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## Overview:

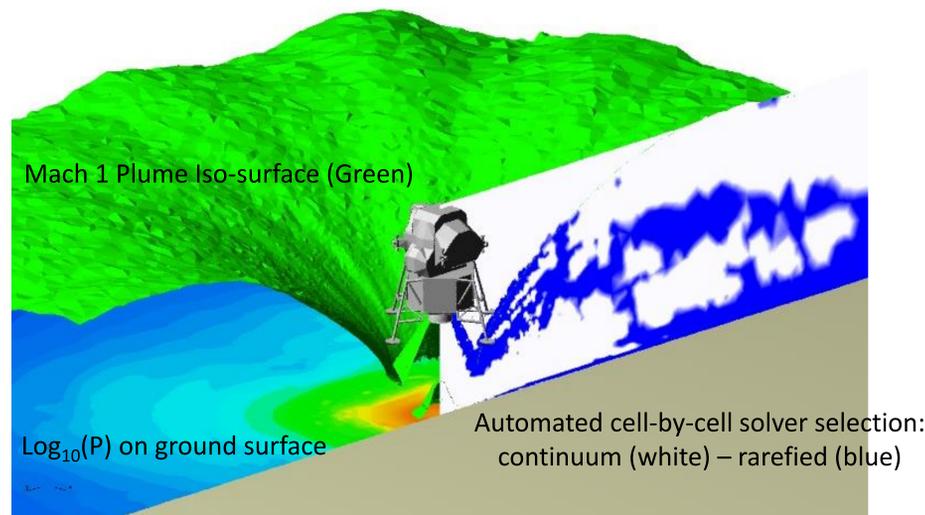
**Plume-Surface Interaction (PSI) between lander engine plumes and native regolith soil presents primary hazards in obscuration and contamination by particle clouds, high-energy ejecta streams, and landing area cratering damage.**

**The MSFC Fluid Dynamics Branch has assembled a portfolio of simulation tools to develop a predictive PSI capability for NASA customers such as the Human Lander System (HLS) and Commercial Lunar Payload Services (CLPS)**

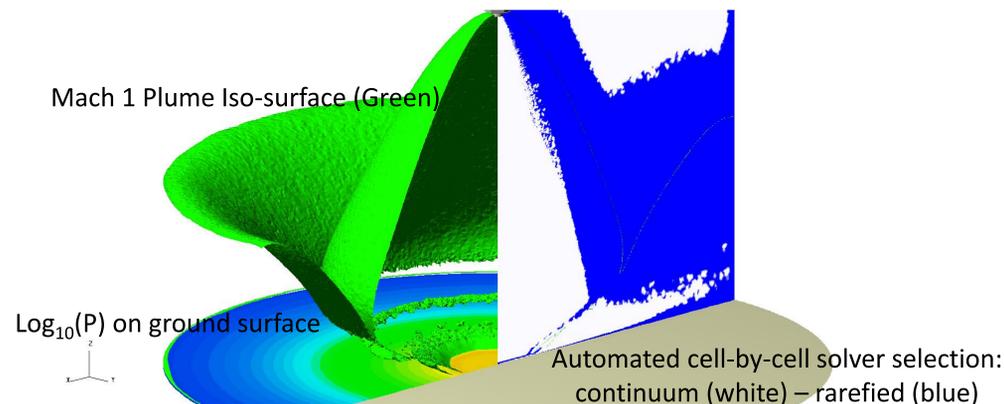
**These tools are matured via funding by NASA's STMD Game Changing Development Program and the NASA SBIR/STTR Program**

## Loci/Chem-Boltzmann Plume Impingement Modeling

The rarefied gas kinetic simulation module named Loci/Boltzmann has been integrated for simultaneous operation with Loci/CHEM in the Loci simulation framework. The hybrid Loci/Chem-Boltzmann allows for automatic cell-by-cell switching between the rarefied gas kinetic solver and the Navier-Stokes continuum CFD solver identified by continuum breakdown criteria within a simulation.



**Loci/CHEM-Boltzmann application example: Apollo Lunar Module at 5m elevation.**



**Loci/CHEM-Boltzmann application example: Apollo Lunar Module at 56m elevation.**

Rarefied regions exist around the expanding plume, at shocks just above the soil surface and at the soil surface at both small and large altitudes.

It is necessary to solve the Boltzmann equations in these regions.

Simulation tools tailored towards predicting PSI environments during extra-terrestrial propulsive landings include:

- **Loci/Chem-Boltzmann:** Computational Fluid Dynamics program for plume impingement flow in mixed rarefied-continuum environments
- **Loci/GGFS Gas-Granular Flow Solver:** Coupled gas-particle two-phase flow simulation to predict PSI induced crater formation and ejecta streams

**These tools are designed to satisfy crucial modeling aspects for lunar PSI:**

- Plume impingement flow modeling in a lunar vacuum background environment requires accurate simulation of the mixed continuum-rarefied plume regions strongly affecting the plume extent and impingement characteristics that drive erosion (impact pressure, surface shear).
- Modeling of liberation of the soil particles and the resulting crater shape and evolution is strongly affected by the extremely cohesive characteristics of the lunar regolith resulting from both the jagged irregular particle shapes and the wide particle size distribution.

