Floatinator

A Low Gravity Simulator to Study Plume-Surface Interactions

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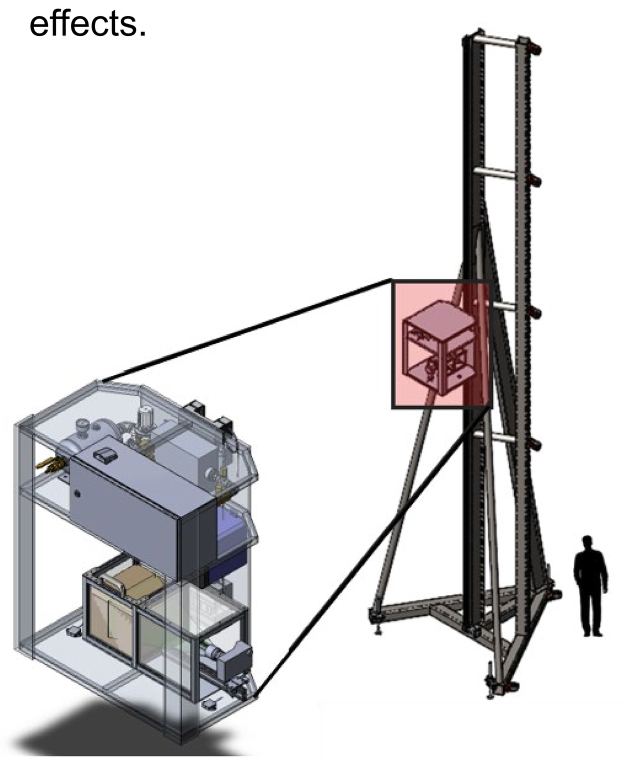
1. Abstract

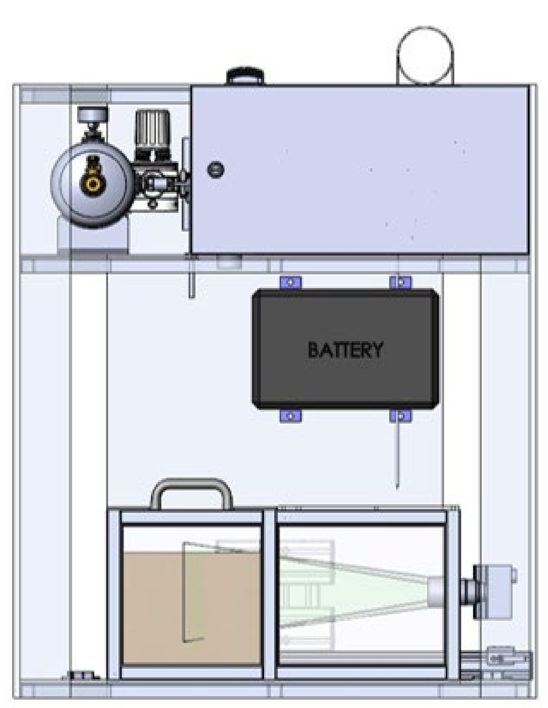
- As vehicles propulsively land on the surface of the Moon, plume-surface interactions (PSI) can generate high-speed ejecta particles and can cause deep cratering. This can be a hazard to nearby personnel and equipment and can even harm the lander itself, however, the physics of PSI are not completely understood.
- PSI experiments are difficult to conduct terrestrially since it is complex to reproduce all aspects of the lunar environment. An ideal experiment would use a large rocket engine firing into a bed of high-fidelity simulant in vacuum and at lunar gravity.
- Astrobotic is partially addressing this challenge by developing **Floatinator** as a PSI test platform that will simulate lunar gravity during PSI experiments. It will do this by accelerating a test platform downwards while directing a cold gas plume into a bed of regolith simulant.
- An SBIR Phase I successfully showed that relevant data could be captured using a low fidelity prototype, and a Phase II will improve on that system by achieving higher and more consistent acceleration rates.

