

Exhaust-regolith interactions: analysis of the instability threshold for the Moon, Mars, and Phobos

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Exhaust-regolith interactions are a necessary consideration for space missions operating on or about an extraterrestrial body. Missions landing within a significant gravity well must understand how regolith will behave in reaction to exhaust flow during the final stages of decent and landing. The presence of an atmosphere is also a factor, due to exhaust collimation and drag forces on lofted particles. Spacecraft operating close to, landing on, or sampling a small body have similar concerns as those around larger bodies, but the low- or microgravity environment presents its own additional challenges.

For this work we employ a gas-flow model to analyze threshold conditions for lofting regolith from asteroidal and planetary surfaces due to gas impingement from rocket exhaust. The pressure distribution from an engine oriented normal to the surface is calculated, which then acts as the boundary condition for the application of Darcy's Law, which models gas flow through porous media; we solve an axisymmetric version using a finite difference algorithm. Regolith parameters are wrapped up into a single time constant which governs the rate at which gas diffuses through the medium.

Regolith instability results when forces due to gas flow exceed the weight and cohesion between particles. We treat these complex interactions with a simplified, conservative model, accounting for vertical forces and neglecting horizontal cohesion. Areas of potential instability are determined, and the minimum soil cohesion necessary to prevent instability calculated. Regolith weight is all but negligible in a microgravity scenario, but becomes more significant on larger bodies. Originally developed in support of NASA's Asteroid Redirect Mission, we extend analysis using this tool to hypothetical scenarios on the Moon, Mars, and Phobos.

Alongside computational work, we are developing a drop tower microgravity experiment to corroborate and improve our computational results. This experiment will test gas impingement on regolith simulant in a vacuum and microgravity environment by directing compressed air through a rocket nozzle toward regolith simulant during a drop. By measuring the surface pressure for each experimental run, we will determine the effect of specific pressure distributions, and determine threshold conditions for disturbing regolith. The results of preliminary ground tests, which determine behavior around the instability threshold in ambient conditions, are presented.