National Aeronautics and
Space Administration

NASA Plume-Surface Interaction (PSI) Testing to Reduce Risk from Propulsive Landing

Ashley Korzun (D205)
NASA Langley Research Center

And the Entire HLS PSI Test Team

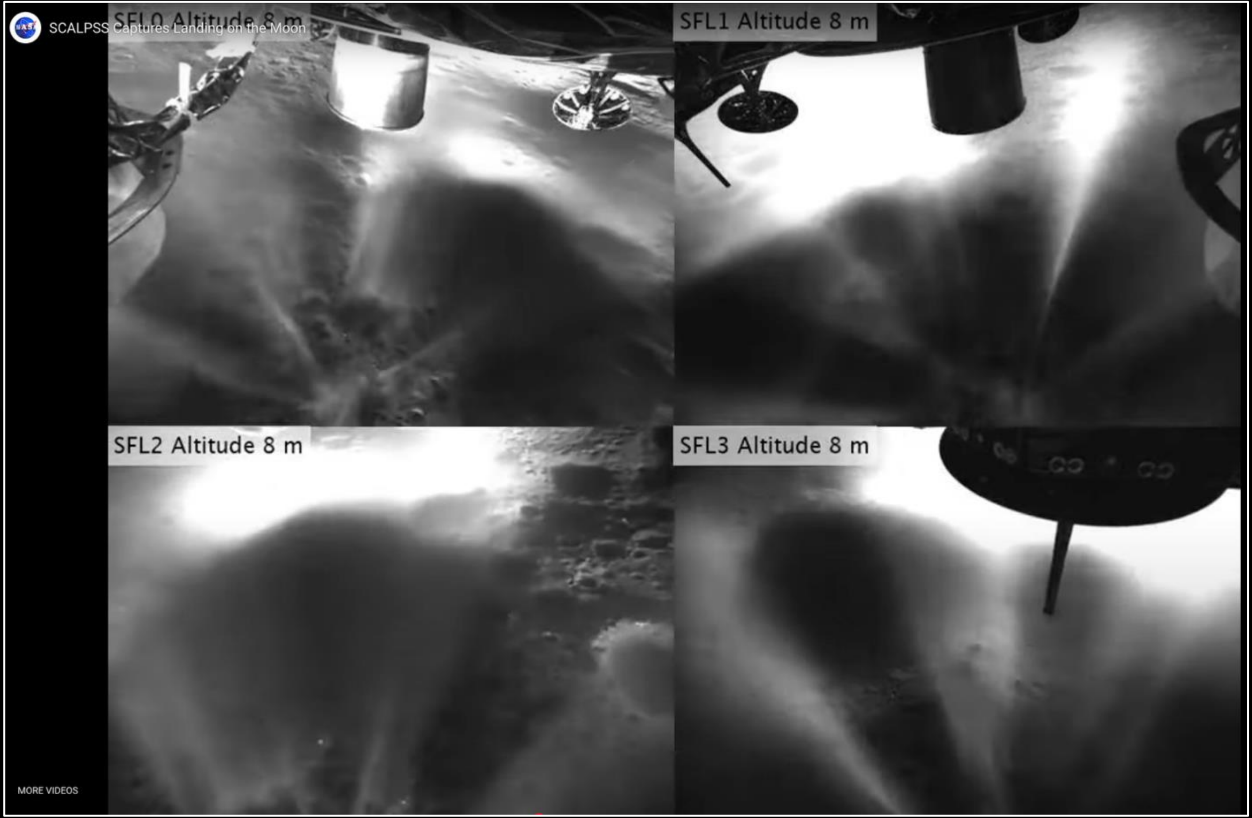
2026 EDL Summer Seminar
13 July 2026

Introduction

*Rocket **plume-surface interaction (PSI)***

describes the lander environment induced by impingement of rocket exhaust on regolith of the Moon or planetary bodies

Apollo 11 (NASA)



SCALPSS Imagery on Firefly Blue Ghost (NASA)

Risks Posed to Landers by PSI

Impacts of PSI erosion and ejecta:

- Visual and sensor obscuration / degraded performance
- Vehicle stability and tilt
- Localized augmentation of heating and/or pressure
- Abrasion damage from debris and ejecta

An understanding of PSI enables the ability to:

- Conduct successful near-surface operations
- Mitigate surface alteration
- Mitigate effects to surrounding assets

Debris on Curiosity rover deck, rocks > 1.5 cm

Image credit: NASA/JPL

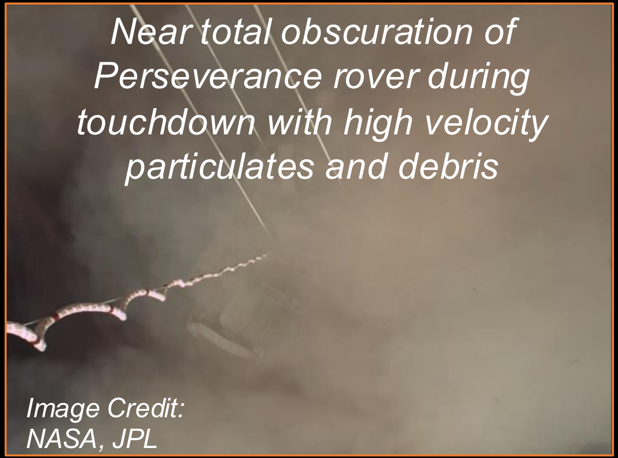
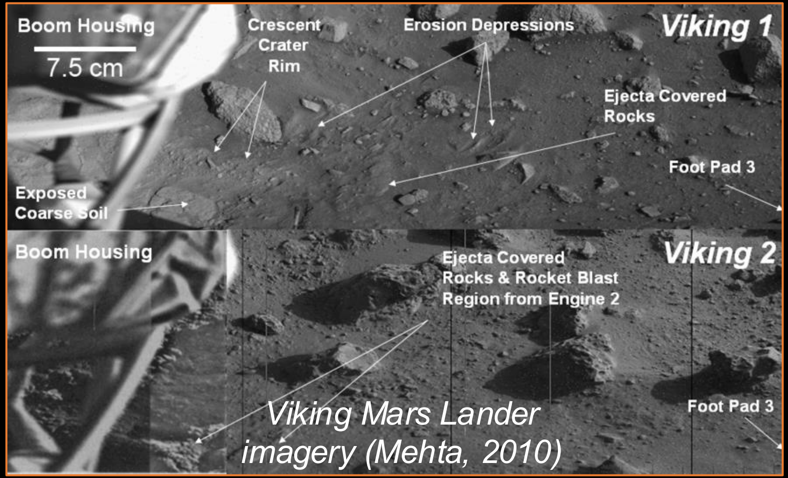

Near total obscuration of Perseverance rover during touchdown with high velocity particulates and debris

Image Credit: NASA, JPL


Visual Obscuration During Apollo 16 Landing (Metzger, 2010)



Viking Mars Lander imagery (Mehta, 2010)

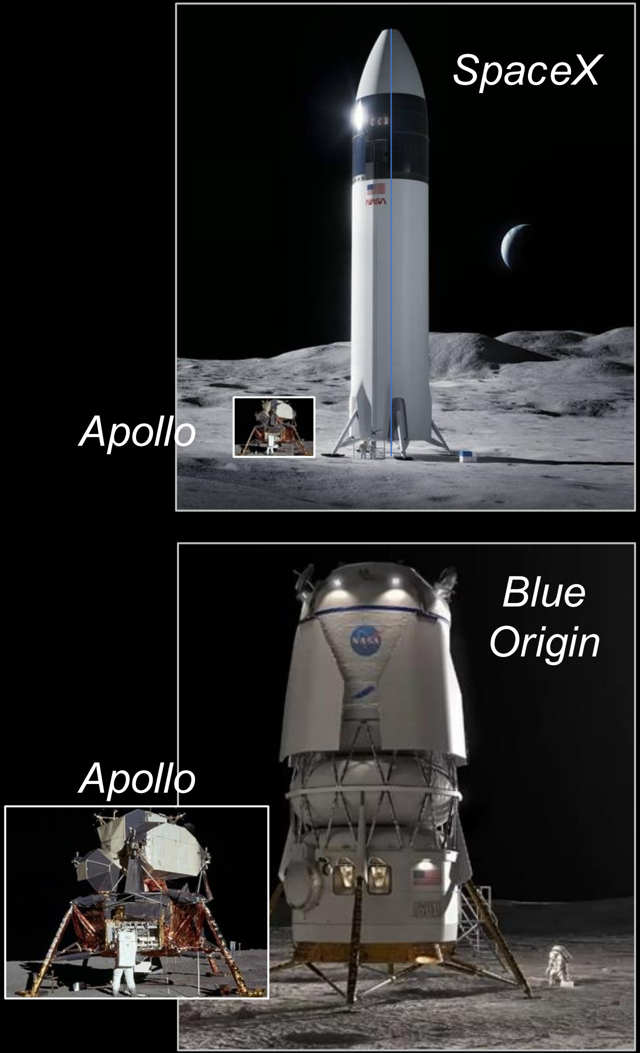
Moving Beyond Apollo

- NASA's Human Landing System (HLS) will take astronauts to the lunar surface using commercial vehicles from SpaceX and Blue Origin as part of the Artemis program

