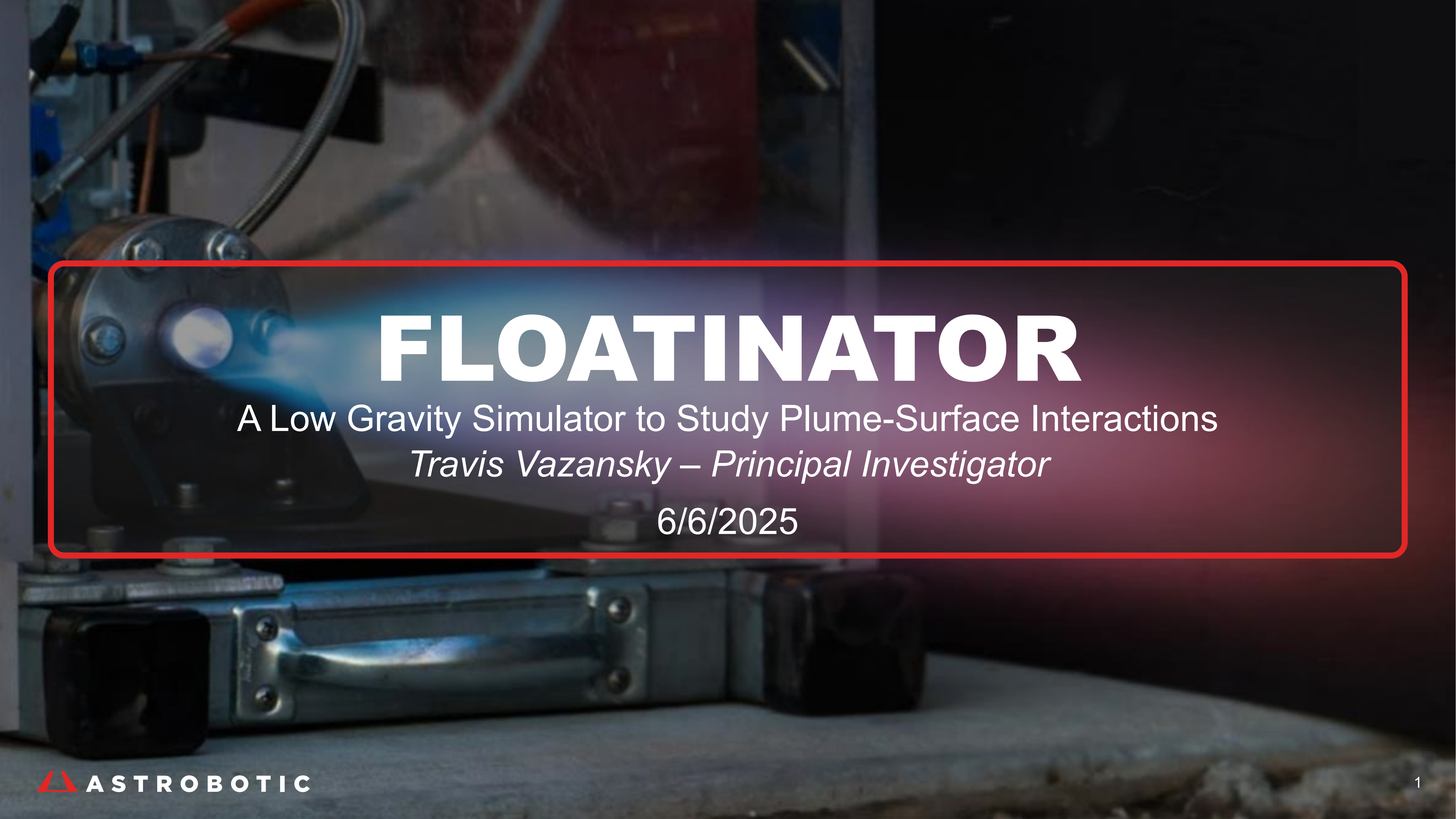


FLOATINATOR

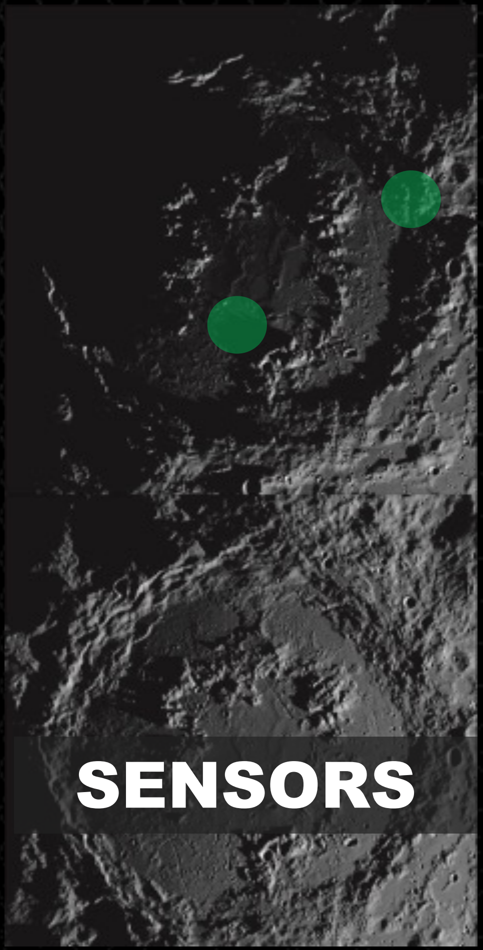
A Low Gravity Simulator to Study Plume-Surface Interactions

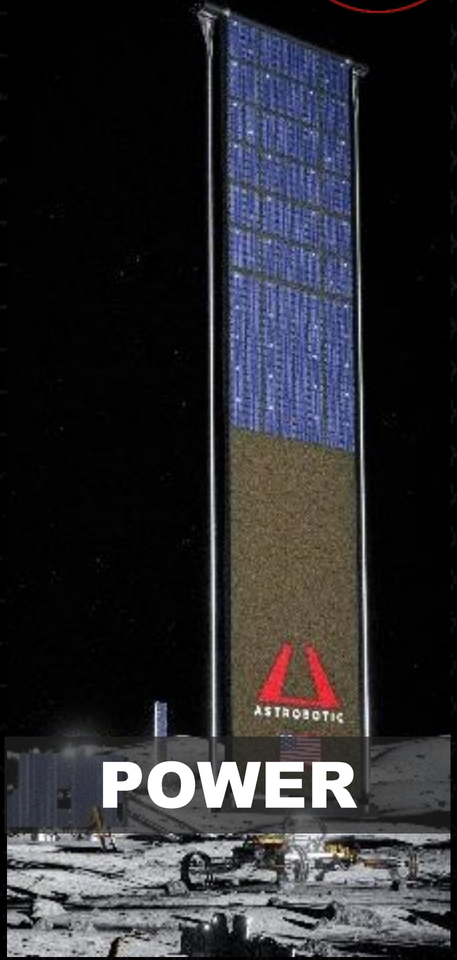
Travis Vazansky – Principal Investigator

6/6/2025

ASTROBOTIC

WHAT WE DO





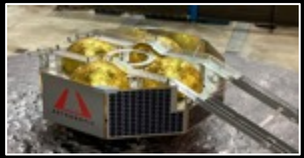
Astrobotic is a leading provider of autonomous space technologies, and over the next five years we are bringing our product lines together to pioneer infrastructure for the Moon.

MAJOR ASTROBOTIC PROGRAMS

DELIVERY

Peregrine Lander
Surface payload: Up to 130 kg

Griffin Lander
Surface payload: 500 kg



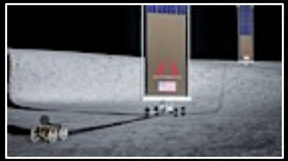
MOBILITY

CubeRover
Surface payload: Up to 24 kg

Polaris Rover
Surface payload: 24 kg

POWER

LunaGrid
Provides 10s of kW of Power



PROP

Xodiac
Suborbital testing up to 500 m

Xogdor
Suborbital testing up to 200 km

PROPULSION & TESTING - MOJAVE

Rocket Testbeds

19 years of vertical-takeoff vertical-landing rocket flight experience.
Testing technologies aboard our reusable VTVL vehicles & engine stands to advance readiness for space.