2. System Overview

- The full-scale system will be a 36' tall drop-tower with an experiment sled that contains all test subsystems listed below. This sled will be lifted to the top of the tower, then accelerated downwards at a controlled rate to reproduce a desired gravity level in the experiment reference frame.
- Experiment Sled Subsystems:
  - **Cold Gas Thruster**: This subsystem generates a nitrogen plume and consists of a pressurized tank, pressure regulator, firing control valve, exit orifice, and associated plumbing.
  - **Simulant Bin:** This bin will be positioned below the thruster and will contain high-fidelity simulant. It will have a split-view window to allow viewing of sub-surface cratering.
  - **High Speed Camera**: This camera will capture high-speed footage of PSI effects.



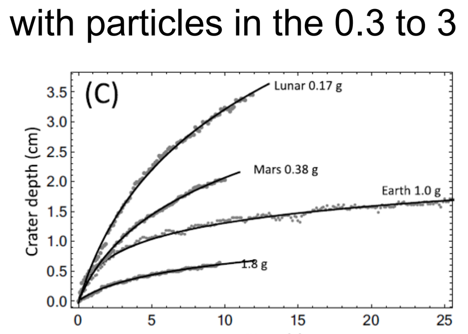
Full-Height Floatinator with Test Sled Detail



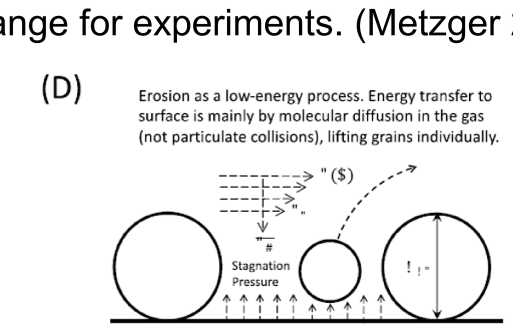
Test Sled Cross Section

3. Key Benefits / Concepts

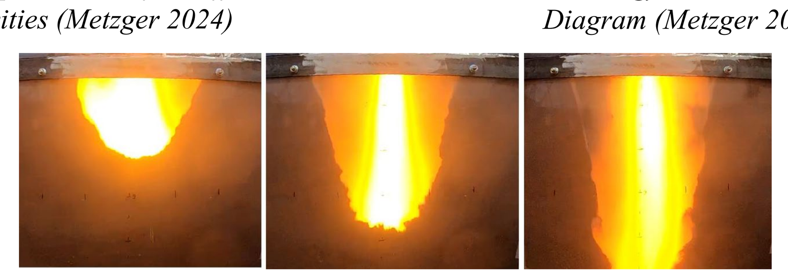
- Deep cratering physics are not well characterized. It will be important to understand what size of landers will initiate deep cratering so we can plan for those hazards.
- Some low-gravity deep cratering experiments have been done at limited setpoints, but understanding the full set of curves will help characterize the underlying physics.
- Floatinator will allow for quick turnaround of multiple experiments at different gravity levels.
- Regolith cohesion is a dominant force in PSI at low gravity, so it is key to use a simulant with particles in the 0.3 to 3 μm range for experiments. (Metzger 2024)



Crater Depth vs. Time for Different Gravities (Metzger 2024)



Low-Energy Erosion Process Diagram (Metzger 2024)



Deep Crater Formation Visible Through Split-View Window During Hot Fire Test (Masten Space Systems 2022)

