# Plume-Surface Interaction Modeling for a Human-Scale Mars Lander

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## Project Description

Landing vehicles impart thermal and strain energy onto the landing site from the retrorocket exhaust. Depending on the design of the vehicle, the energy may be great enough to cause spallation at the landing site. This damage may be minor and repairable in the case of landing on a terrestrial landing pad. For missions to other planetary bodies, the spallation may cause the landing site to become uneven and unstable, as well as damage.

Simulating this phenomenon in a laboratory or computationally would require a significant amount of time and other resources. These resources typically are not available during the design phase of a mission. This paper presents a computationally-efficient model for the temperature and stress distributions that arise during landing. These quantities can be used along with existing failure criteria, such as the Hoek-Brown criterion for geological materials, to quickly determine whether spallation will occur.

The stress and temperature distributions at the landing site are inherently 3D; however, there is a plane of symmetry and in that plane the distributions are 2D. Both quantities are modeled using series solutions to their governing partial differential equations (PDEs). The stress is modeled using the Airy stress potential function and its governing PDE is the biharmonic equation. The temperature is governed by Fourier's law. The models assume that stress due to gravity can be neglected, the points in the plane do not accelerate, and that the material properties are constant.

## Work Accomplished

The work items that have been completed, so far, are itemized in the list below.

- Make introductions with members of ARES and EG3
- Review literature on Mars geophysical properties
- Create a MATLAB implementation of the plume impingement source flow model
- Integrate source flow model with Airy stress potential model
- Present research at ARES brown bag lunch
- Develop heat transfer code to include thermal stresses
- Research analytic modeling of thermal spallation

## Impact

I have created a tool for estimating the damage to the solid surface of Mars when a lander's retrorocket plumes are impinging on it. This tool quickly assesses whether damage is possible and indicates if more sophisticated analysis is required. It rapidly predict the stress and temperature distributions under the surface using a source flow model developed in EG. The pressure, shear, and convective heat flux calculated by this model is treated as a boundary condition and there effects are propagated through the surface. This sort of analysis capability is also applicable to estimating damage to a heatshield during planetary entry. The hypersonic post-shock environment is significantly different from an under-expanded rocket plume, but that only changes the inputs to the tool and not the solution process. The difference in geometry from the flat surface of Mars to the curved surface of a heat shield can also be handled through a coordinate system transformation.