FLOATINATOR: A LOW GRAVITY SIMULATOR TO STUDY PLUME-SURFACE INTERACTIONS.

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Introduction: Plume-surface interaction (PSI) mitigation is recognized to be one of the top priorities for any permanent or long-term outpost on other planetary bodies. Regolith ejected from vehicles upon landing or takeoff has the potential to cause significant harm to personnel or equipment located in the vicinity of the landing area [1], and deep cratering beneath a landing vehicle can potentially destabilize the soil and cause a tipping hazard [2]. In order to understand and model these phenomena, terrestrial test platforms must closely simulate environmental characteristics of planetary bodies where landings will occur. Ideally a test platform would include a full-scale rocket engine firing into a bed of high fidelity regolith simulant in vacuum and at reduced gravity, however, it can be challenging to mimic all of those parameters at once. Floatinator is being developed by Astrobotic as a PSI test platform that can address some of these challenges by allowing for a range of controlled accelerations, enabling it to simulate the gravity of the Moon, Mars, asteroids, and other celestial bodies. Initial iterations of the platform will test with cold gas in an ambient environment, but with the option to scale for hot fire and vacuum conditions in the future.

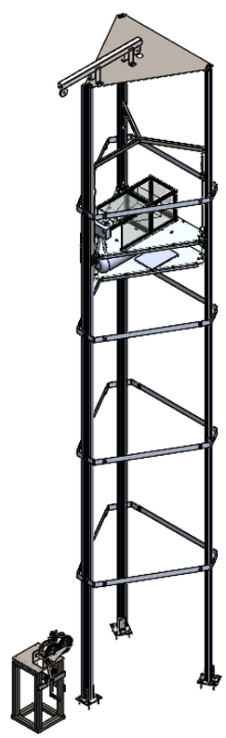

Figure 1: SBIR Phase II Floatinator design, 20' tall

SBIR Phase I Demonstrator: Initial development for Floatinator occurred under a NASA SBIR Phase I, completing in January 2024. Floatinator was demonstrated using a small-scale stand to prove out core capabilities of the system. Primarily, the goal of the Phase I effort was to build out a test unit where all elements move in a single reference frame. This included a cold-flow engine (using compressed gas) and split-view simulant bin to view subsurface cratering. The stand also integrated an accelerometer to track movement of the stand and high-speed camera mounting areas that were protected from regolith dust and ejecta. All system elements were hung from a platform beneath Astrobotic's existing dynamic PSI test platform, which has been previously used to move a rocket downwards while it fires onto a test sample. This existing infrastructure provided a good basis for the Floatinator system elements.

Figure 2: Phase I demonstrator

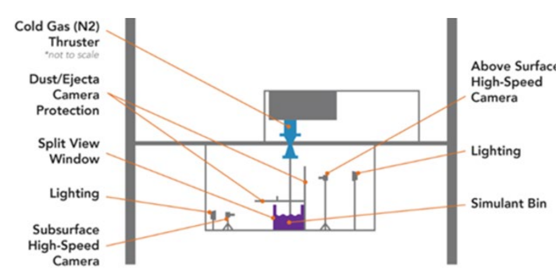

Figure 3: Phase I demonstrator diagram

Test Results from Phase I. The Phase I demonstrator had limited capability to achieve acceleration for extended periods, reaching a max velocity of 0.6 m/s in approximately 1,000 ms, however, it was able to show how a system could be operated to capture PSI phenomena in a low-gravity environment. Figure 4 shows a side-by-side comparison of crater progression during reduced gravity vs. 1-g gravity testing where the same plume gas supply pressure was used in both scenarios. Snapshots in Figure 4 were taken at the same time after the cold gas valve was actuated. From these images, plus the crater progression plot in Figure 5, it is clear that the crater formation progressed more rapidly in the reduced gravity scenario.

