Response of Lunar Regolith from Low-Velocity Impacts in Microgravity

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Introduction

Lunar regolith has a combination of unfavorable physical properties which makes it hazardous to work around. Unfortunately, the moon is covered in lunar regolith. When impacts excite lunar regolith with kinetic energy we call it ejecta. Due to the lack of atmosphere and reduced gravity, even low-velocity impacts can produce a significant amount of lunar ejecta. To prevent mechanical and biological damage caused by contact with ejecta, our goal was to better understand the effect that the impact angle had on ejecta velocity and concentration trends.

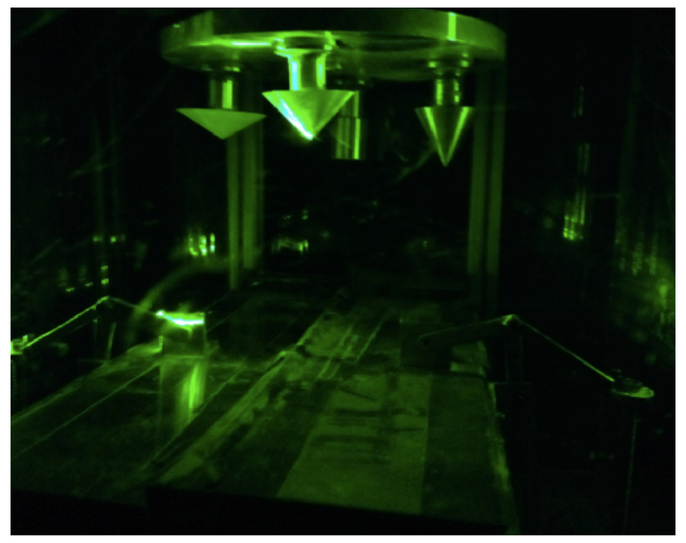

Figure 1: Inside of vacuum chamber with PIV laser activated.

Figure 2: Top view of experimental apparatus.

Lunar Regolith

Lunar regolith is composed of different aggregates and native FeO with highly irregular shapes. This makes the regolith highly abrasive. Particles range in size from 1 mm to 20 μm. This makes it possible for regolith to get into small spaces including deep within the lungs and into sensitive electronics. Finally, the reduced gravity and atmosphere allow for more high energy and ionized ejecta.

Lunar regolith is dangerous. It was discovered during the Apollo missions that the lunar regolith was abrasive enough to wear through multiple layers of the Kevlar-like material used to form the boot. Our goal is to minimize regolith-related damage.

Method

To simulate different impact angles, cones with varying aperture angles were used as impact surfaces. Instead of building multiple self-contained impact environments we attempted to design an "all-in-one" impact environment. To achieve this we designed a rotary used to interchange the cones. A pneumatic system was used to perform uniform impacts, and a two-stage mating system was used to mate the piston with the variable impact surfaces. A reset mechanism was designed to reset the regolith to a uniform initial condition. This impacts occurred inside a custom built vacuum chamber

Optical systems and Arduinos were used to record data. We used a laser and high speed camera to record footage used in Particle Image Velocimetry (PIV), and used infrared emitters and sensors to record changes in concentration.