Xombie


Xoie


Xaero-A

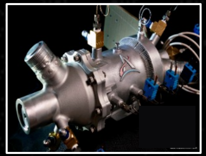

Xaero-B

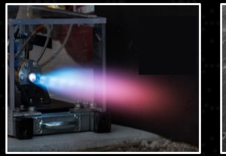

Xodiac


Xogdor

Tech Development

Developing mission-enabling technologies to solve the most pressing space challenges

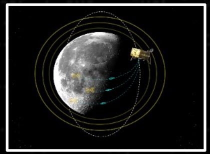

3D-printed rocket parts


Propulsion technologies (RDRE)


Landing pad technologies


Heat & power systems


Rocket mining system

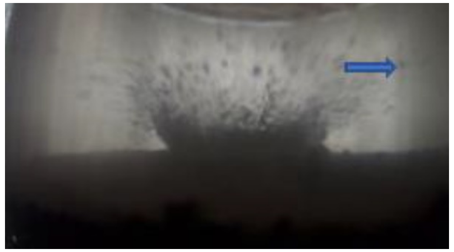

Lunar "GPS" network

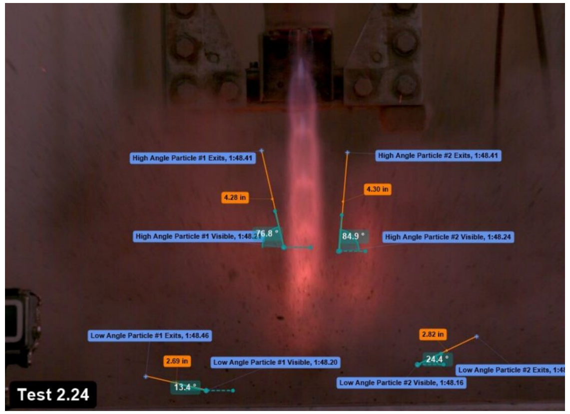
PRIOR PSI WORK

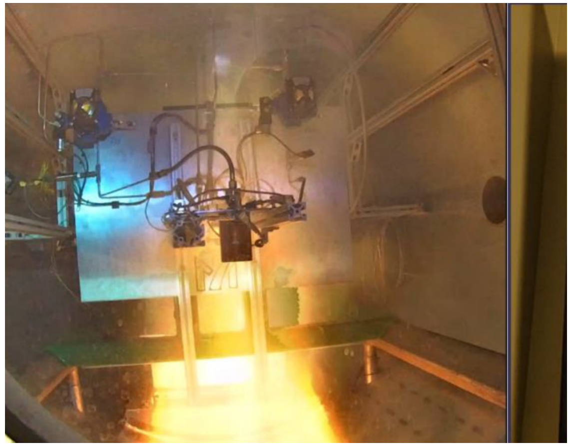
- Tests Conducted
  - 22 hot fires (6 split view)
  - 20 cold gas
  - 35 vacuum + free fall
  - 2 vacuum tests

- Test Stands / Engines
  - 100 lbf ambient stand
  - 50 lbf vacuum
  - Cold gas vacuum

- Collected Data
  - Engine parameters
  - Material compaction
  - Surface particle velocity and angle
  - Subsurface crater formation





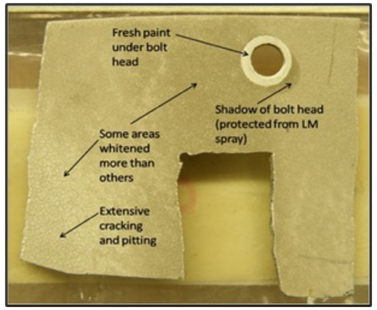


PROGRAM BACKGROUND AND GOALS

Apollo 15 landing video. Source: UCF CLASS [1]

Relevance

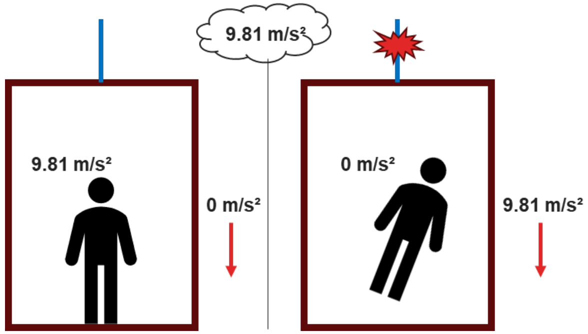
- Computational models are used to predict plume-surface interaction (PSI) phenomena
- Models are validated by comparison to historical footage or terrestrial testing
  - Historical footage is limited
  - Terrestrial testing does not capture all aspects of a relevant environment, including reduced gravity and atmospheric characteristics
- The value of reduced gravity tests has been demonstrated by surface scouring experiments that led to successful unraveling of surface erosion physics

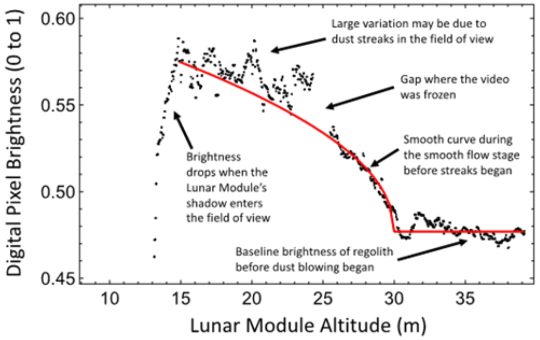


Surveyor 3 sample retrieved during Apollo 12. Sources: UCF CLASS [1] and Immer (2011) [3]

Solution - Floatinator

- Develop a test stand that is capable of simulating a reduced gravity environment during PSI test fires that generate deep cratering effects
- Direct a plume into a bed of simulant while accelerating both the plume source and simulant bin together, producing a reduced gravity environment
- Use high speed cameras to film PSI phenomena:
  - Surface-level ejecta
  - Deep cratering viewed through a subsurface observation split-view window
- Use data from multiple simulated gravity levels to determine where interparticle forces dominate over lower gravity effects





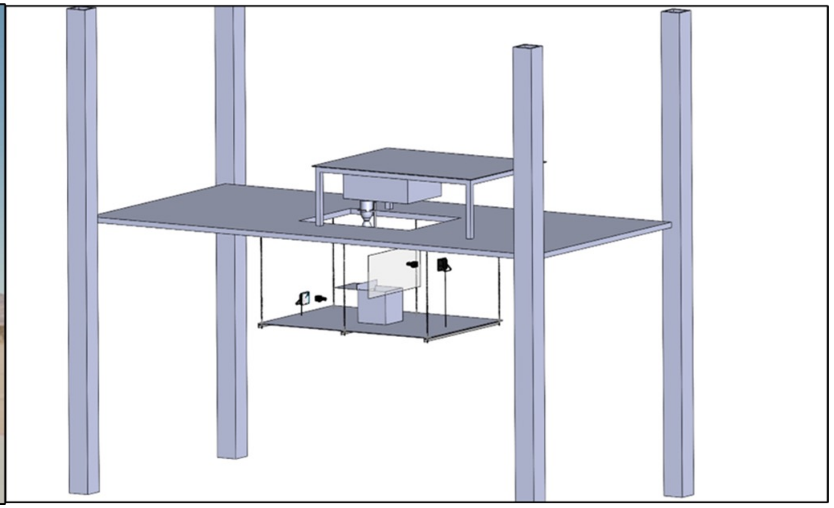
Results showing surface scouring theory developed with data from reduced gravity tests. Source: Metzger & Sapkota (2022) [2]