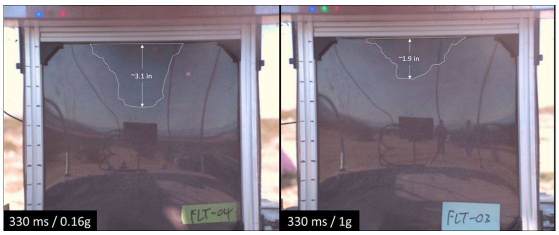

Figure 4: Reduced gravity vs. 1-g gravity; Snapshots at 330 ms with 400 psi plume supply pressure

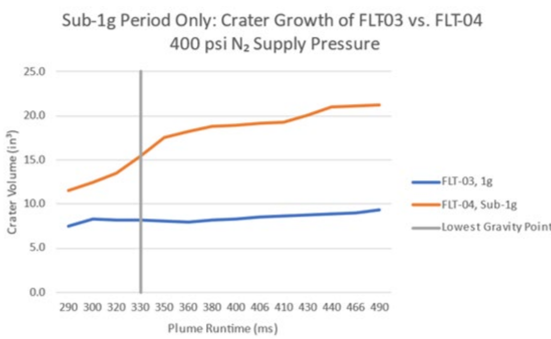

Figure 5: Plot of crater growth over time for reduced gravity vs. 1-g gravity tests

SBIR Phase II Objectives: Phase II began in July 2024, and the technical objectives during this ongoing phase are to build out a version of Floatinator with more capability to gather relevant PSI test data. The stand will be taller to allow for longer test durations as the system drops, and the acceleration will be tunable to achieve various desired values. It will be important to gather data at different accelerations in order to determine the relationship curves between gravity and granular material characteristics (cohesion, particle size, etc.). Astrobotic is working with Dr. Phil Metzger at the University of Central Florida to ensure Floatinator is designed and built in a way that progresses PSI research, particularly in the area of deep crater formation. This will compliment his recently published work regarding surface erosion [3].

SBIR Phase II Progress. The Phase II system requirements have been developed, and an initial prototype of the system has been designed and partially assembled (Figure 1, Figure 6). This prototype will be approximately 20 ft tall and will be used to iterate on different design solutions for the acceleration control mechanism. This mechanism will be key to successful operation of the system, and various different solutions will be trialed on the prototype. This may include counterweights, caliper brakes, electromagnetic brakes, or a combination of these mechanisms. Once an acceleration control system is successfully developed, Floatinator's height will be extended to approximately 50 ft, and final checkout testing will confirm consistent operations.

Figure 6: Initial assembly of 20' tall prototype

Future Applications: Beyond the Phase II program, Floatinator could be outfitted with a hot gas thruster to allow for more realistic plume structures. The current system is being designed with this in mind and could accommodate a simple pressure fed gaseous methane/oxygen rocket engine with heat sink cooling, similar to the engine used in prior PSI test programs at Astrobotic's Mojave facilities (formerly Masten Space Systems). Additionally, there may be opportunities to operate the system in large scale vacuum facilities, such as the Planetary Aeolian Laboratory (PAL) at NASA Ames Research Center, which has a 30 meter tall environmental test-chamber that could accommodate Floatinator [4]. Operating a hot-fire version of Floatinator in this facility would provide an environment that includes all major factors for PSI testing: reduced gravity, vacuum, realistic plume structure, and high-fidelity simulant.

References: [1] C. Immer *et al.*, "Apollo 12 Lunar Module exhaust plume impingement on Lunar Surveyor III," *Icarus*, vol. 211, issue 2, pp. 1089-1102, Feb. 2011. [2] P.T. Metzger and J.G. Mantovani, "Dust Transport and Its Effects Due to Landing Spacecraft," in *The Impact of Lunar Dust on Human Exploration*, J.S. Levine Ed. United Kingdom: Cambridge Scholars Publishing, 2021, pp. 67-87. [3] P.T. Metzger, "Erosion rate of lunar soil under a landing rocket, part 1: Identifying the rate-limiting physics," *Icarus*, vol. 417, May 2024. [4] National Aeronautics and Space Administration (NASA), "NASA Ames Planetary Aeolian Laboratory". https://www.nasa.gov/.