- Each vehicle is considerably larger and uses a different concept of operations than that from Apollo

Apollo flight experience cannot be extrapolated to upcoming large Human Landing Systems (HLS) for PSI

→ new data and modeling required

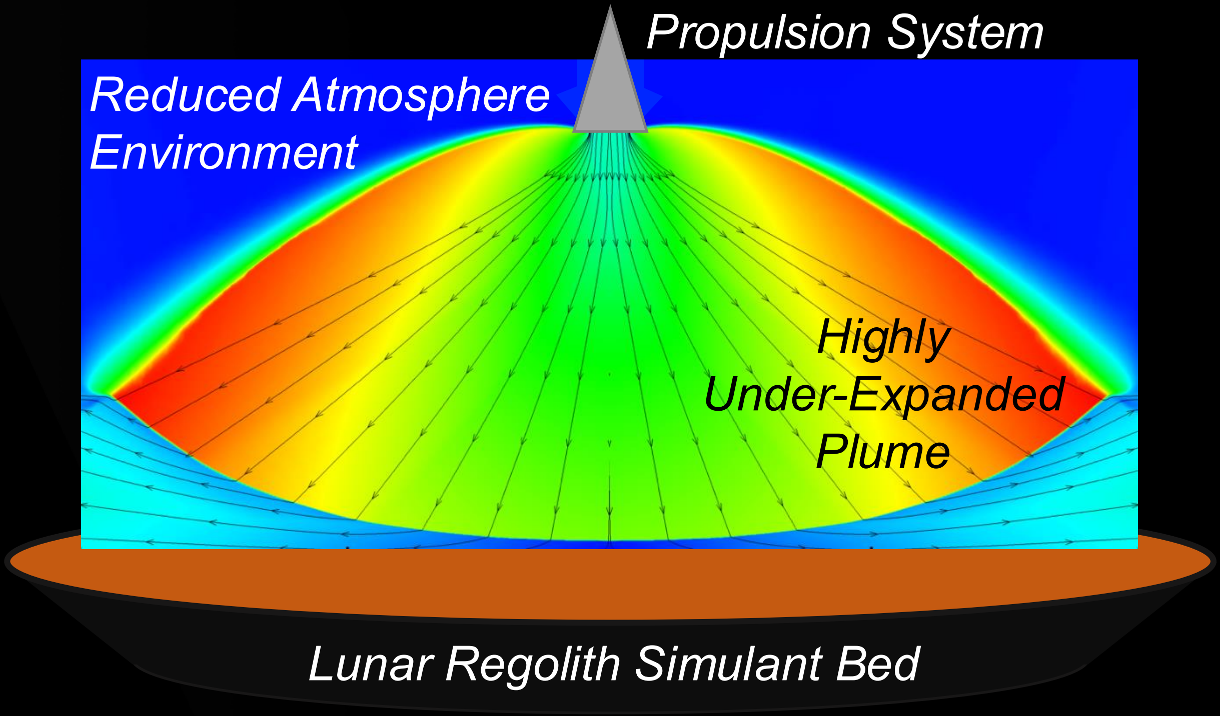


HLS Lander Concepts

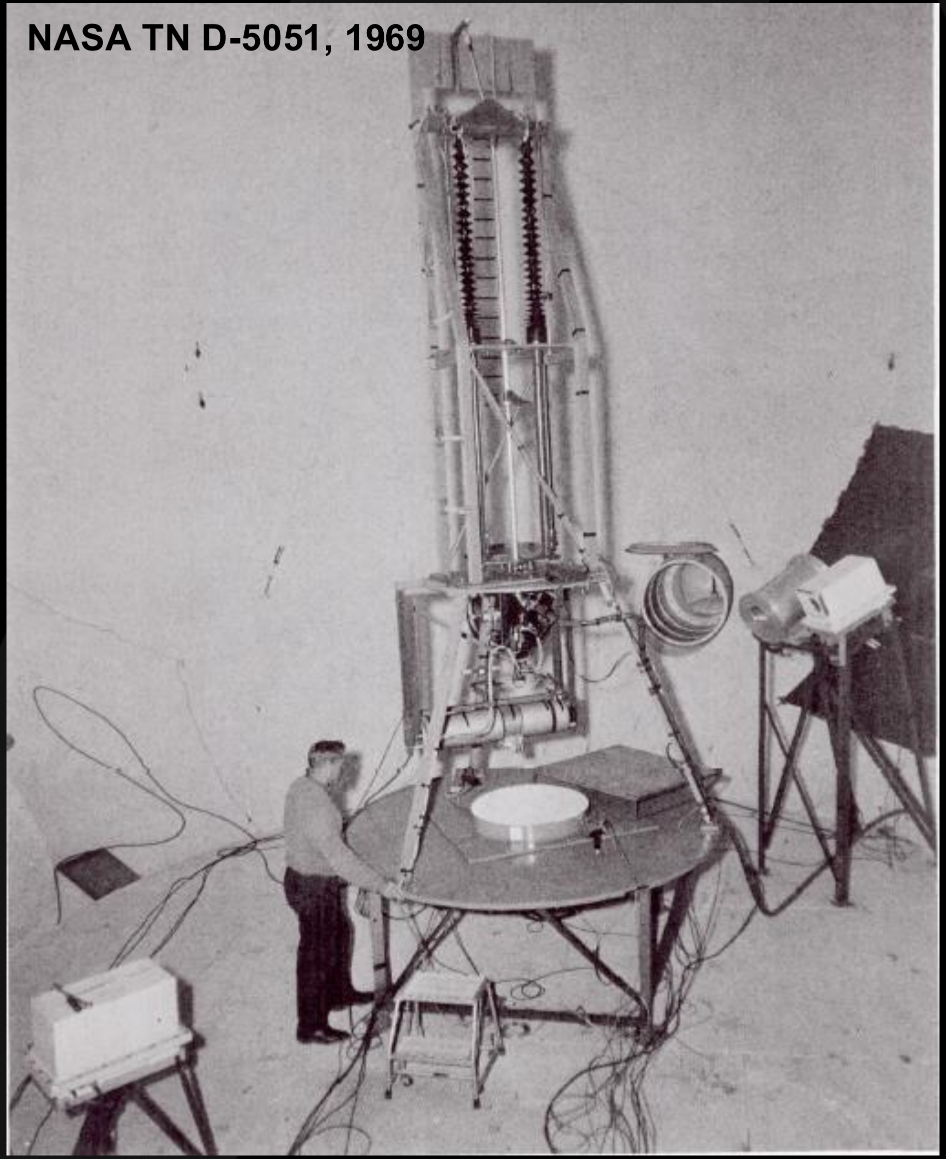
Anatomy of this PSI Test

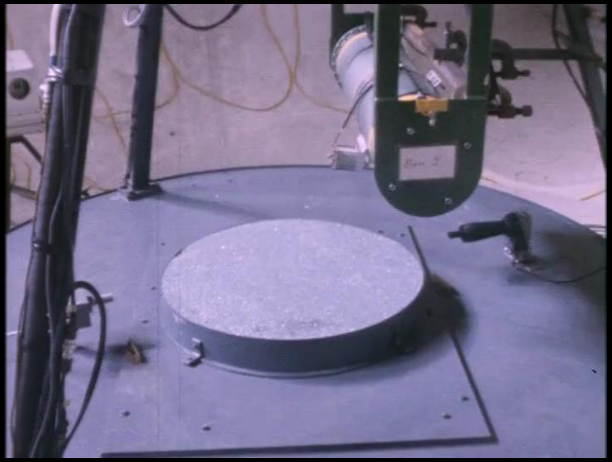
Objective: Acquire scaled ground test data for PSI erosion and ejecta at mission-relevant conditions to quantify and reduce uncertainty in PSI predictions through improvements to and validation of modeling capabilities

- Target scaled flight conditions and maximize test envelope:
  - Plume simulant
  - Regolith simulant
  - Reduced atmosphere environment
- Parameters:
  - Nozzle height above regolith
  - Plume total pressure (mass flow rate)
- Two propulsion systems:
  - Heated ethane (non-combusting) (<100 lbf thrust)
  - GOX/ABS hybrid motor (<40 lbf thrust)
- Impingement plate followed by regolith
- 6 second test duration



Historical Lunar PSI Testing

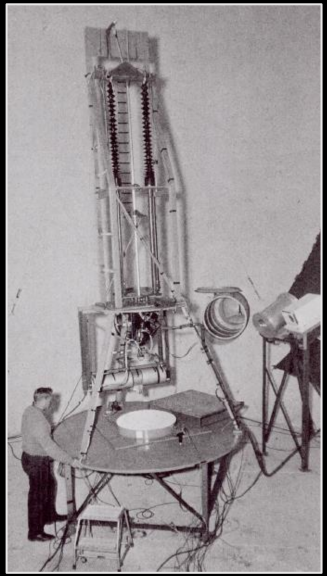




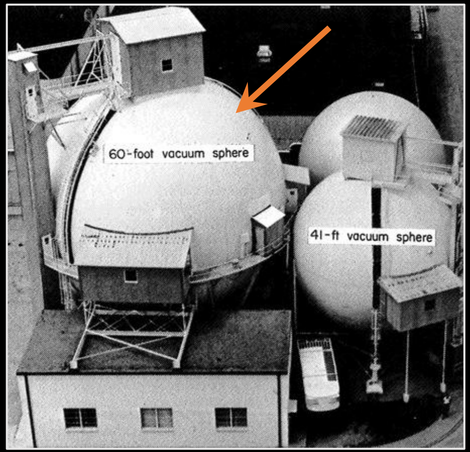
Land and Scholl (1969)

