granular CFD Modeling Validated Against Cratering Experiments

Demonstration of Combined Physics Modeling Framework

A. Propulsion activates on descending vehicle modeled with moving body CFD
B. Initial plume impingement and splash on surface
C. Plume begins to erode a crater in the regolith surface
D. Plume splash direction is altered by growing crater and is directed toward the landing spacecraft.

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