## Path forward in PSI tool maturation for the remaining 3 years of PSI GCD project

- Continue to mature Loci/Chem-Boltzmann
  - Including linking GGFS
  - Extending to di-atomic and equivalent species
  - Acceleration via GPU extensions
- Continue maturation of Loci/GGFS
  - Full poly-disperse capability
  - Implementation of turbulence model suite
  - Prescribed motion via overset to enable landing vehicle simulation
- Develop ability to create complex soil models for use with Loci/GGFS
  - Lunar and Martian regolith along with simulants for validation efforts
- Develop models of particle cloud drag and particle turbulent kinetic energy
- Conduct validation assessments of the following categories for both Lunar and Martian environments
  - Plume Structure
  - Soil erosion and crater formation
  - Soil particulate ejecta and transport

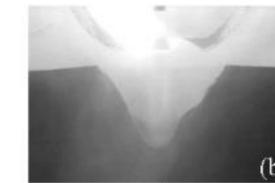
## Loci/GGFS Gas-Particle Interaction Modeling

GGFS features a two-phase Eulerian-Eulerian modeling approach, treating both gas and particle mixture as continuum phases.

Eulerian granular material physics closure models (stress, cohesion, etc.) for non-spherical particle mixtures are extracted from small-scale particle DEM (Discrete Element Model) simulations.



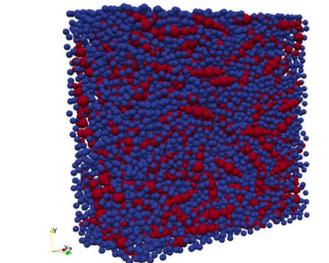
Glass Spheres (150-425 μm)



JSC-1A



**Irregular particle shape modeled by linked elemental spheres**

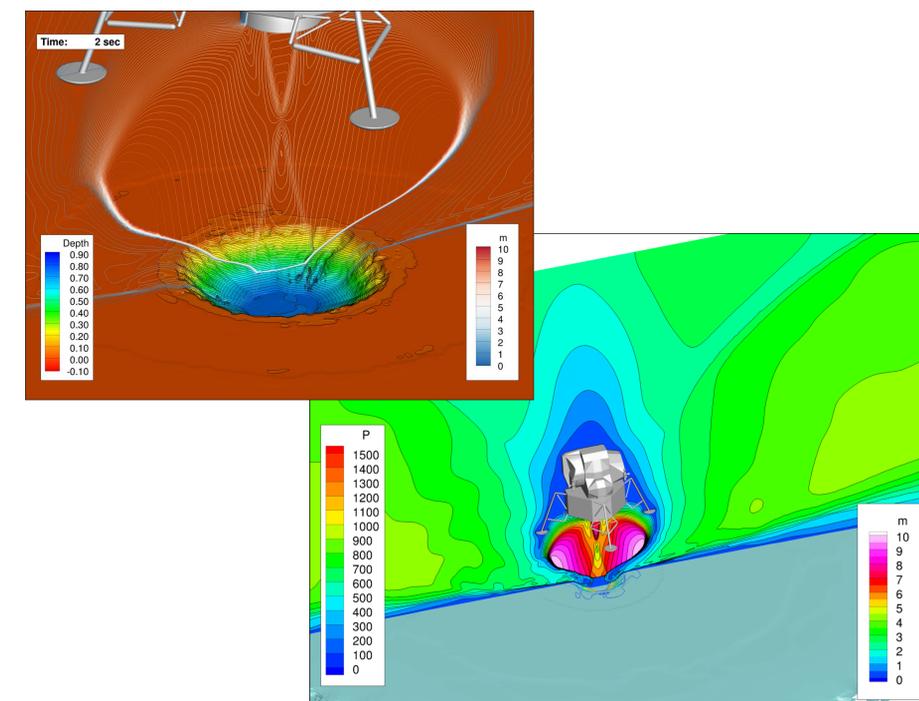


**Poly-disperse irregular particle mixture properties from DEM simulation**

**Strong effect of poly-disperse, irregular shape particle physics on crater characteristics**

Current Loci/GGFS application capability:

- 3D and axi-symmetric crater formation simulations
- Soil models for mono-disperse spherical and elongated particles
- Initial operational capability to perform bi-disperse modeling; extension to arbitrary poly-disperse mixture under development



**Recent Loci/GGFS application demo example: Apollo Lunar Module crater formation at 5m elevation for mono-disperse 100 micron particles.**