FLOATINATOR SBIR PHASE I

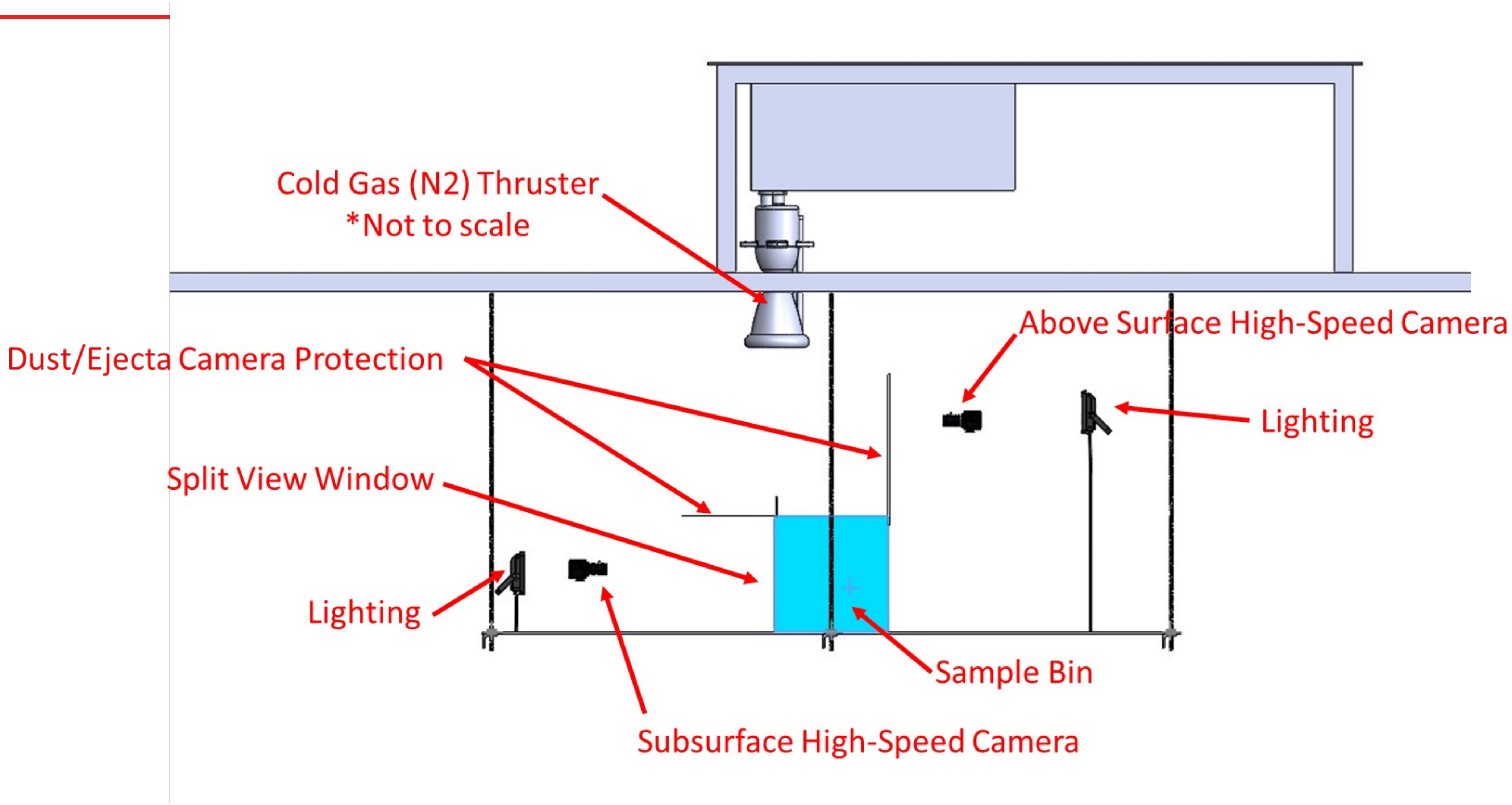
UCF
UNIVERSITY OF CENTRAL FLORIDA

- Primary Objective
  - Build out a PSI test unit where all elements move in a single reference frame and successfully capture data related to reduced gravity effects

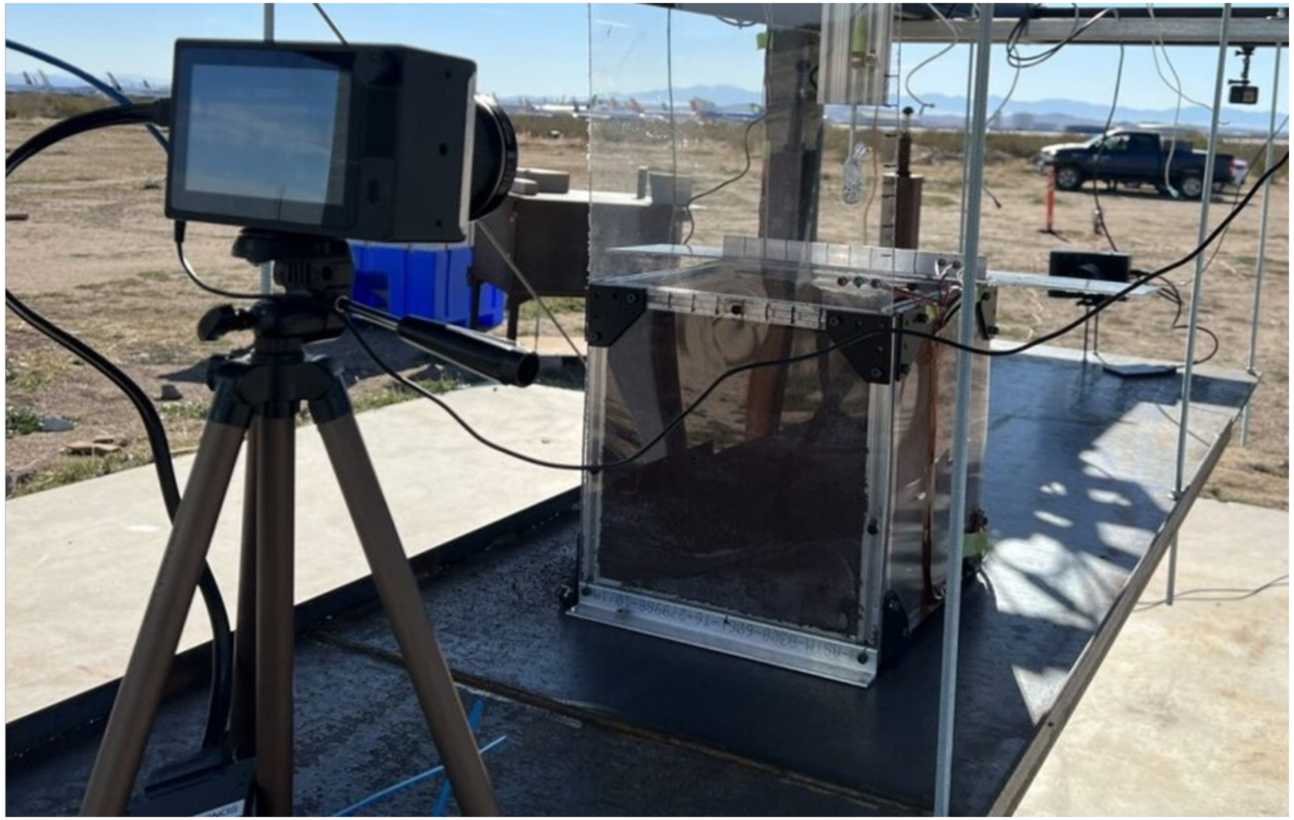
- Test Stand Elements
  - Used Dropinator test stand as base platform
  - Limited acceleration profile, but sufficient to observe reduced gravity effects during a PSI event
  - Cold flow, compressed gas plume
  - 1 ft³ split view simulant bin
  - High speed cameras