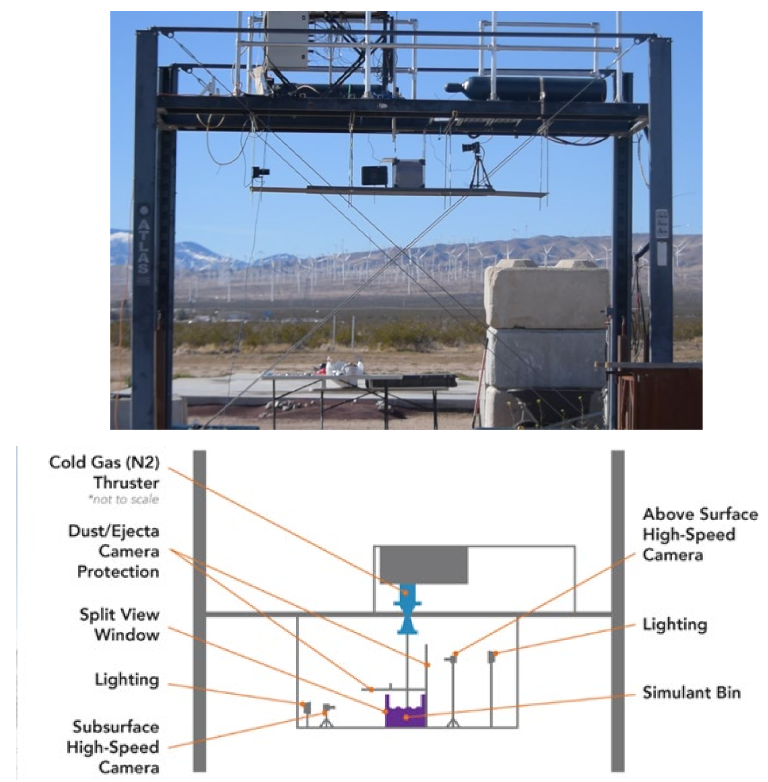
NASA SBIR Phase I & II Activities

4. Phase I System Setup

- Used existing dynamic PSI test stand in Mojave, CA to mount extended platform for Floatinator experiment systems
- Underlying car-lift mechanism allowed limited acceleration period; 490 ms to reach max velocity of 0.6 m/s
- Test objective was to prove feasibility of capturing relevant PSI data while accelerating downward, even if limited

Subsurface High-Speed Camera (Left); Top-Down View from Cold Gas Feed Line (Right)

Simulant Bin, Front (Left); Simulant Bin, Side (Right)



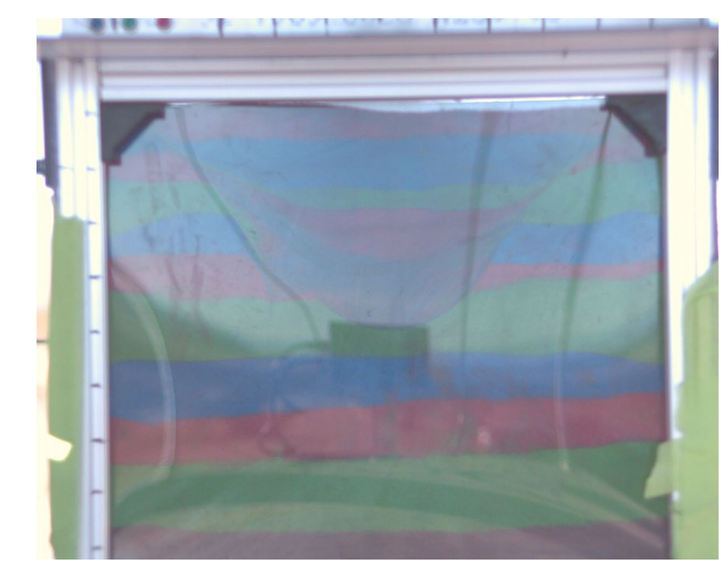
Phase I Test Platform (Top); Platform Diagram (Below)

5. Phase I Test Matrix

- Performed tests at certain fixed feed pressures, first at 1-g and then at reduced gravity
- Regolith simulant was low-fidelity, sieved with No. 50 sieve mesh (< 297 μm particles)
- Also tested using layered colored sand to visualize how bulk shearing occurred