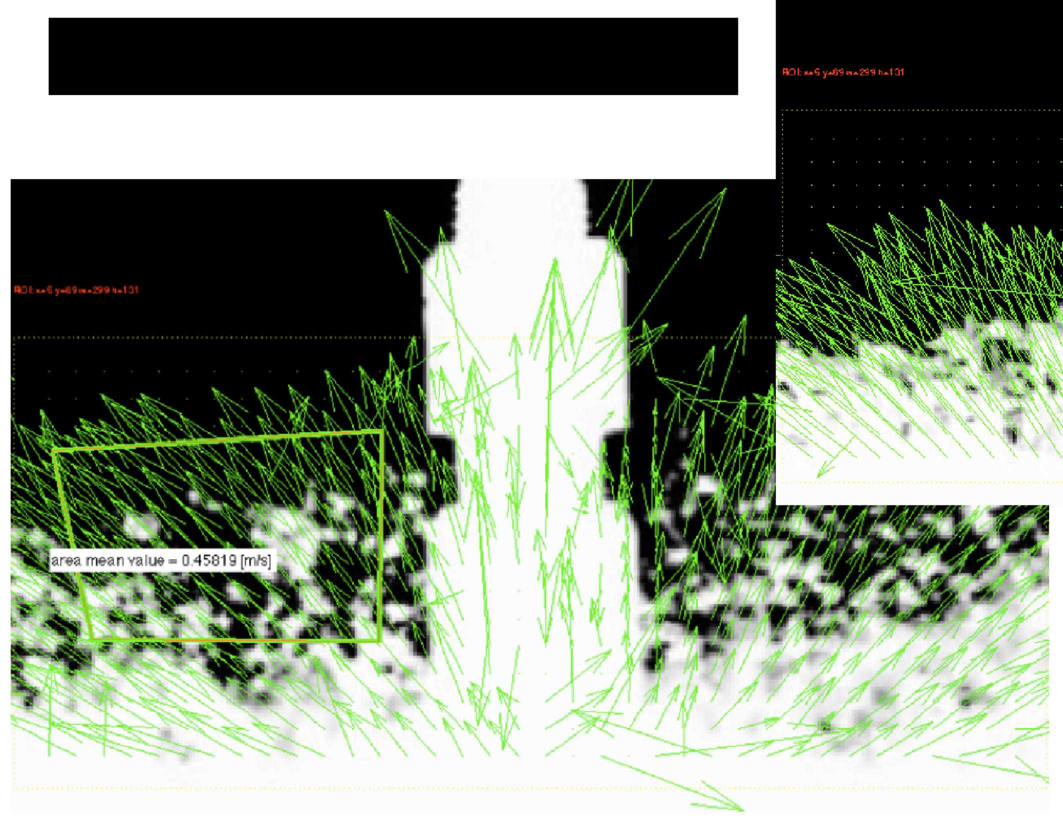

Figure 3: 120 ˚ geometry impact.

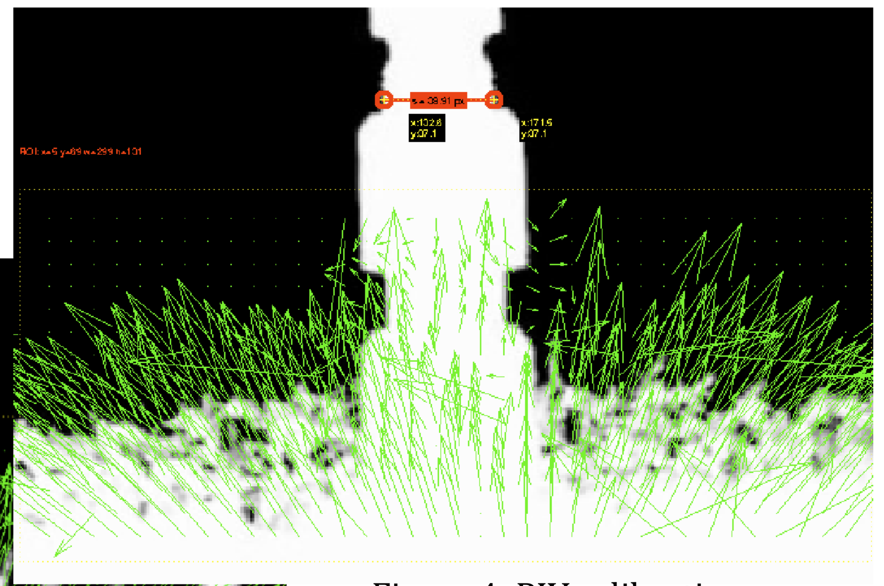

Figure 4: PIV calibration.

Results

Unfortunately, we had pneumatic issues during the flight that prevented us from obtaining any data during the microgravity flights.

However, we were able to obtain promising ground data, as shown in Table 1 and Figure 6. The ground data shows that the 120˚ geometry created the fastest and largest amount of ejecta, while the cylindrical geometry produced the slowest and least amount of ejecta. Figure 5 shows the good agreement between the data collected a simple ballistics model. The ballistics model is shown in Equation 1.

Table 1: Average velocity of ground impacts.