Vacuum Test Facility

- 60-ft vacuum sphere at NASA Langley Research Center
- Historically used to test PSI for Apollo and Viking
- Provides very large volume to minimize ambient pressure rise during PSI testing
- Target test condition (facility capability): 0.75 Torr (100 Pa)



NASA TN D-5051, 1969

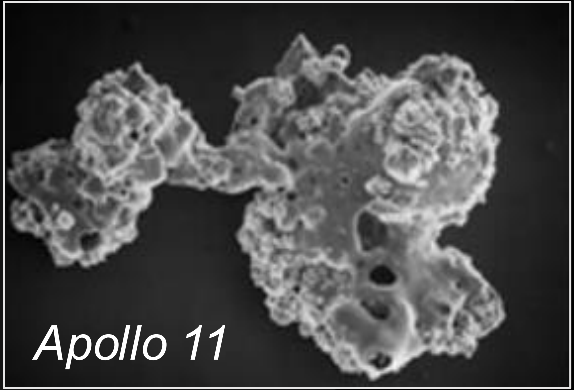


60-ft Vacuum Sphere (part of the NASA Langley Aerothermodynamics Laboratory Facility)

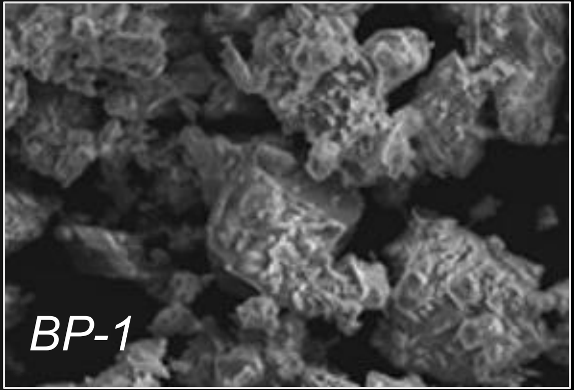
Lunar Regolith Simulant

- Black Point - 1 (BP-1) crushed basalt lunar regolith simulant with similar geotechnical properties to the lunar South Pole
- Handling, preparation, and hardware design requires drying, venting, PPE, and specialized procedures for use

Regolith moisture removal



Apollo 11



BP-1

Cohesiveness of BP-1 (NASA KSC)

Regolith bin for PSI testing (~2m diameter, ~1700 kg of simulant per test)

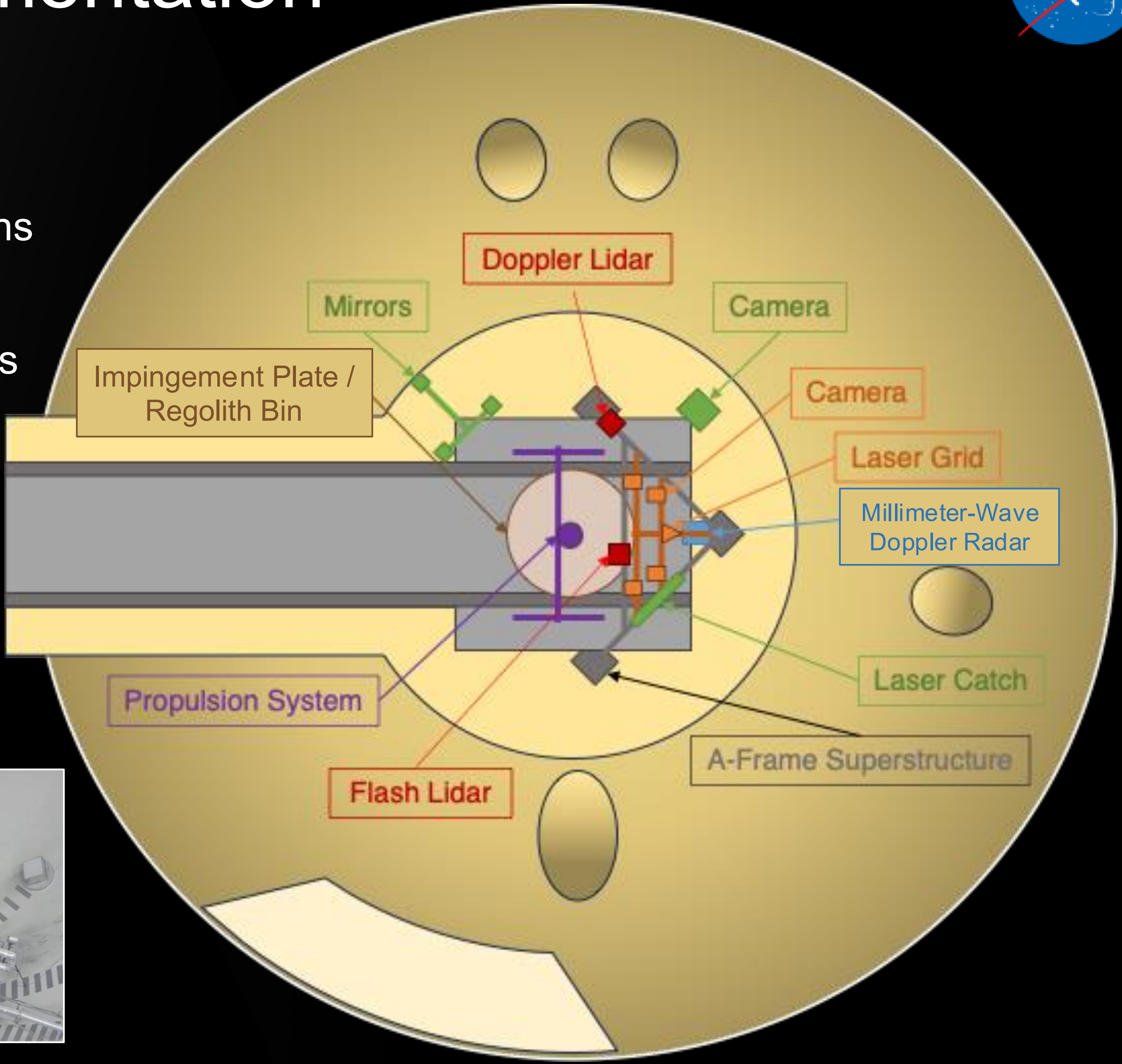
Data Products and Instrumentation

Primary

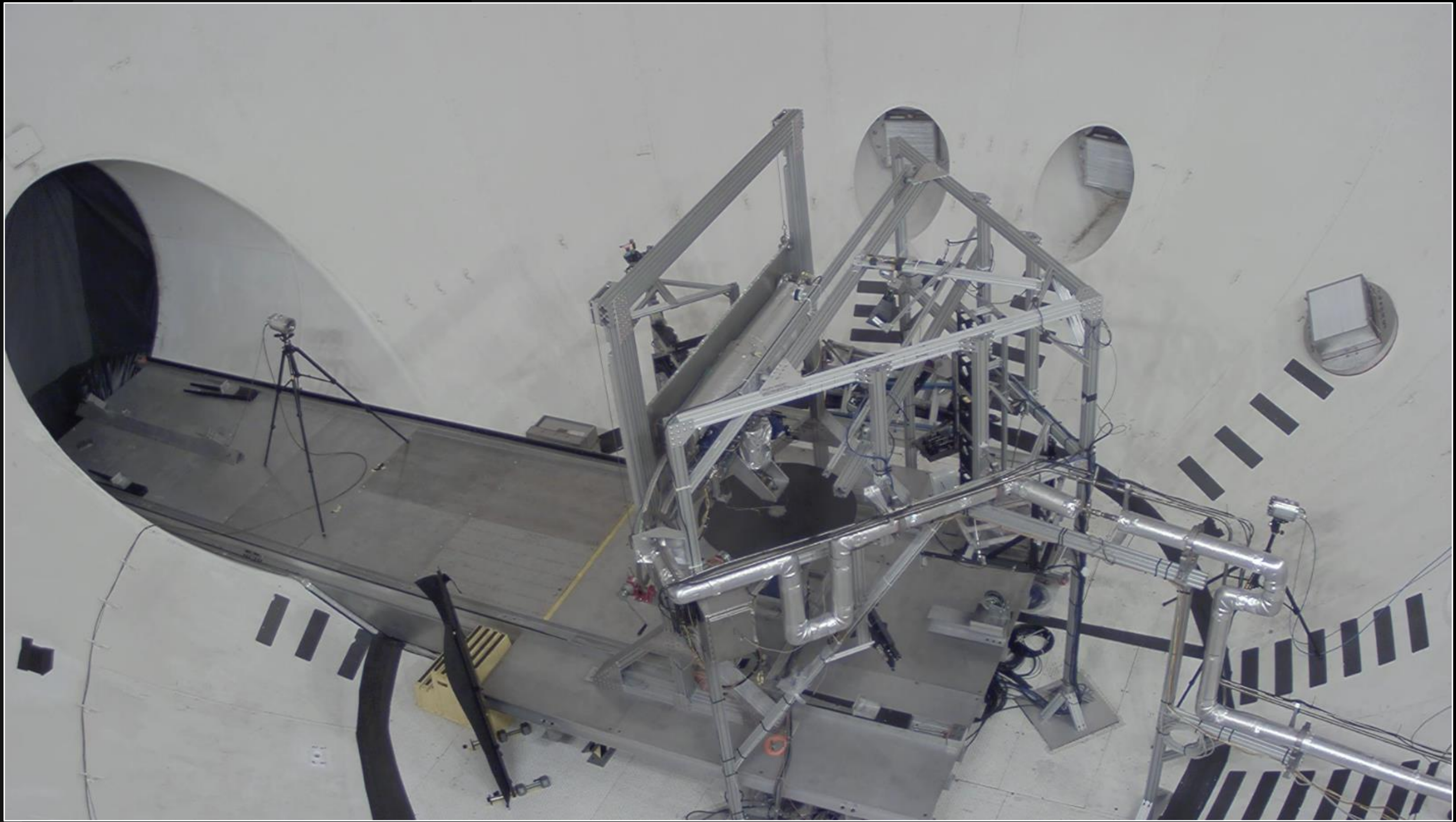
- ***Erosion*** onset; transient and final surfaces in 3D
- ***Ejecta*** energy measurements at discrete locations
- ***Ejecta*** particle velocity and size distributions
- Facility ambient and propulsion system conditions

