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SIMULATING MELTING-SOLIDIFICATION OF LUNAR REGOLITH PARTICLES USING COUPLED CFD METHODS

Abstract

Lunar exploration endeavors, such as the Artemis program, provide a renewed interest in the behavior of lunar dust. Lunar landing scenarios involve high-enthalpy interactions with lunar regolith. Such a scenario involves a continuum interaction with the regolith, followed by a gradual approach to a rarified flow. The interaction is a topic of interest to NASA and Artemis as it involves preventing damage to lunar operation surfaces. This work proposes that regolith particles experience a melting mechanism, making a “sticky” partially-melted liquid outer layer, leading to unique interactions between regolith and structures on the lunar surface. Exploring this interaction using the numerical approach computational fluid dynamics is proposed. Regolith is commonly simulated as Lagrangian particles coupled to the thruster plume involving a continuum, Navier-Stokes-based solution, driving particle dislodgement from the ground. The dust then enters a rarefied flow, interacting with statistical methods like the direct simulation Monte Carlo method. Previous studies of this event have not explored melting processes of regolith. Current, unpublished work suggests that for sand particles experiencing high temperatures, a liquid outer layer forms around the sand particle. These layers provide the proposed stickiness and adhere to surfaces. In lunar operations, this could lead to surface contamination. The proposed paper extends a validated approach discussed above for particle melting to study the effect relevant to regolith dynamics. The effort simulates the particle aerodynamics, conjugate heat transfer, and solidification/melting of a plume impingement event relevant to the lunar environment. The model extends one formulated for sand ingestion into aircraft but is uniquely adapted to study NASA lunar exploration missions. The volume-of-fluid method was used to capture the transition from solid to partial solid/liquid and eventually complete liquid phase change dynamics of the melting regolith particles. The applied variable thermal conditions correspond to the thruster plume of a lunar landing. The temperature will govern the solid phase and includes conduction, latent heat of fusion, and external convection heating. The regolith phase can transition from solid-to-liquid states and participate in the flow solution. The final paper presents novel studies elucidating dynamic properties of melting regolith. Simulations involve initializing a dust particle at ambient conditions and the surrounding fluid to rocket plume conditions. Time-varying temperature, melting, aerodynamic character, and shape are extracted. Non-dimensional variables, including Reynolds, Weber, and Ohnesorge numbers, are explored. The outcome of this paper will provide guidance relevant to the fouling of surfaces from partially-melted regolith during landings.