	Cylindrical Geometry	60˚ Geometry	90˚ Geometry	120˚ Geometry
Average Impact Velocity (m/s)	1.13	0.98	0.96	1.04
Average Ejecta Velocity (m/s)	0.22	0.48	0.40	0.60
Qualitative Density	Low	Moderate	Moderate	High

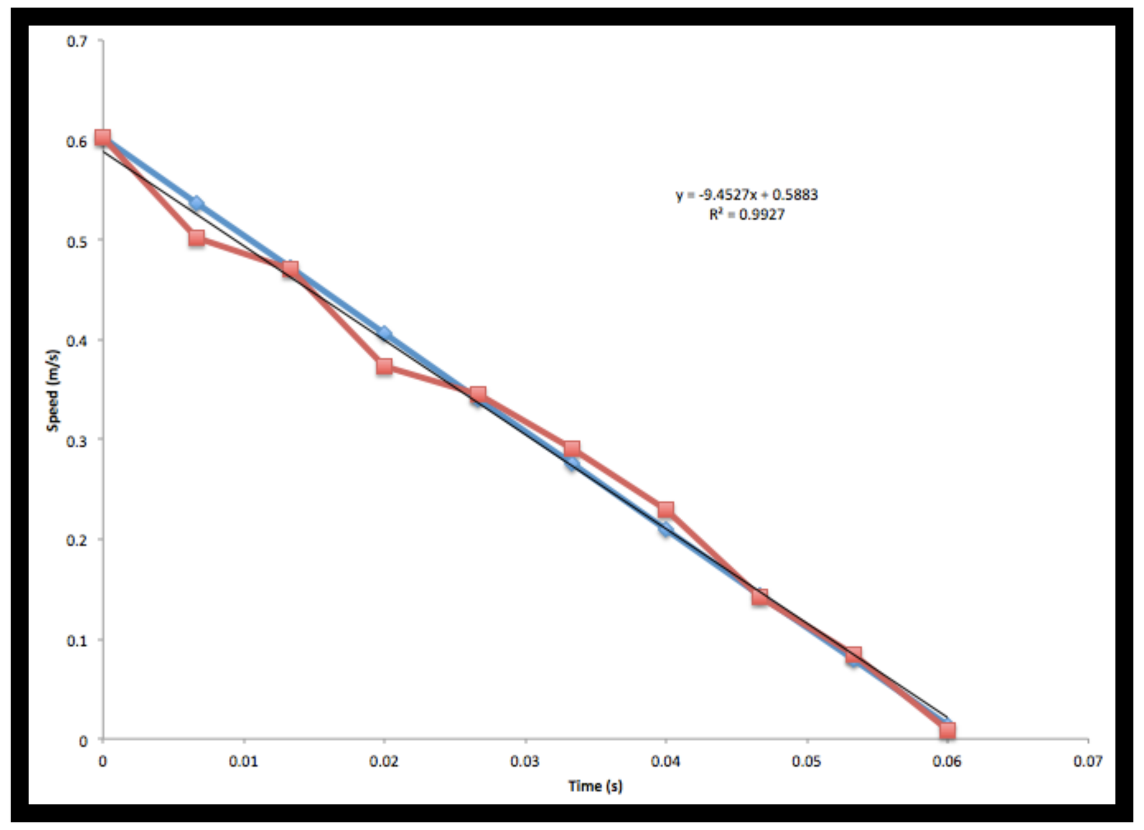

Figure 5: Data validation.

Conclusion

This experiment as a whole was a learning experience. The complexity of our experiment required many different systems. This leads to one of the main lessons learned: new systems under development must undergo simple design and build because of all the unforeseen issues that will occur.

In terms of lessons learned for NASA and dust mitigation researchers, the study found that greater impact surface areas have a large influence on the speed and amount of ejected regolith. Future researchers will be able to build off our lessons learned and determine the appropriate dust mitigation design for moon missions.