Secondary

- Direct quantitative verification of ***plume*** impingement conditions (pressure, shear)
- ***Plume*** flow visualization and characterization
- Passively collected data for dust



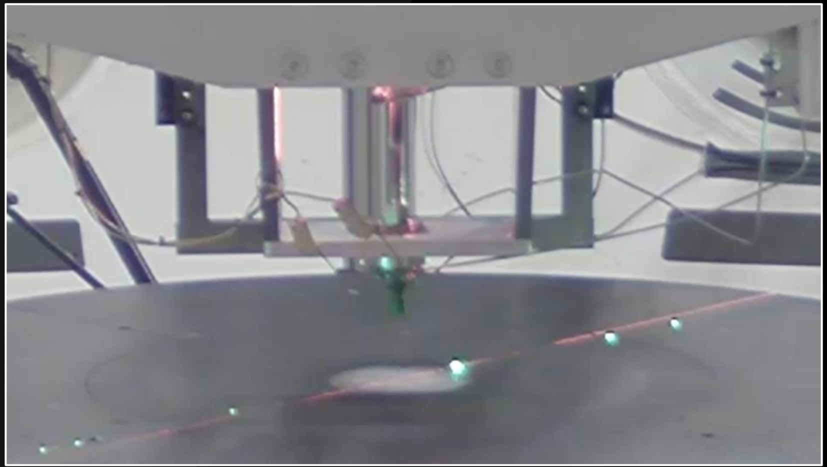
Top View of Test Setup (Impingement Plate)



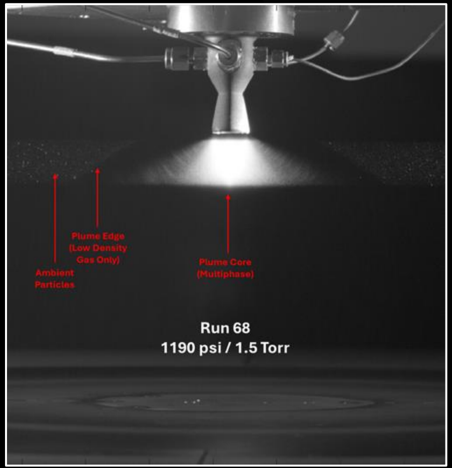
Impingement Plate Testing

- Flat plate instrumented for pressure, shear, and temperature
- 80 total test runs completed with the impingement plate, 78 runs under vacuum
- Paint and sensor damage incurred due to initial heating issues and inherent soot particle formation from ethane pyrolysis

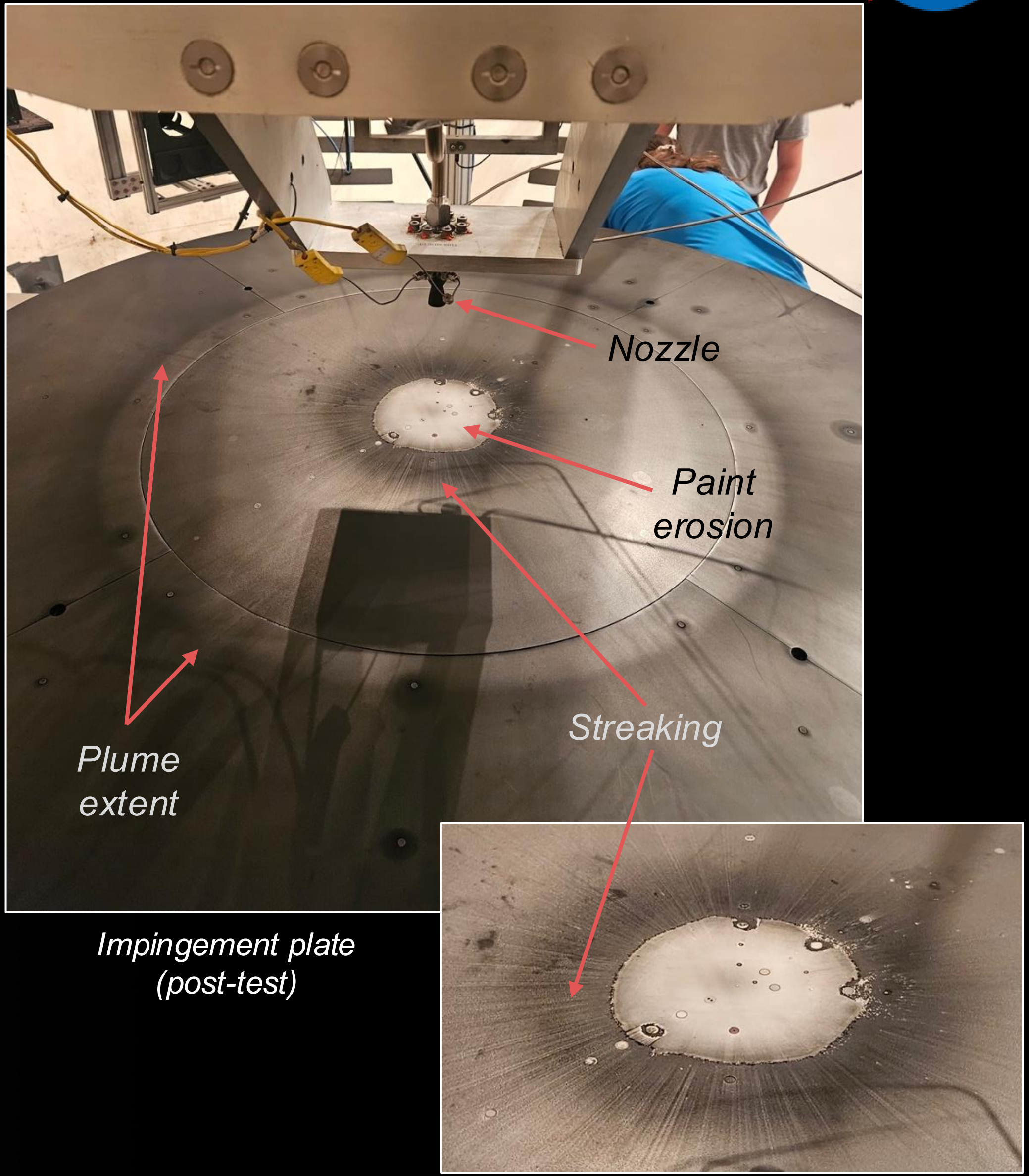
PSI hardware setup



High-pressure test run at lowest nozzle height



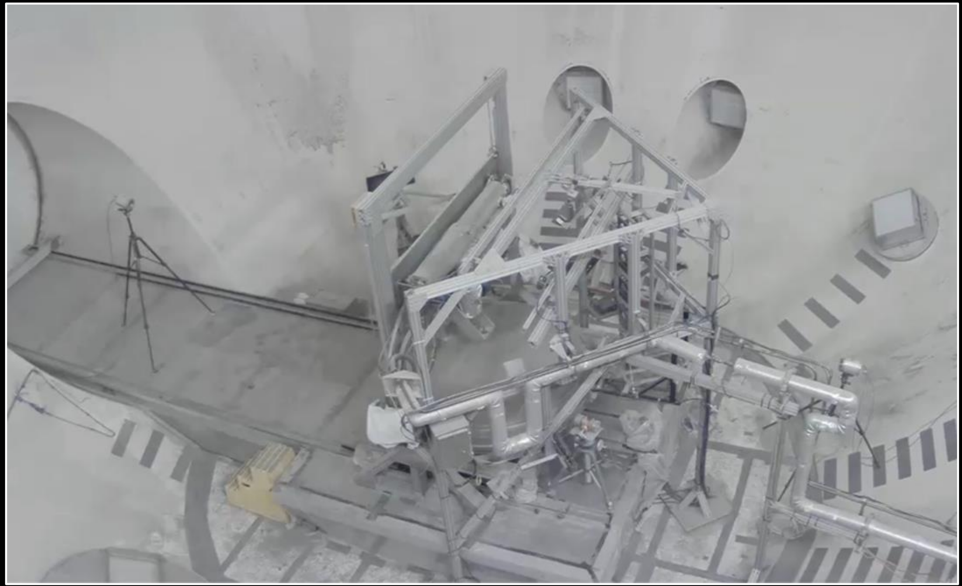
Plume visualization (credit: N. Rodrigues and T. Schwartz)