Test No.	Gravity	Duration	Thruster Pressure	Nozzle Height	Test Material
FLT-01	1g	4 s	300 psi	3.88"	Regolith Simulant
FLT-02	0.16–1g	4 s	300 psi	3.88"	Regolith Simulant
FLT-03	1g	4 s	400 psi	3.88"	Regolith Simulant
FLT-04	0.16–1g	4 s	400 psi	3.88"	Regolith Simulant
FLT-05	0.16–1g	4 s	400 psi	3.88"	Colored Sand
FLT-05_2	0.16–1g	4 s	400 psi	3.88"	Colored Sand

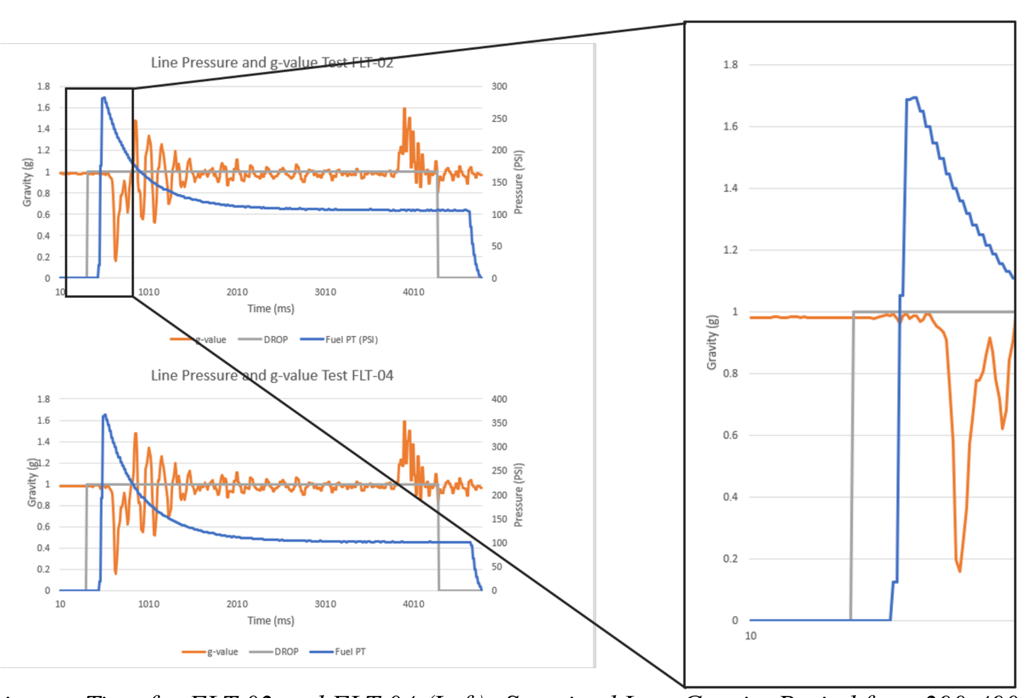
Low-Fidelity Simulant Material