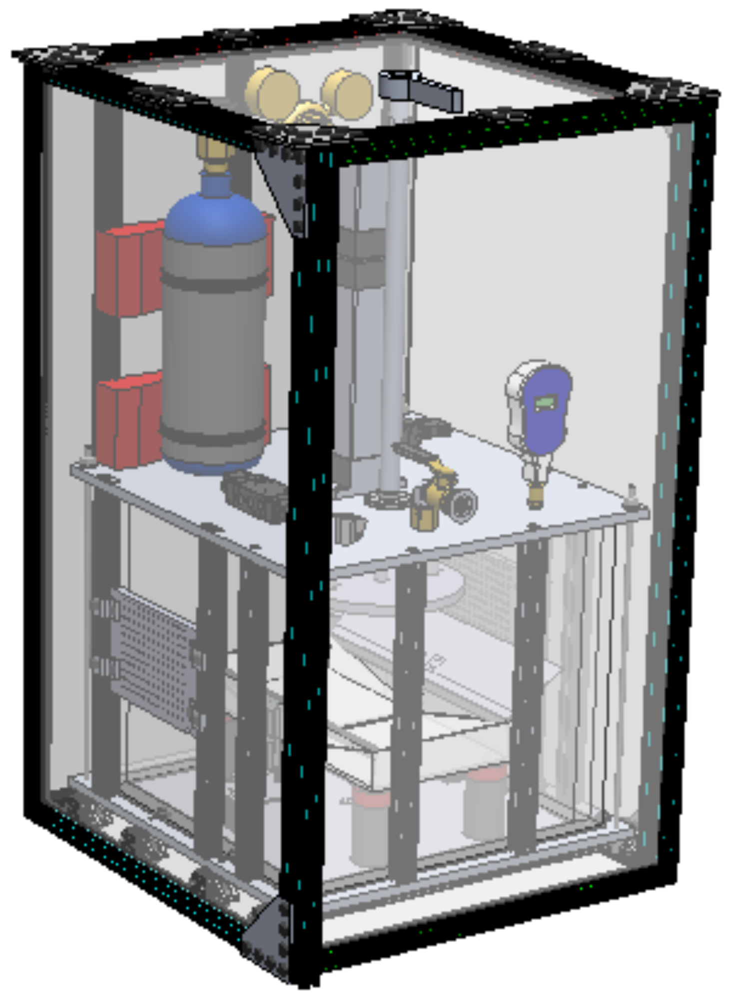

Figure 6: Full assembly of experimental apparatus.

Acknowledgements

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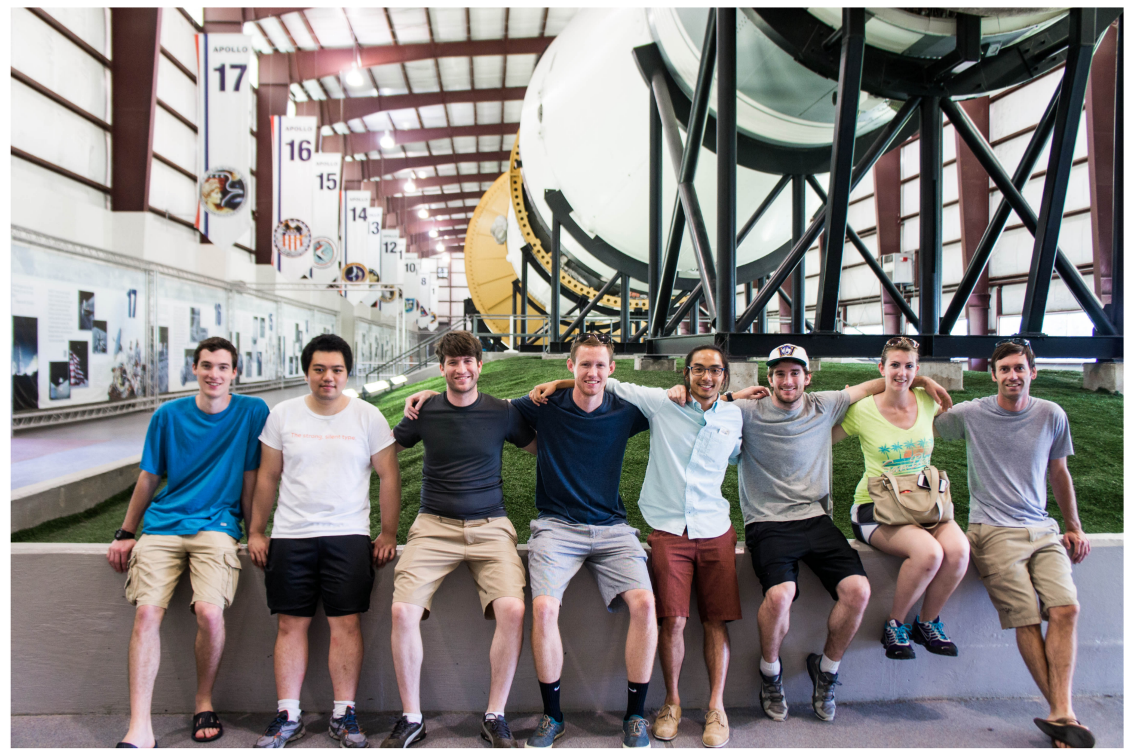

Figure 7: The Astrodawgs