Impingement plate (post-test)

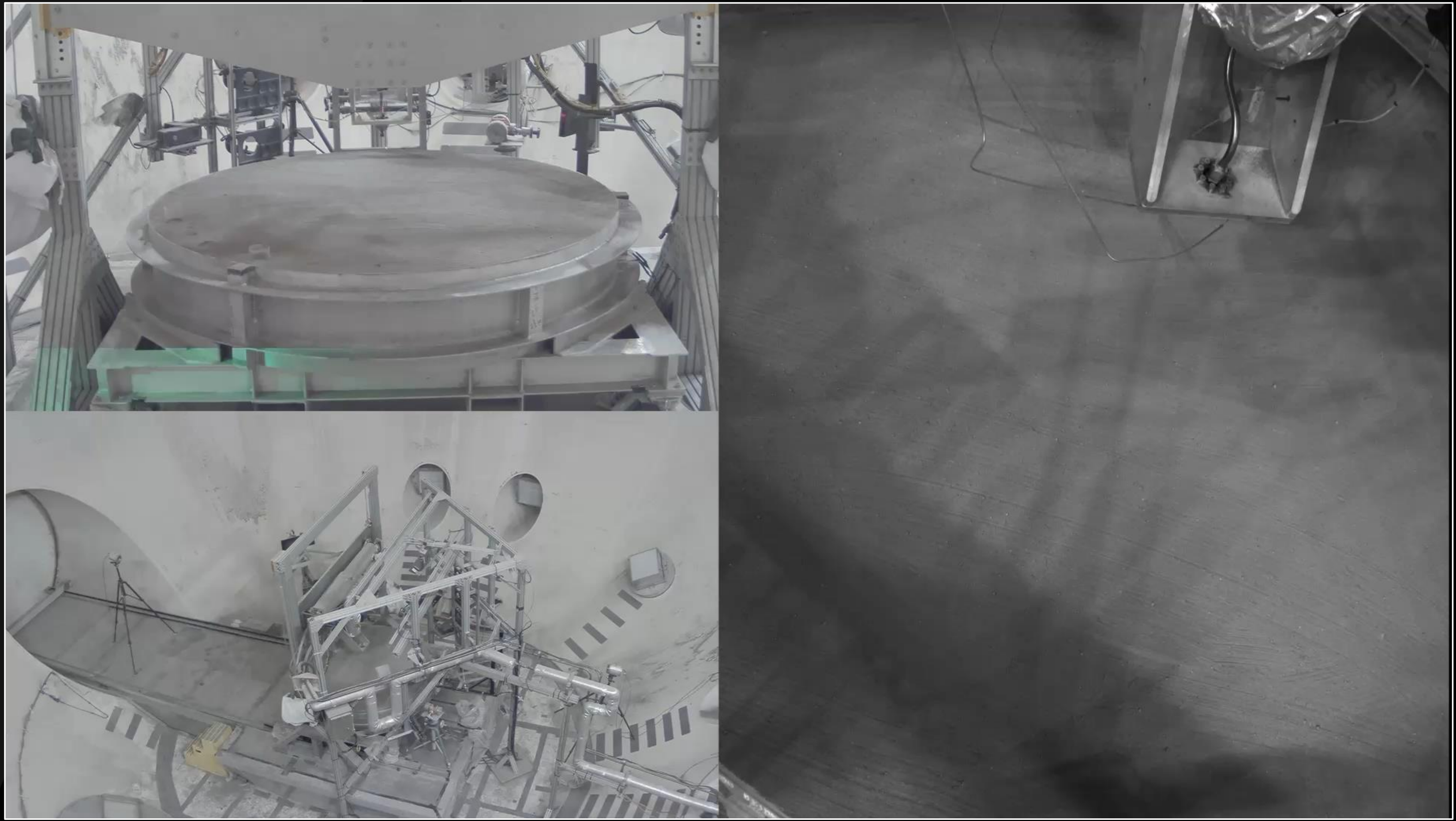
Top View of Test Setup (Lunar Regolith Prep)

First loading of lunar regolith simulant (~1700 kg)



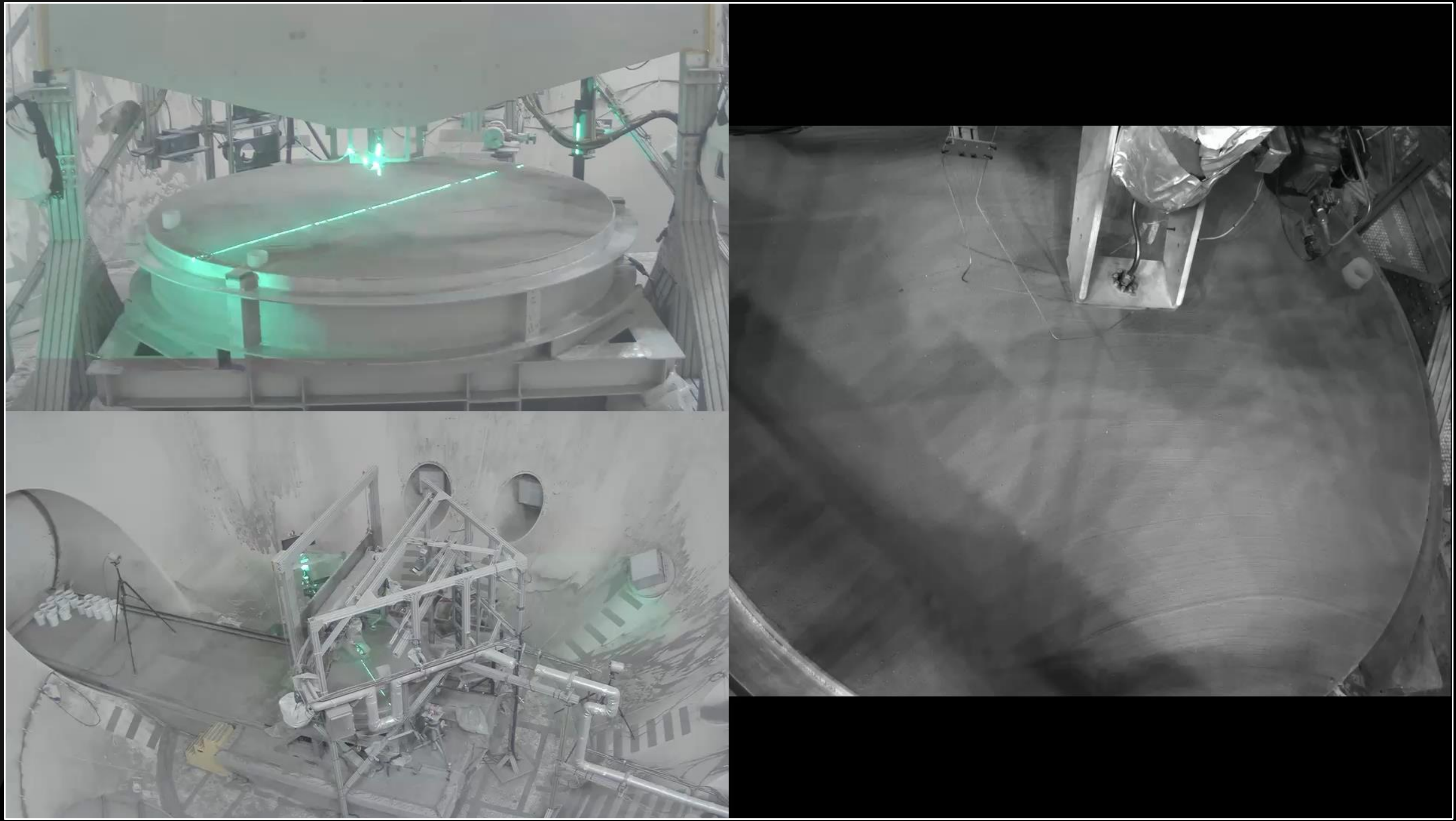
Full in-sphere test setup with regolith
Image Credit: M. Wilson

PSI (4 Years in the Making…)