FLOATINATOR SBIR PHASE I

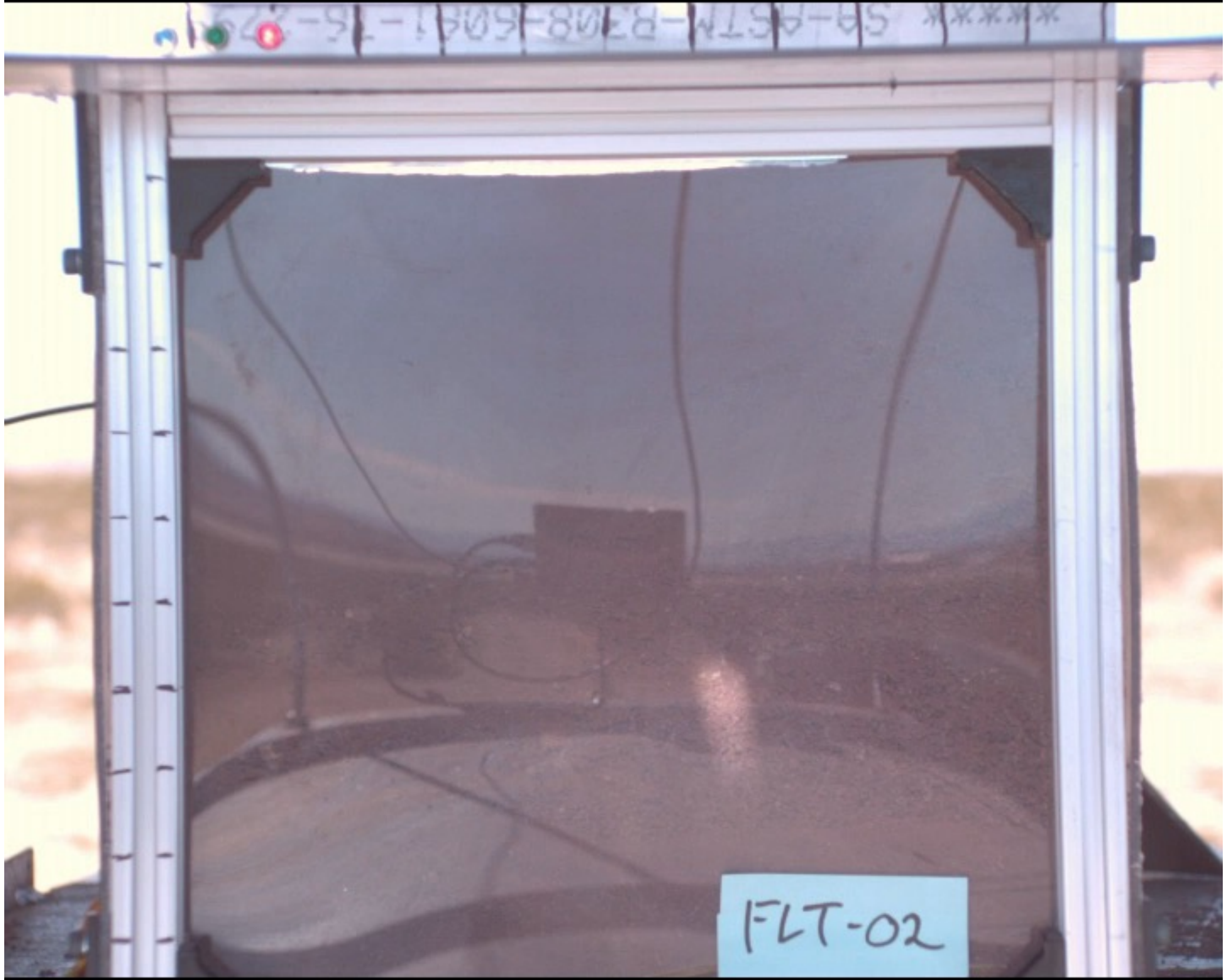


FLOATINATOR SBIR PHASE I



FLOATINATOR SBIR PHASE I

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



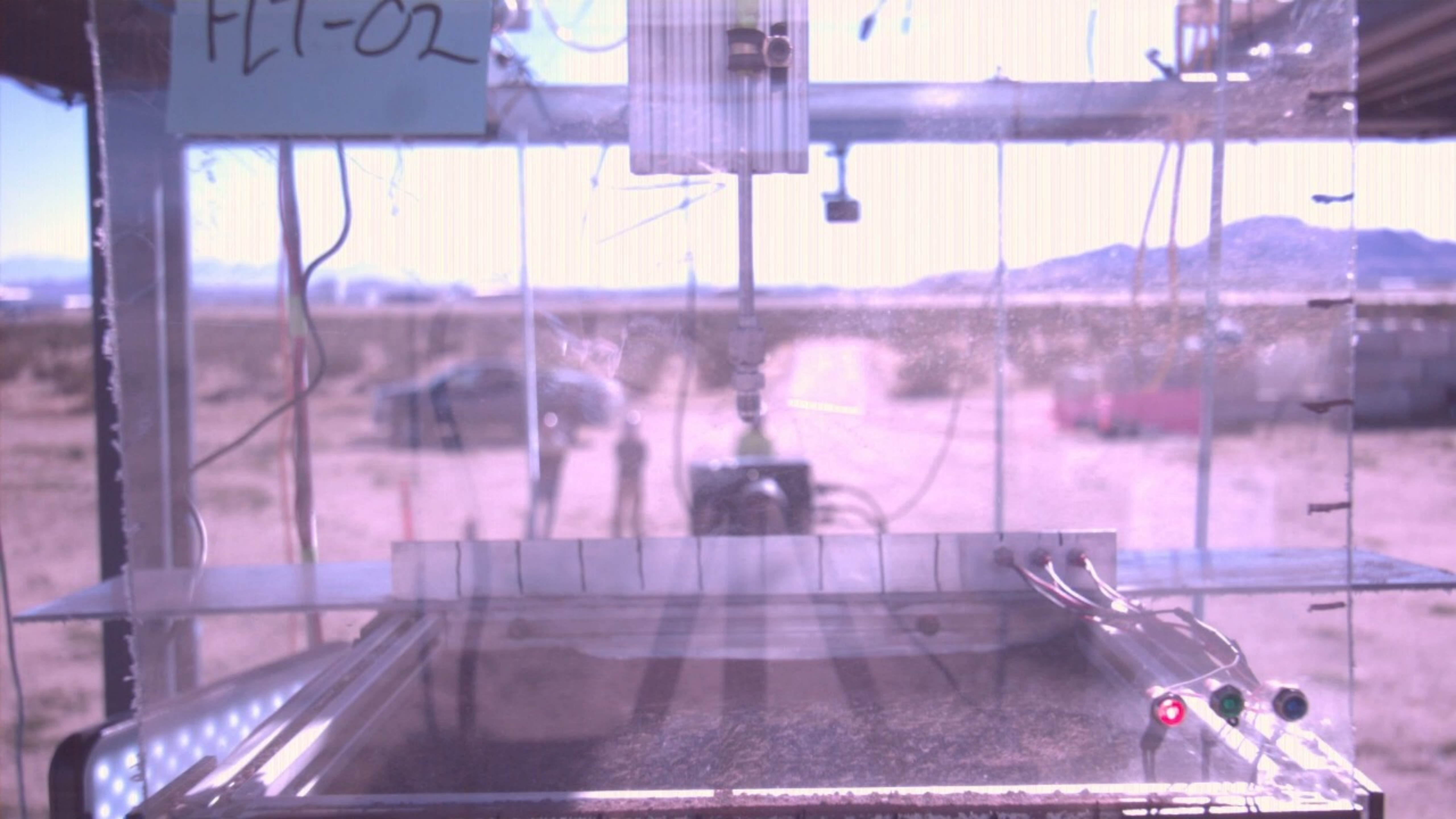
LED indicators

- Locks disengage = red
- Drop relays activate = green
- Run valve = blue

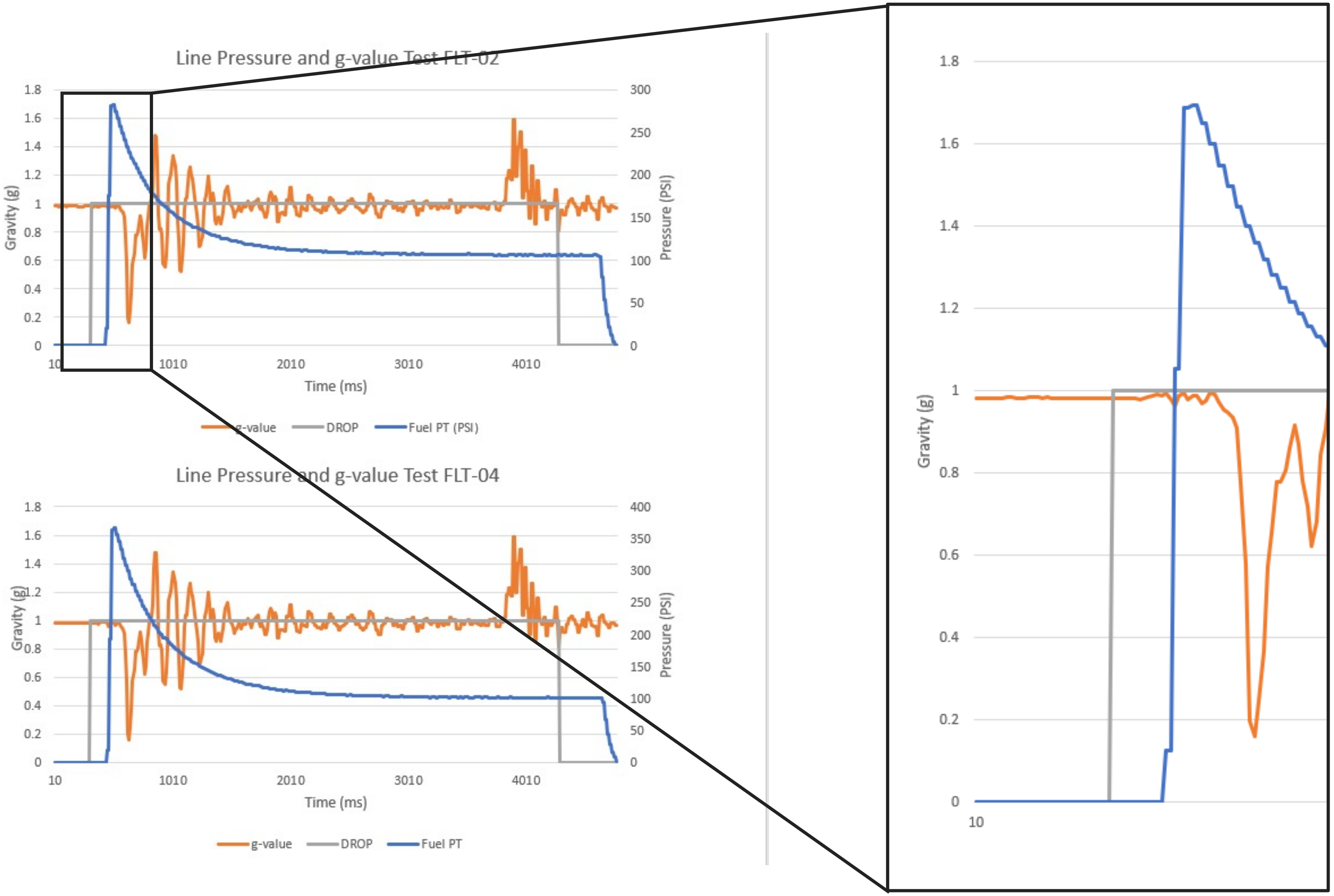
<u>LED indicators</u>

- Locks disengage = red
- Drop relays activate = green
- Run valve = blue


FLT-04
FLT-03

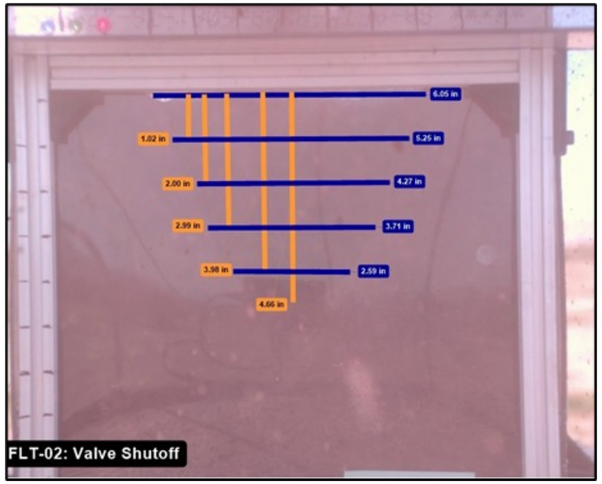


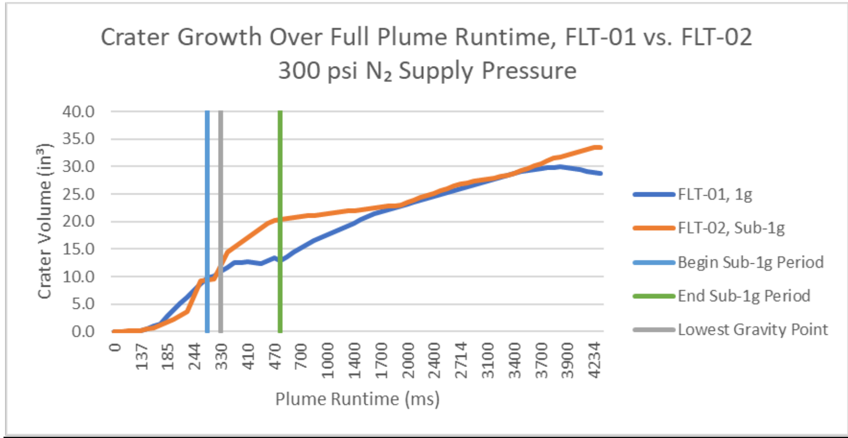
FLOATINATOR SBIR PHASE I

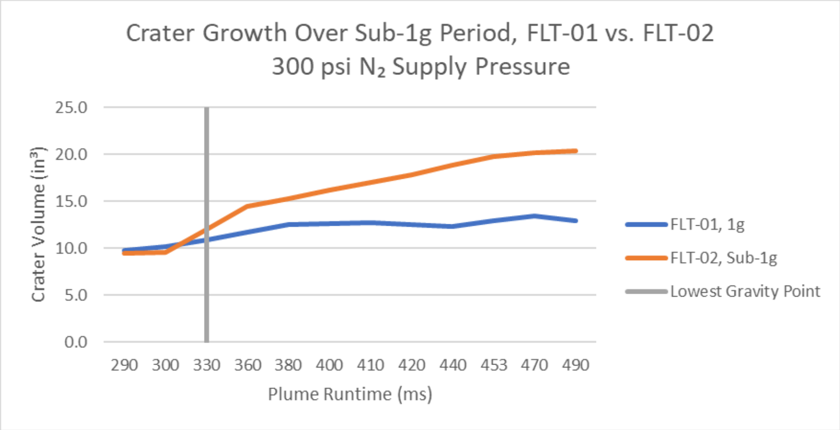