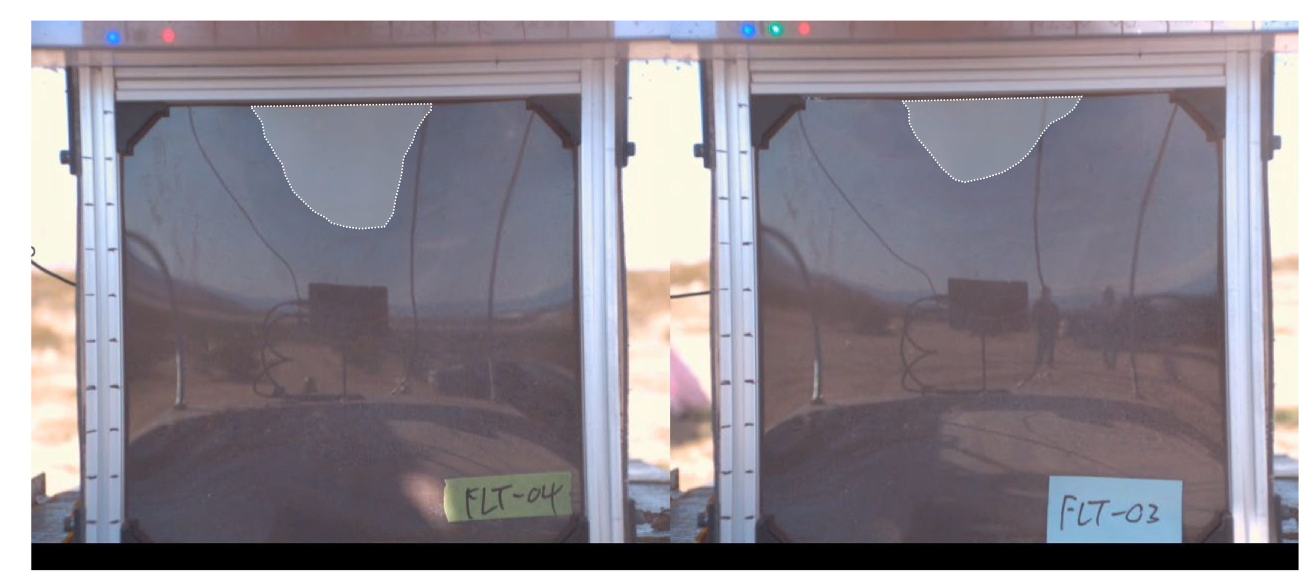
Colored Sand Layered in Sample Bin

6. Phase I Test Results

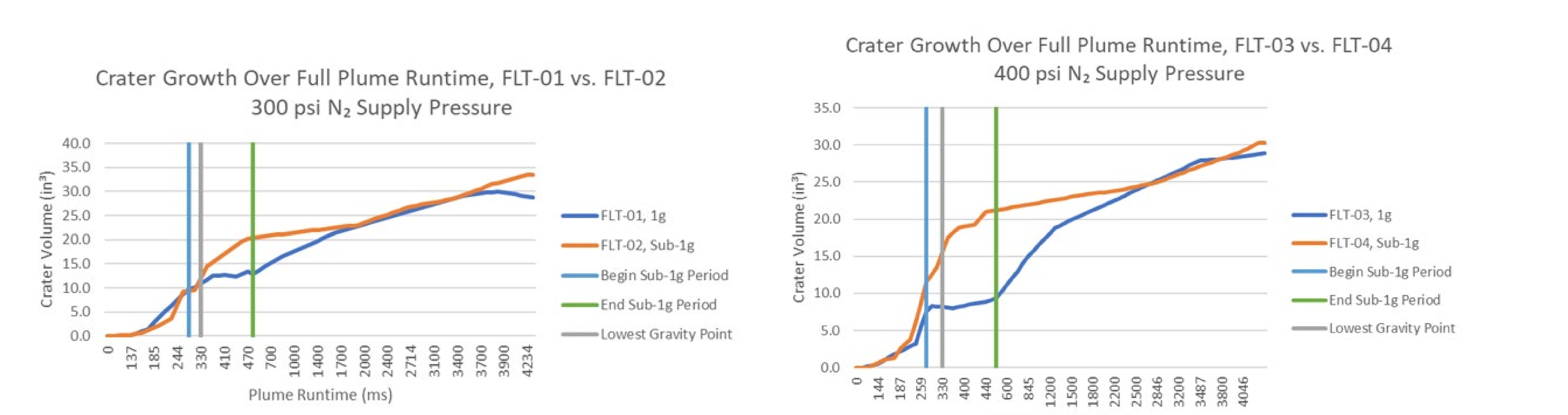
- Tests exhibited a limited and inconsistent low-gravity period for 200 ms before the platform reached max velocity
  - Low-Gravity Period: 290-490 ms
  - Maximum Low-Gravity Point: 0.16 g at 330 ms
- Despite the limited low-gravity period, data showed a distinct increase in crater growth rate during that time