Intermediate nozzle height (h/D_e = 16) at 1190 psi target plume pressure
Left: context camera views (M. Wilson)
Right: SCALPSS (downsampled spatially and temporally) (O. Tyrrell and T. Takahashi)

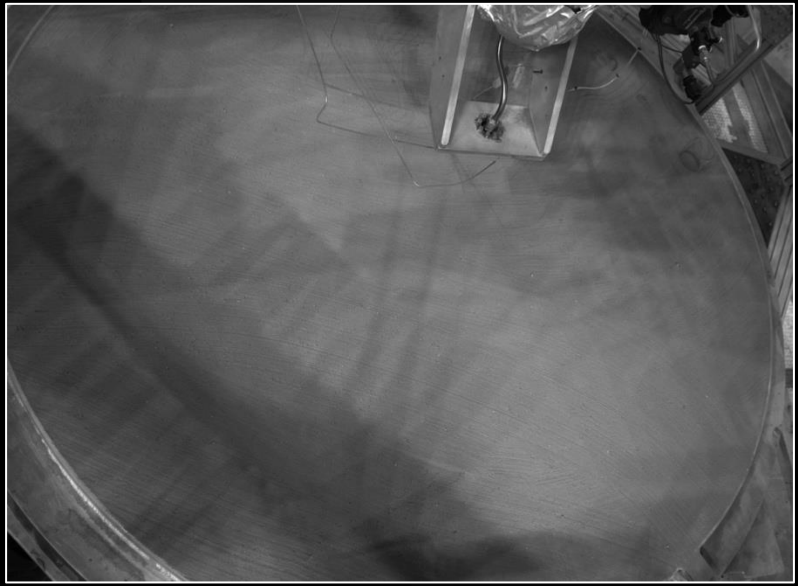
First Results with Regolith – Fluidization(!)



Lower nozzle height (h/D_e = 8) at 660 psi target plume pressure
Left: context camera views (M. Wilson)
Right: SCALPSS (O. Tyrrell and T. Takahashi)

First Results with Regolith – Plume Pressure

$P_{c,target}$ = *660 psi*



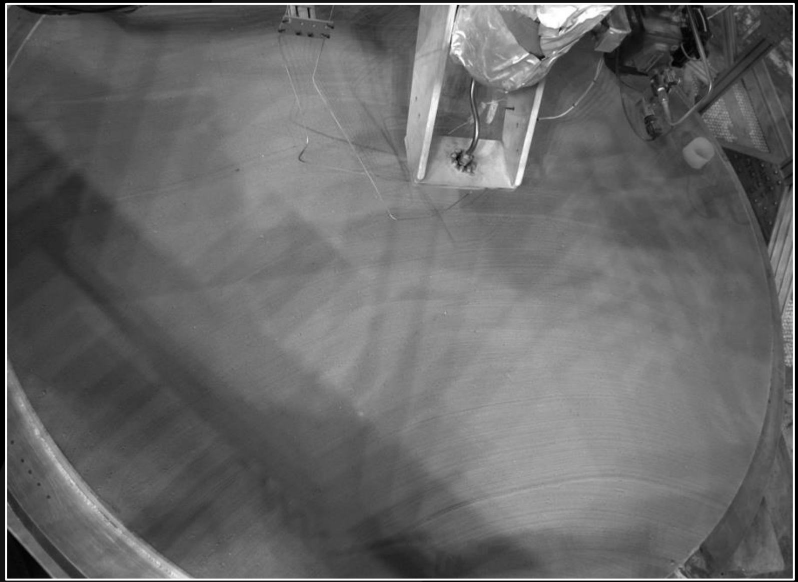
$P_{c,target}$ = *1190 psi*

$P_{c,target}$ = *1740 psi*

Increasing plume impingement pressure at the same altitude (h/D_e = 16)

**SCALPSS imagery*

First Results with Regolith – Plume Pressure



$P_{c,target}$ = 660 psi

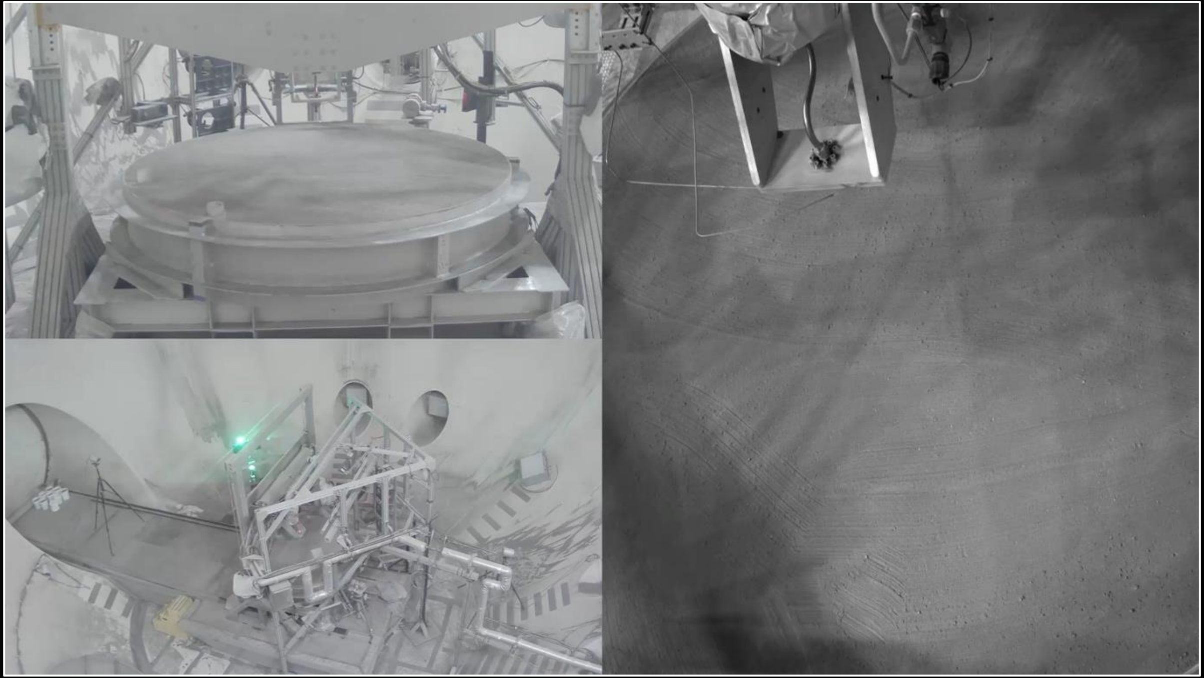
$P_{c,target}$ = 1190 psi

$P_{c,target}$ = 1740 psi

Increasing plume impingement pressure at the same altitude (h/D_e = 8)