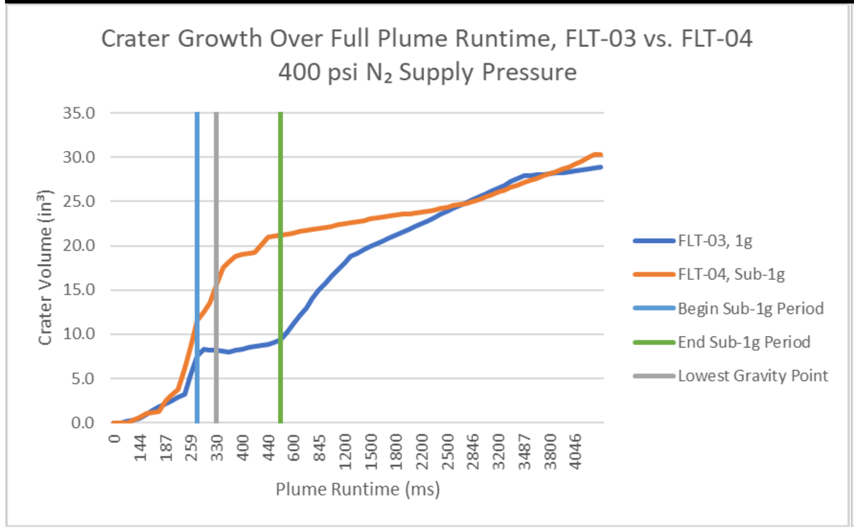
FLOATINATOR SBIR PHASE I

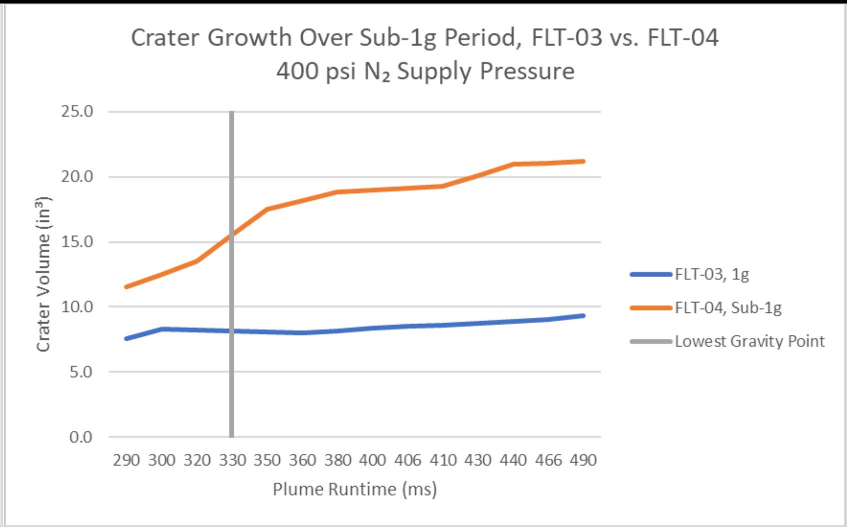
- Differences in crater growth rate are apparent
- Even short duration low gravity periods capture relevant data (~200ms)







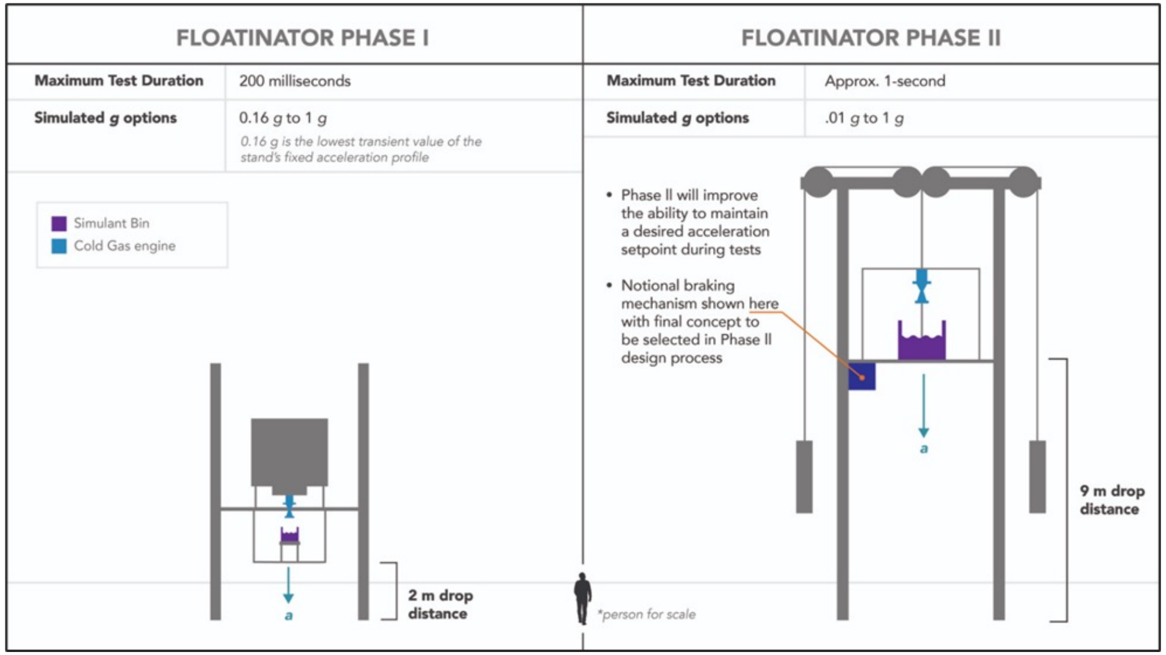




*Note: Paraboloid shape assumed for volume; V = π/2 * (Crater Radius)^2 * (Crater Depth)/2

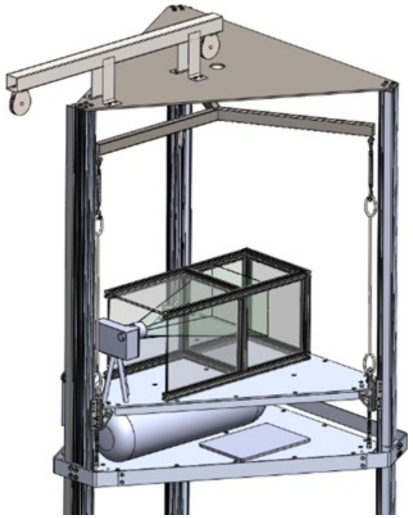
SBIR PHASE II OVERVIEW

- Design and construct larger Floatinator system to allow for faster and more consistent acceleration with more travel distance
- Implement cold gas thruster and include accommodations for future hot fire thruster