Acceleration vs. Time for FLT-02 and FLT-04 (Left); Sustained Low-Gravity Period from 290-490 ms (Right)



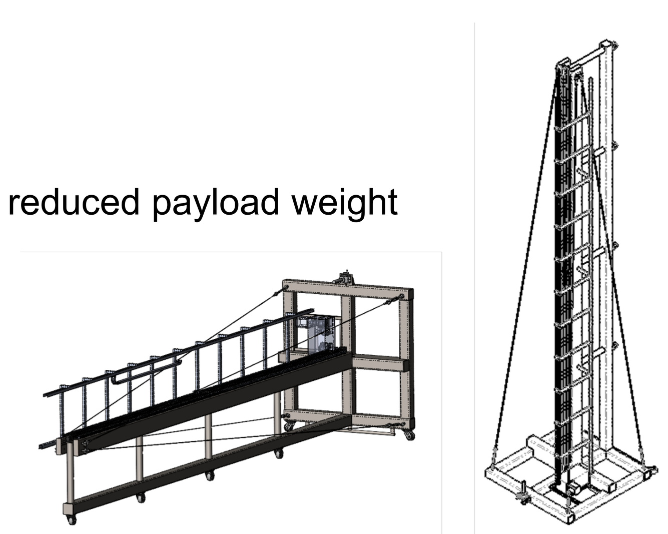
Crater Formation Comparison During Tests (Highlighted); Test No. FLT-04 at Reduced Gravity (Left); Test No. FLT-03 at 1-g Gravity (Right)



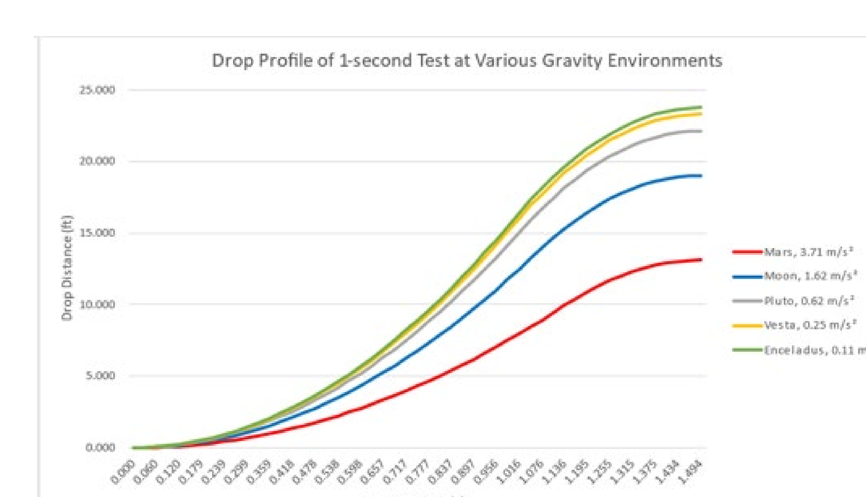
Charts Showing Increased Crater Growth Rate During Low Gravity Periods; FLT-01 vs. FLT-02 (Left); FLT-03 vs. FLT-04 (right)

7. Phase II Progress & Future Work

- Designed primary structure and procuring components for motion control subsystem
- Targeting 700 ms at lunar gravity with 550 lbs payload; Longer experiment times would need reduced payload weight
- Final verification testing Q3 2026
- Future Work
  - Complete system integration
  - Perform full test to verify functionality
  - Explore opportunities for additional tests campaigns to support model development and verification



Full-Height 36' Tall Floatinator Stand; Horizontal for Integration (Left); Vertical for Testing (Right)



Notional Drop Profiles for Various Tested Gravity Levels

References: P.T. Metzger, "Erosion rate of lunar soil under a landing rocket, part 1: Identifying the rate-limiting physics," Icarus, vol. 417, Jul. 2024.