First Results with Regolith – Scaled Altitude

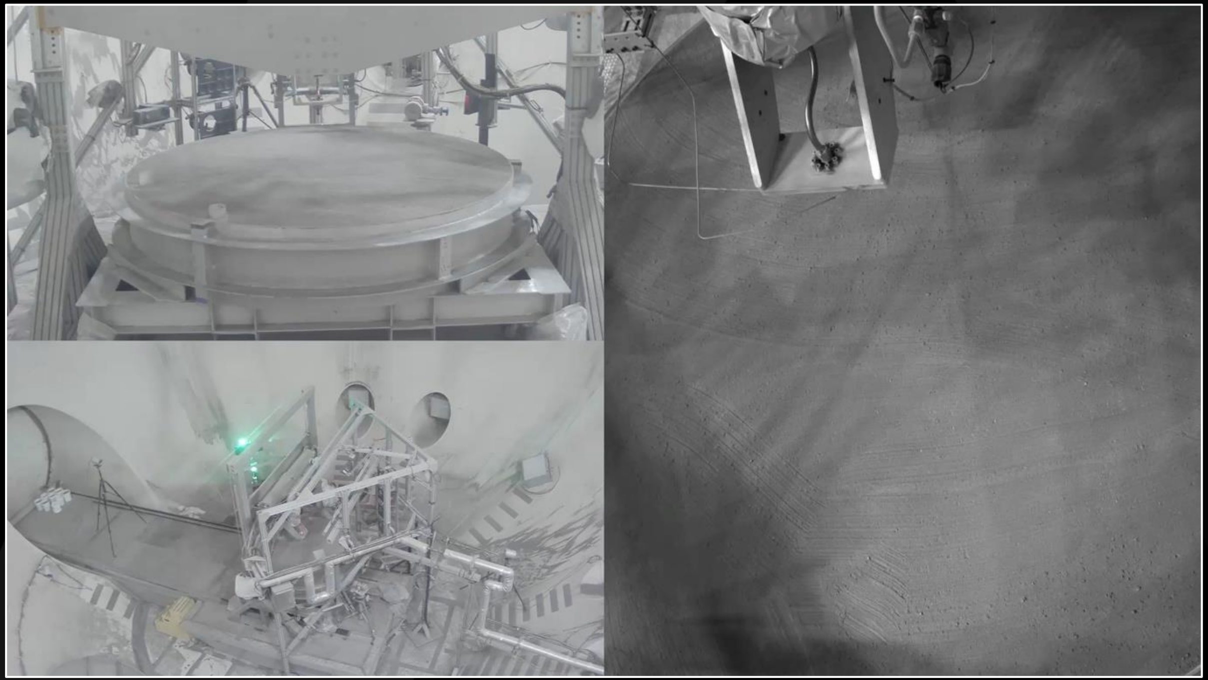
$h/D_e = 32$



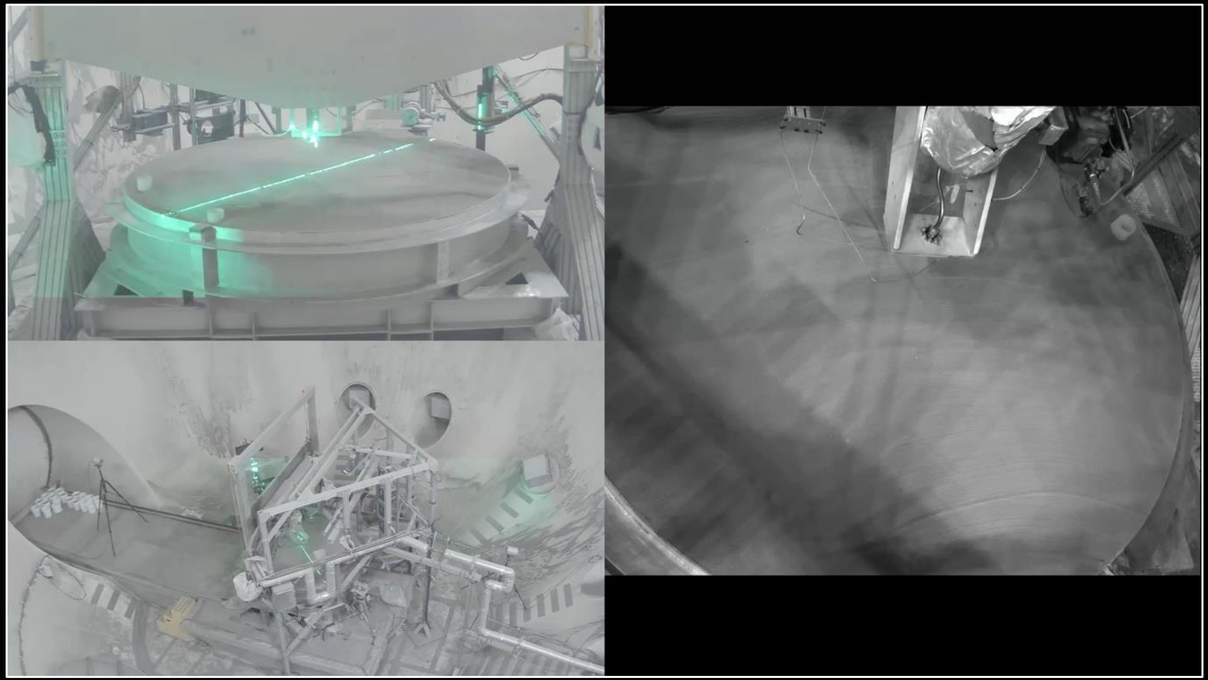
$h/D_e = 16$

Decreasing nozzle height at the plume impingement pressure ($P_{c,target}$ = 660 psi)

First Results with Regolith – Scaled Altitude



$h/D_e = 16$

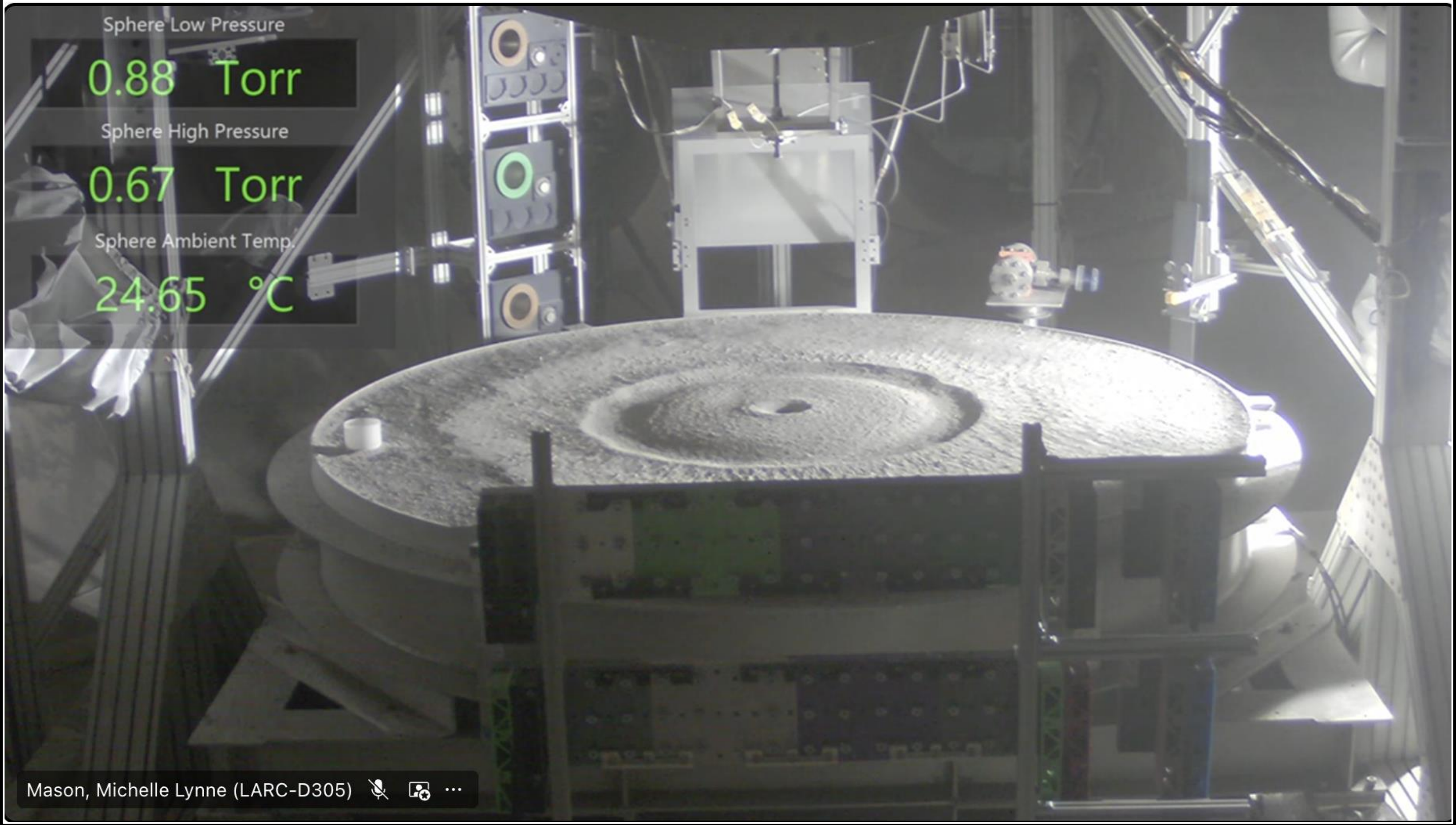


$h/D_e = 8$

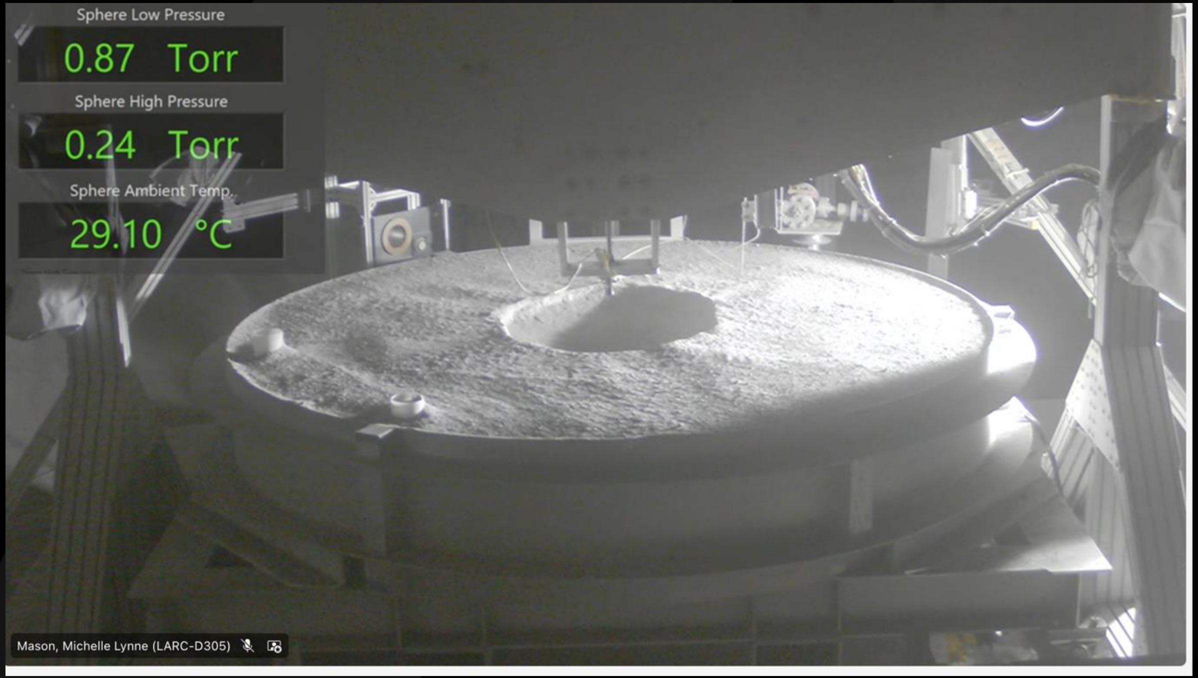
Decreasing nozzle height at the plume impingement pressure ($P_{c,target}$ = 660 psi)