- Evaluate alternatives for braking mechanisms to accurately control acceleration rate
- Demonstrate performance and collect data at multiple gravity levels



PHASE II PROGRESS

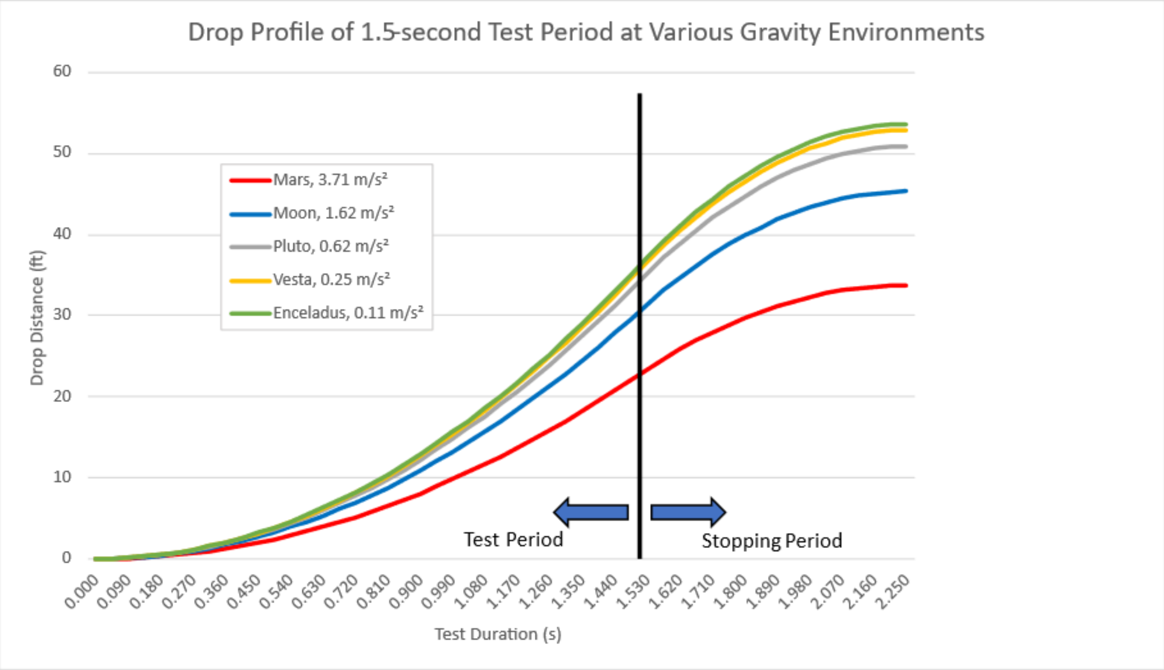
- Designed short (20 ft) prototype for braking system development
- 3 ft equilateral triangle platform allows for :
  - 1 ft³ container of regolith
  - High Speed camera
  - Nitrogen cylinder and cold gas thruster
  - DAQ
  - Power supply
- 20 ft sections of 80/20 can be extended in next iteration to increase test stand height
- Procured LHS-1E lunar highlands simulant from Space Resource Technologies

