INVESTIGATING PLUME SURFACE INTERACTION (PSI) EFFECTS ON THE LUNAR SURFACE.

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Introduction: Rocket Plume Surface Interaction (PSI) can eject large amounts of regolith particles, limiting visibility and reducing flight safety. Particles ejected from the surface at high velocities can damage the spacecraft, its instruments, and any surrounding hardware [1]. We have learned from the Apollo missions that the mean time to failure of a system can be significantly reduced by the presence of lunar dust on materials and mechanisms. Upcoming lunar lander missions are expected to force dust transport across the Moon whenever a lander's rocket plume impinges on the lunar surface eroding the surface and ejecting particles at high speeds. As a result, this interaction poses multiple risks to future lunar exploration missions, especially for astronauts. Thus, understanding PSI processes is paramount to the safety of the lunar exploration program.

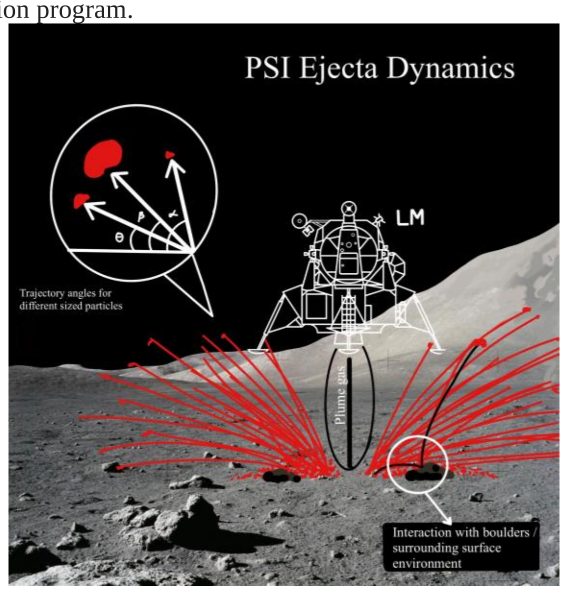

Fig 1. PSI Ejecta Dynamics diagram demonstrating the trajectory path of ejected lunar regolith particles of varying sizes at different angles and velocities. On the bottom right section, an alternating path is shown that can occur when the particles interact with the non-flat lunar surface. Illustrated by: Ariana Bueno.

In order to better understand PSI, we are developing in-flight instrumentation and conducting ground tests to simulate PSI and measure its effects. A dedicated suite of PSI instruments is being developed to be used during descent and landing. These instruments are designed to quantify Plume Surface Interaction (PSI) effects in the actual lunar environment for the first time ever, by collecting data that can only be obtained during landings on the Moon.

Since PSI is poorly known and these instruments are first of a kind, it is necessary to calculate estimates of different parameters including distance traveled, particle concentration, particle size distribution, particle impingement time, velocity range of ejected particles, and energy of impacts, to asses the requirements of the PSI dedicated instrumentation. These initial estimates have been done using various methods along with analysis of Apollo lunar data. The estimate will give us a better understanding of PSI effects we will observe in future lunar missions.

Methods: We start the calculations by making a few assumptions based on Apollo mission data and results from numerical simulations. The assumptions include impingement on a flat surface, single engine module, and mean particle size of 70 μm [2]. The calculations are done for two basic cases: an Apollo class lander and a smaller class lander similar in size to the future CPLS landers.

Distance traveled. We gathered the values for plume gas velocity (maximum case) based on the smaller class lander case [3] and information on ejection angles based on the Apollo mission data using video photogrammetry [4]. With this information the distance travelled was calculated for particles ejected from a small class lander.

Particle concentration. This estimate is based on an Apollo class lander. Using the total mass of regolith ejected during an Apollo landing event [4] and information on particle size and density we estimated the total number of particles ejected. This will help us determine the requirements of our instrumentation since we are collecting data based on each particle impact. Particle flux was also determined for a certain surface area based on the size of the Apollo lunar lander, this can tell us where we should be mounting the instruments.

Particle time impingement. Based on evidence collected during the Apollo missions, the altitude in which PSI begins was determined and using the transcript information on how fast the lander was descending we calculated the time of PSI.