→

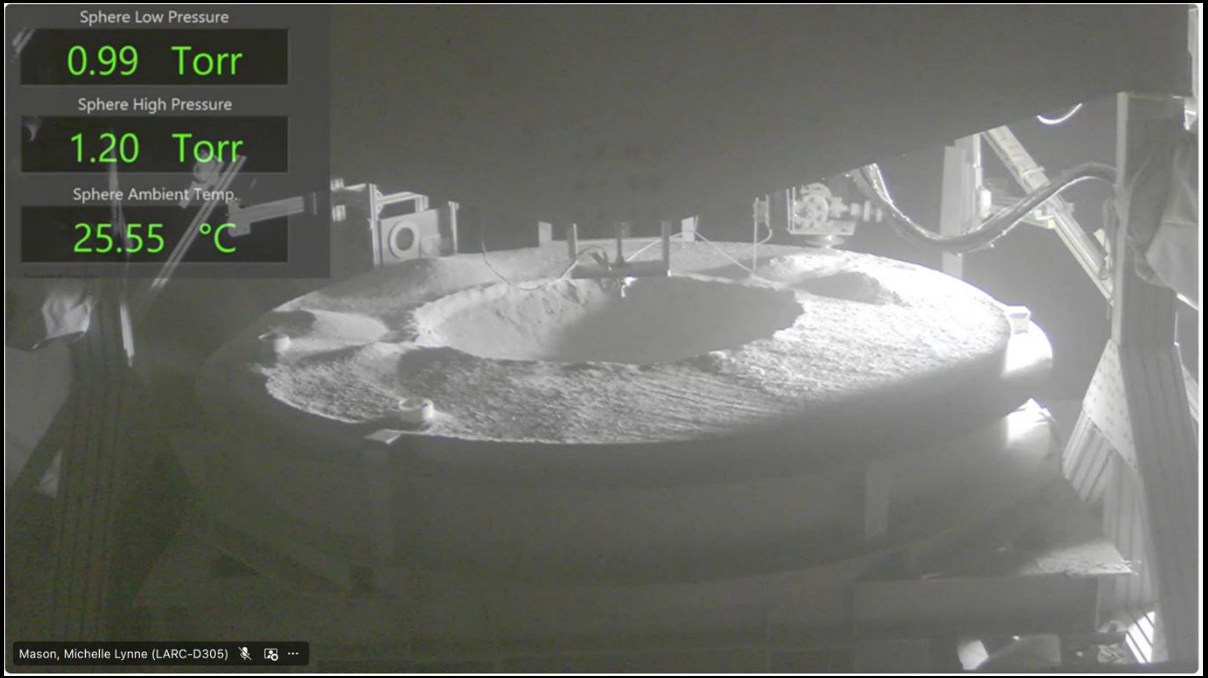
Highest Nozzle Height (h/D_e = 32, 660 psi)



Lowest Nozzle Height ($h/D_e = 4$)



660 psi



1190 psi

Summary and Forward Work

- PSI testing continues through at least the end of 2026
  - Full set of conditions with the ethane plume simulant, including compacted regolith
  - Full set of conditions with the hybrid rocket motor
- Post-processing of data and direct infusion into data-driven modeling to predict erosion and ejecta for large lunar landers and nearby surface assets and infrastructure
- Potential expanded scope:
  - Multiple plume impingement
  - Radar degradation in near-surface landing environments
  - Acoustics effects and lander base/leg environments
  - New candidates for flight instrumentation and payloads
  - Testing for destinations other than the moon

New NASA PSI test capability to characterize PSI erosion and ejecta – relevant for Moon and Mars

Questions?

National Aeronautics and
Space Administration

Ground Testing – HLS PSI Test Campaign

Facility: NASA LaRC 60-ft Vacuum Sphere

- Legacy facility for Apollo and Viking PSI testing
- 0.75 Torr initial ambient pressure
- Large volume reduces transients to ambient conditions
- "Dirty" facility – permits regolith use

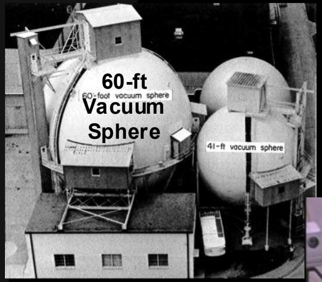
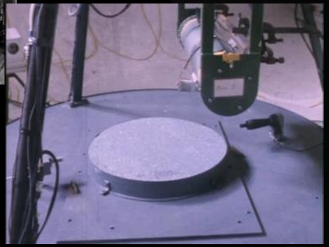


Image credit: NASA



Land and Scholl (1969)

Plume Gas Simulants: Heated Ethane and Hybrid Rocket Motor

- Heated ethane: proven scaled test capability for hot-fire engine plumes
- Small GOX/ABS hybrid rocket motor with water in the exhaust; true hot-fire testing
- Two separate run matrices with scaled conditions relevant for understanding PSI from large lunar landers

Hybrid Motor

Ethane System

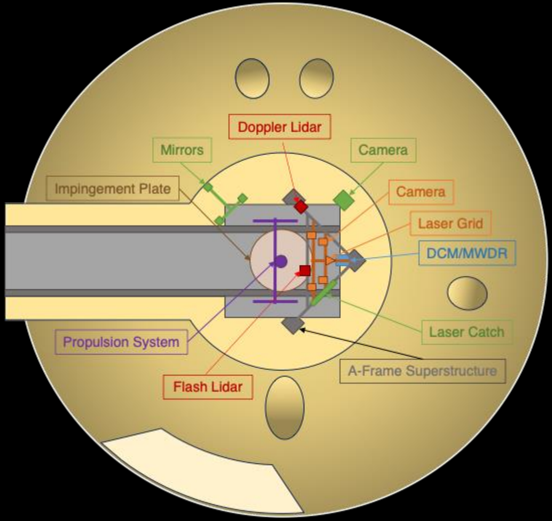
Regolith Simulant

- BP-1 Lunar regolith simulant
- Geotechnical properties considerations:
  - Particle size distribution
  - Particle morphology/shape
  - Bulk/relative density
  - Cohesion/angle of internal friction
  - Permeability
- Previous experience in PSI testing and existing geotechnical characterization

Regolith bin for PSI testing (~2m diameter)

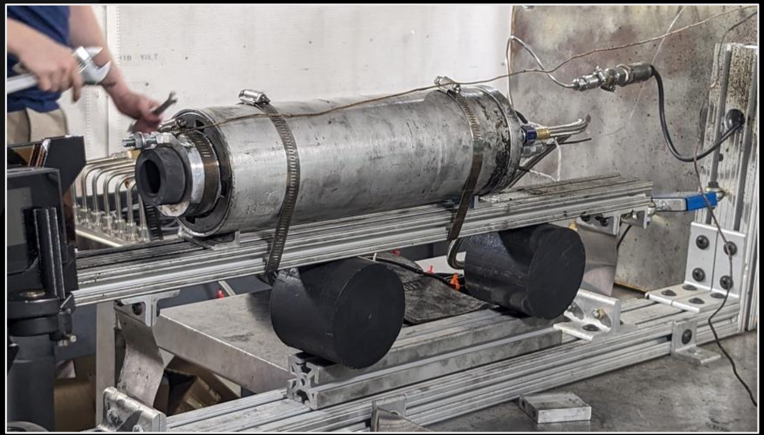
Data Products

- 3D erosion geometry as a function of time, including onset (start) and final profiles and erosion rates
- Ejecta energy measurements at discrete locations
- Plume flow visualization
- Pressure and shear on an impingement plate



Propulsion Elements – Rocket Plume Simulants

- Highly under-expanded exhaust plume matching absolute peak and radially scaled distributions for surface impingement pressure and shear
- Firing durations: 6 seconds per test run
- PSI testing using two separate propulsion elements
  - Non-combusting, heated ethane plume (Purdue Univ. / NASA SSC)
    - Thrust < 100 lb_f
  - GOX/ABS hybrid rocket motor (Utah State Univ. / NASA MSFC)
    - Thrust < 40 lb_f



98 mm GOX/ABS Hybrid Motor (Utah State Univ. / NASA MSFC)

Ethane Supply Skid (External) (Purdue Univ. / NASA SSC)