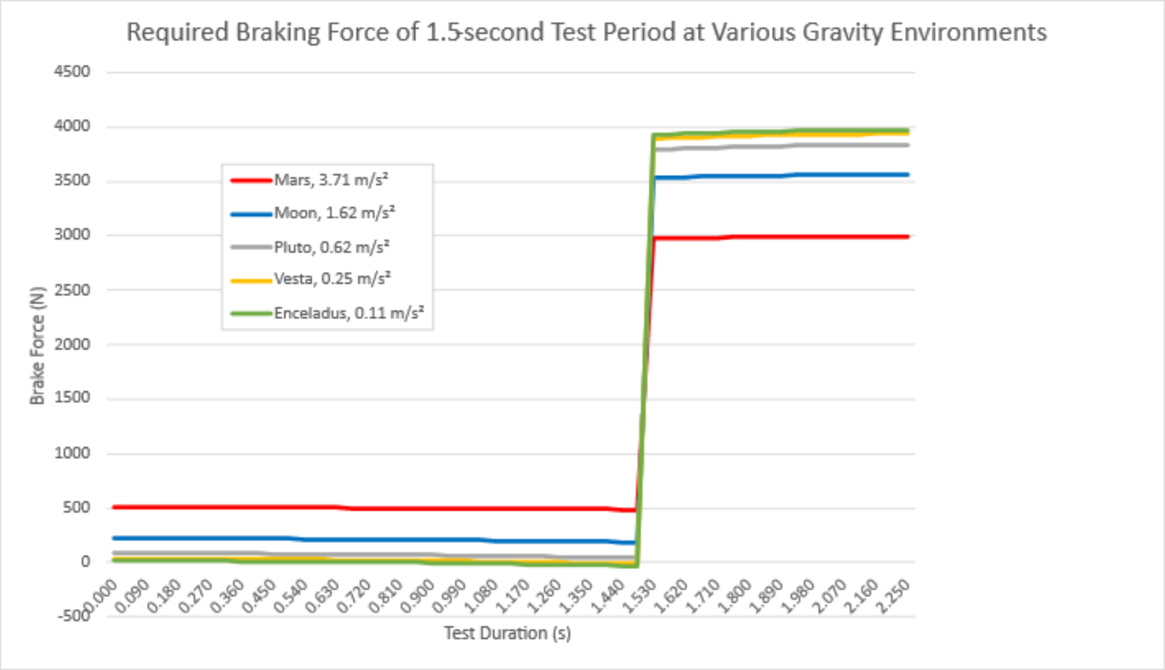


Simulant Name: Engineering Grade Lunar Highlands Simulant
Simulant Type: Engineering Grade
Reference Material: Average lunar highlands
Uncompressed Bulk Density: 1.27 g/cm^3
Median Particle Size: 60 µm
Particle Size Range: <0.04 µm – 1000 µm

PHASE II PROGRESS

- Approximately 50 ft drop height required to achieve 1.5 second test period at lower gravity levels
- Assumes deceleration during the stopping period is twice the acceleration
- Example:
  - Desired Gravity: 1.62 m/s²
  - Required Test Period Acceleration: 8.19 m/s²
  - Stopping Period Deceleration: 16.38 m/s³





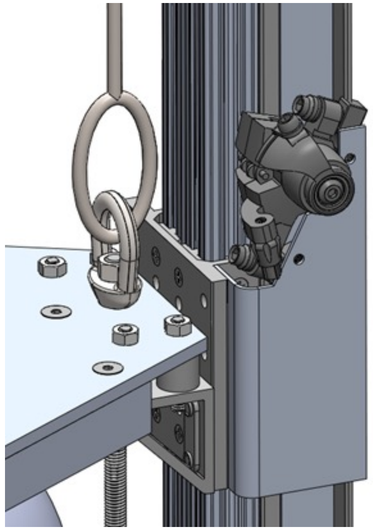
PHASE II NEXT STEPS

- Test out various braking mechanism options
  - Caliper brakes
  - Counterweights
  - Electromagnetic brakes

- Develop controls to accurately maintain desired acceleration throughout descent

- Perform checkout test campaign
  - Majority of project resources dedicated to test stand development
  - Follow-on campaign will be required to fully investigate PSI phenomena and advance understanding of underlying physics

- Project completion July 2026

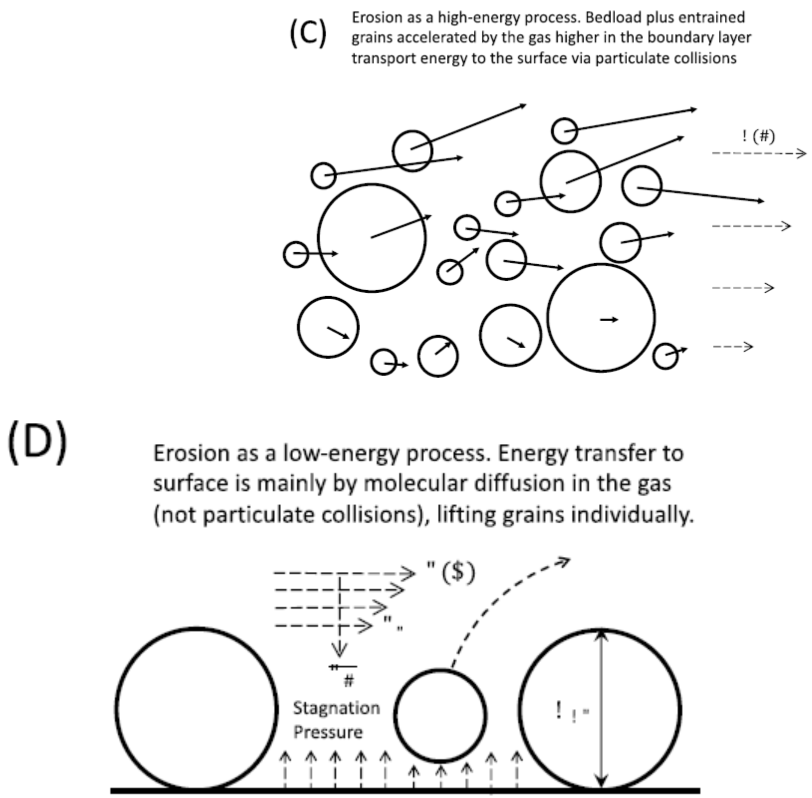


Linear Eddy Current Brakes. Source: Wikipedia [4]

USING FLOATINATOR TO UNDERSTAND PSI

- What is the current understanding of erosion physics?
  - This is a low energy process dominated by gas lifting grains individually off the surface, not high energy particulate collisions
  - This means the amount of ejecta entrained in the plume stream does not affect the erosion rate, rather it is driven by molecular diffusion of plume gas from the laminar stream down into the granular surface
  - The parameter <D>, mean particle diameter of the soil grains, is presumably the average height a grain must reach before it be swept downwind by the plume gas stream
  - This understanding suggests that cohesive energy density plays a dominate role in low gravity environments
  - Cohesive energy density arises primarily from particles in the 0.3 to 3 μm size range

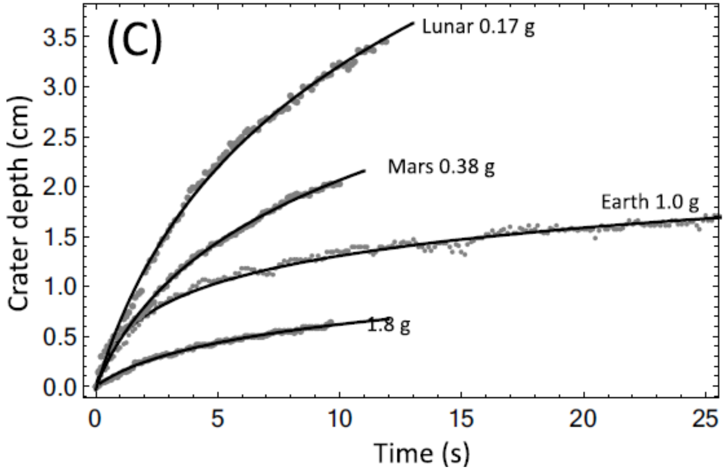
- What gaps in the theory need to be investigated by experiment?
  - Accurate measurement of <D> through observation of crater formation at various gravity levels
  - What are the threshold conditions where deep cratering begins?