Particle velocity range. One of the most important parameters for this analysis is velocity. Velocity will help us determine how far the ejected particles will travel, the energy of their impacts and the overall damage they can cause. Considering the small class lander case we have the initial plume gas velocity. To calculate the appropriate range of velocities of the ejected particles we need to consider plume drag and friction effects on the ejected particles.

These additional considerations will alter our ejection velocity of the particles, specifically with respect to size of the particle. Larger particles will not be able to reach the gas velocity and we need to determine what range of size particles will be able to travel close to the gas velocity, in turn revealing what particle sizes are most dangerous.

For these calculations we are now considering specifically the particle interaction with the plume gas as seen in the figure below.

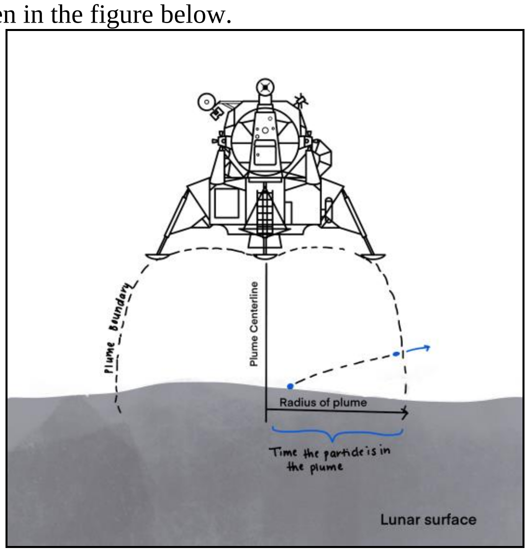

Figure 2 Diagram of the particle traveling through the plume gas during the plume-surface interaction. The particle will be accelerated by the plume and the time of interaction is the time the particle is in the radius of the plume. Illustrated by: Ariana Bueno.

Using a force balance diagram including the drag force, frictional force, and gravity, we determined the separable first order differential equation that we can solve for to determine the particle velocity, using an initial time assumption. We are currently also working on creating a method to determine the actual time based on iterating the velocity outputs.

Energy of impacts. We then used the new velocity estimates to calculate the kinetic energy impacts of ejected particles with respect to their size (based on density and radius), using the fundamental kinetic energy equation.

Results: We have obtained rough estimates of the values of different parameters of PSI effects as discussed in the previous sections. The velocity results demonstrate that drag and friction effects play a significant role. Based on particle size distribution, silt size range makes up 51% of the regolith particles. Our results indicate that smaller particles will be ejected at much faster speeds. Below are the results for this range.

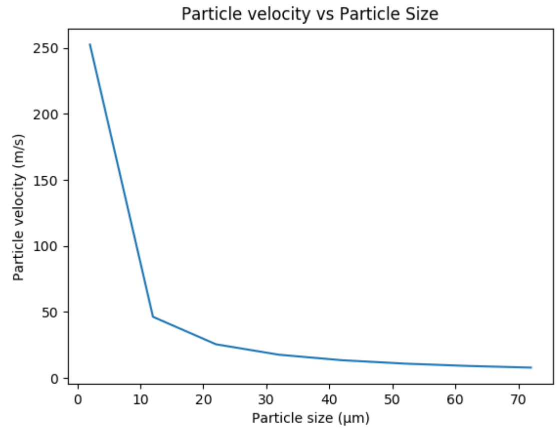

Figure 3 Graph of particle velocities for silt size (2-70μm) range particles.

The velocities for larger sized particles were also calculated. Evidence from the Apollo missions have shown us that rocks of about 10 cm have been moved during landing, but at very low speeds. The results obtained accurately represent the observations made during the Apollo missions.

Summary: The initial estimates calculated will help us determine the requirements necessary for the PSI dedicated instrument. These instruments will in turn help advance lunar science by providing the scientific community with observational data regarding particle movement and distribution and inform commercial providers of Human Lander Systems (HLS) and CLPS (Commercial Lunar Payload Services) landers of the potential risks to their vehicles during lunar landings due to PSI effects. The data collected from these instruments will be used to improve prediction capabilities for future missions and support the development of mitigation strategies. The data will also support scientists and engineers developing dust mitigation technologies to protect future lunar surface systems. This is crucial in ensuring safety during landings on the Moon and possibly other planetary bodies like Mars.

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References:

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