

Simulating Underexpanded Jets in Martian and Lunar Environments

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As part of the Game Changing Development (GCD) Program, funded by NASA's Space Technology Mission Directorate (STMD), the development of simulation capability for the prediction of extra-terrestrial Plume Surface Interaction (PSI) environments has been undertaken by the Fluid Dynamics Branch at NASA/MSFC. The GCD PSI Project, planned to be accomplished over a four year period, contains a Predictive Simulation Capability (PSC) Element focused on creating simulation capability for the reliable and accurate prediction of PSI in Martian (~650 Pa) and Lunar (vacuum) ambient environments. In addition to the PSC Element, the PSI Project also contains a companion Ground Testing Element for development of focused datasets for validation of predictive capability as well as a Flight-focused Instrumentation Element.

This paper describes the activities and accomplishments in the past year for the Prediction of Plume Flow in low pressure environments component of the PSI Project. While the Loci/Chem Computational fluid dynamics (CFD) application has been validated and used extensively for simulating launch environments in atmospheric conditions, use of this tool for simulating supersonic plumes at Mars-like ambient pressure requires further validation. CFD simulations of underexpanded jets have been performed using Loci/Chem for Mars-like conditions to predict several metrics for steady laminar, turbulent, and impinging plumes. The CFD results are compared with an experimental data set for low Reynolds number plumes at these conditions in order to evaluate the current capability of the Loci/Chem tool for these types of environments. The CFD validation results to date show reasonable agreement with the experimental data across all of the metrics of interest for the configurations considered.

The Loci/Chem-Boltzmann CFD application is a hybrid continuum/rarefied flow solver which extends modeling capabilities to very low pressure environments such as those on the Moon. The Loci/Chem-Boltzmann solver uses a gradient-based continuum breakdown criterion to restrict solution of the computationally expensive Boltzmann equation to only a subset of the domain, while using the Navier-Stokes equations elsewhere. This CFD application is under active development, and current efforts toward establishing production ready capability for evaluating Lunar plume surface interactions are well under way. Initial simulations of an Apollo LEM indicate that several regions of the flow require solving the Boltzmann equations due to extreme rarefaction. Early simulations are promising, indicating reasonable overall computational time for a full 3D human scale lander simulation.