High-energy erosion process (top) vs. Low-energy erosion process (bottom). Source: Metzger (2024) [5]

USING FLOATINATOR TO UNDERSTAND PSI

- Describe a test campaign to address these gaps
  - Types of granular materials tested
    - Coarse sand, where α=0, to use as a baseline for determining gravity scaling
    - Lunar simulants
  - Accurately characterize granular materials
    - Particle size distribution, P(D)
    - Cohesive energy per volume of soil, α (J/m³)
  - Test materials at multiple gravity levels
    - Test each material at Earth gravity, lunar gravity, and several points in between
  - Required instrumentation & measurements
    - Split view window to observe crater formation
    - High speed cameras
  - Cold gas plume



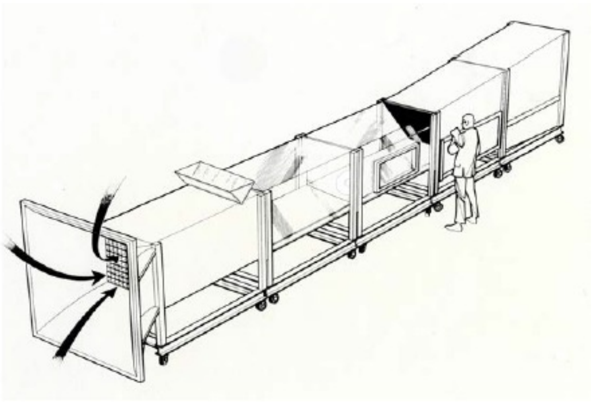
Crater depth vs. time for different gravities fitted by logarithmic functions. Floatinator would help fill in the gaps at intermediate gravities. Source: Metzger (2024) [5]

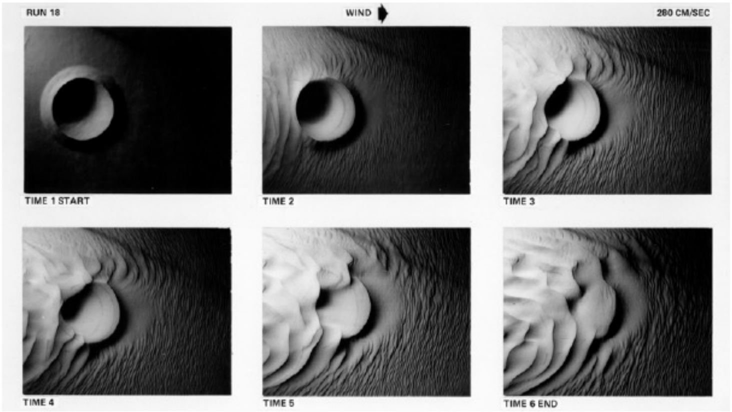
Take Away

- We want to understand the underlying physics, not just the phenomena at a particular location
- Investing many different gravity levels will help build out the curves
- Floatinator is designed to do this quickly at many different gravity levels

BEYOND PHASE II

- Comprehensive test campaign – Build out the curves
  - Larger test matrix to collect more data at multiple gravity levels
- Testing at lower pressure atmosphere
  - Preliminary discussions with NASA Ames Planetary Aeolian Laboratory (PAL)
  - 140,000 ft^3 test volume able to accommodate 50’ tall Floatinator system
  - Chamber can achieve Martian equivalent atmosphere (5.26 millibars)
- Implement hot fire thruster
- Other system tests needing reduced gravity
  - Regolith conveyance systems
  - Other ideas from the community are welcome!

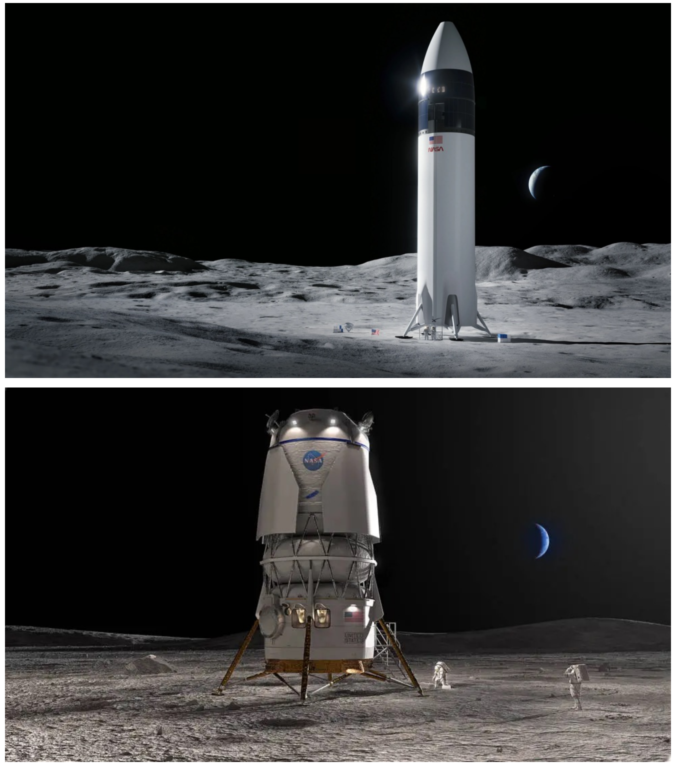




Martian Surface Wind Tunnel (MARSWIT) Operating within the Ame’s PAL Chamber. Source: NASA [6]

WHY?

- Safely explore the surface of the Moon and Mars
- Safely land vehicles through a complete understanding of PSI mechanics
- Protect people and physical assets from harmful ejecta
- Better understand requirements for outpost layout and hazard mitigation



Artemis HLS landers. Source: NASA [7]

Artemis Base Camp. Source: NASA [8]

Questions?

REFERENCES

[1] University of Central Florida, Center for Lunar & Asteroid Surface Science (CLASS), “Why Planetary Landing Plume Effects are Important,” [Online]. Available: https://sciences.ucf.edu/class/landing-team/background/. [Accessed May 29, 2025].

[2] P.T. Metzger and D. Sapkota, “Post-Processing of Existing Experimental Data Describing Surface Erosion for Second Year Support of the NASA/MSFC Plume Surface Interaction Task,” Final Report (Year 2), NASA Grant 80NSSC20K0810, University of Central Florida, Sep. 6, 2022.

[3] 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.

[4] Wikipedia. “Eddy current brake.” [Online]. Available: https://en.wikipedia.org/wiki/Eddy_current_brake. [Accessed: May 29, 2025].

[5] P.T. Metzger, “Erosion rate of lunar soil under a landing rocket, part 1: Identifying the rate-limiting physics,” Icarus, vol. 417, Jul. 2024.

[6] National Aeronautics and Space Administration (NASA), “NASA’s Planetary Aeolian Laboratory: Guidebook for Proposers”. [Online]. Available: https://rgcps.asu.edu/documents/PAL_Proposers_Guidebook_2023_v10.pdf. [Accessed: May 29, 2025].

[7] National Aeronautics and Space Administration (NASA), “About Human Landing Systems Development”. [Online]. Available: https://www.nasa.gov/reference/human-landing-systems/. [Accessed: May 29, 2025].

[8] National Aeronautics and Space Administration (NASA), “Lunar Living: NASA’s Artemis Base Camp Concept”. [Online]. Available: https://www.nasa.gov/blogs/missions/2020/10/28/lunar-living-nasas-artemis-base-camp-concept/. [Accessed: Jun. 5, 2025].