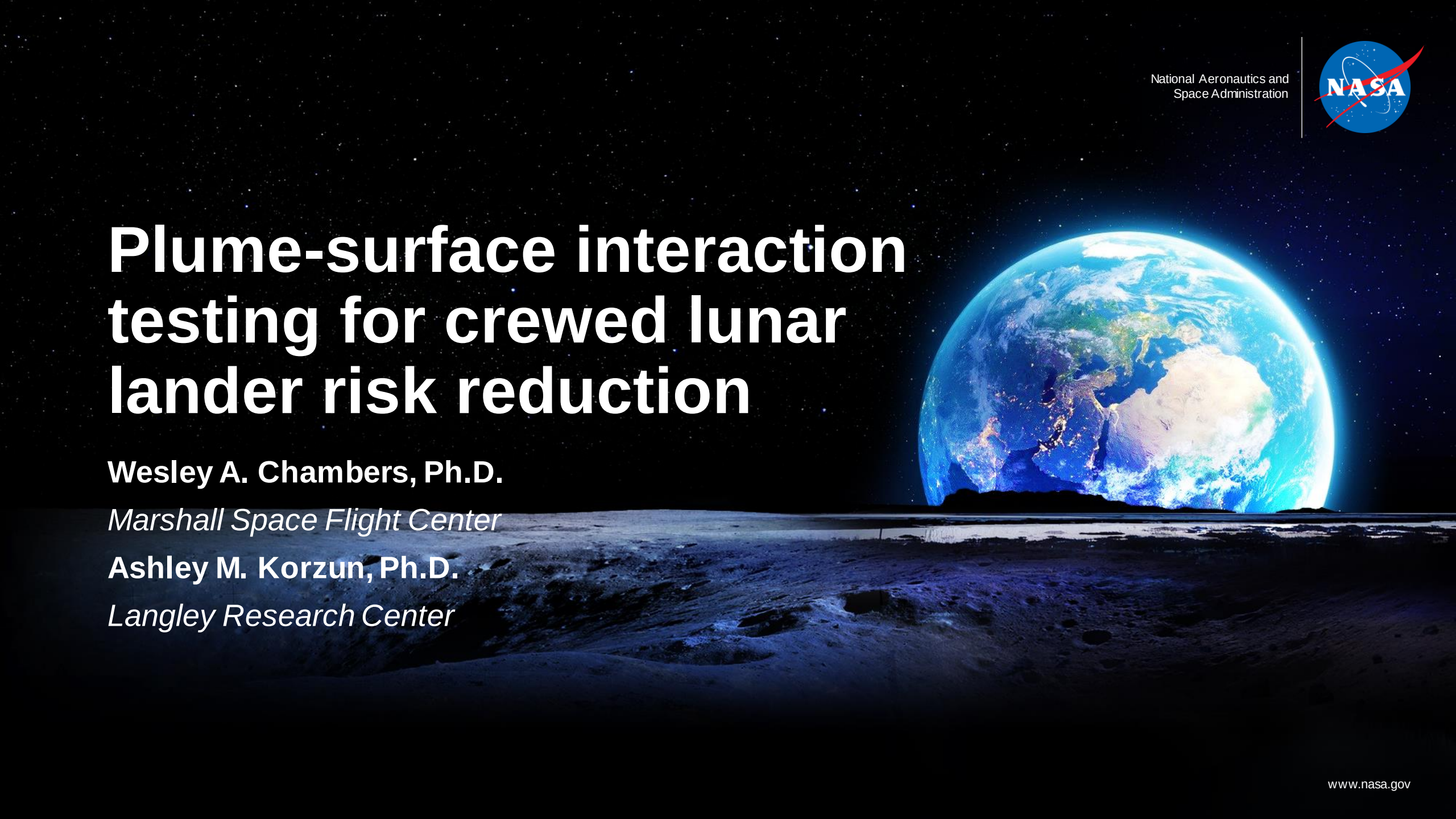
National Aeronautics and Space Administration



Plume-surface interaction testing for crewed lunar lander risk reduction

Wesley A. Chambers, Ph.D.

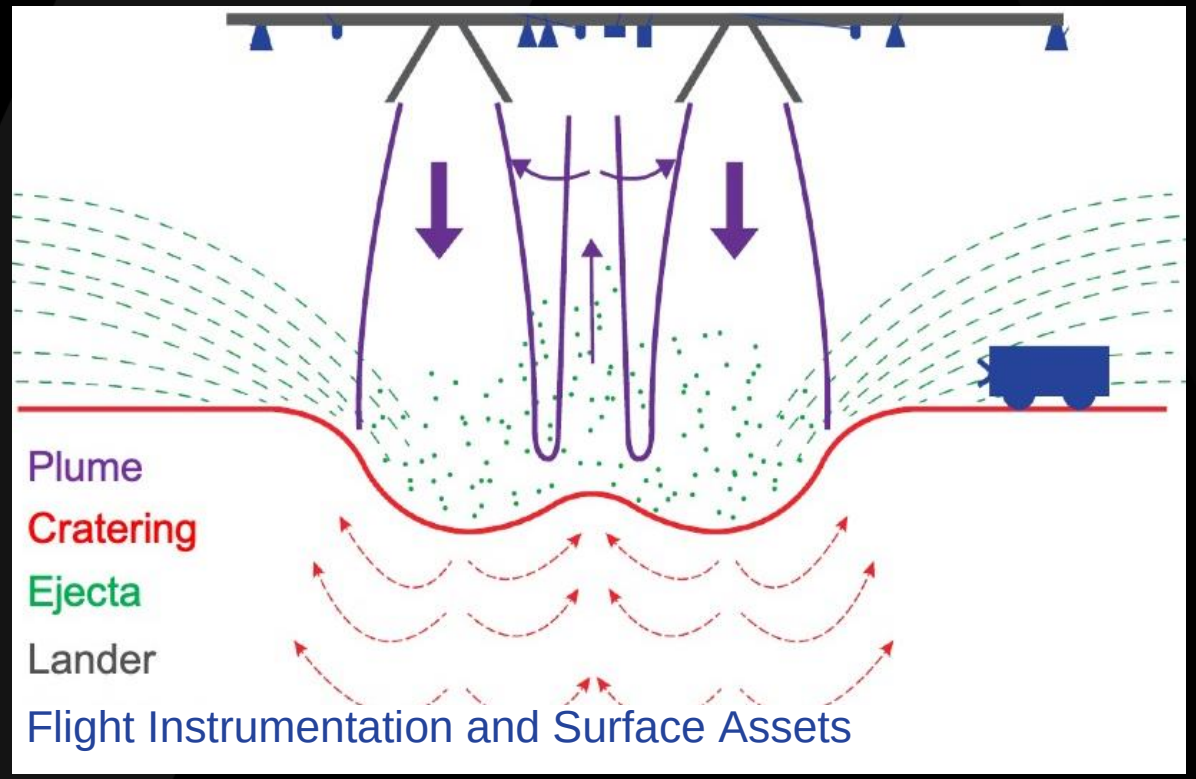
Marshall Space Flight Center

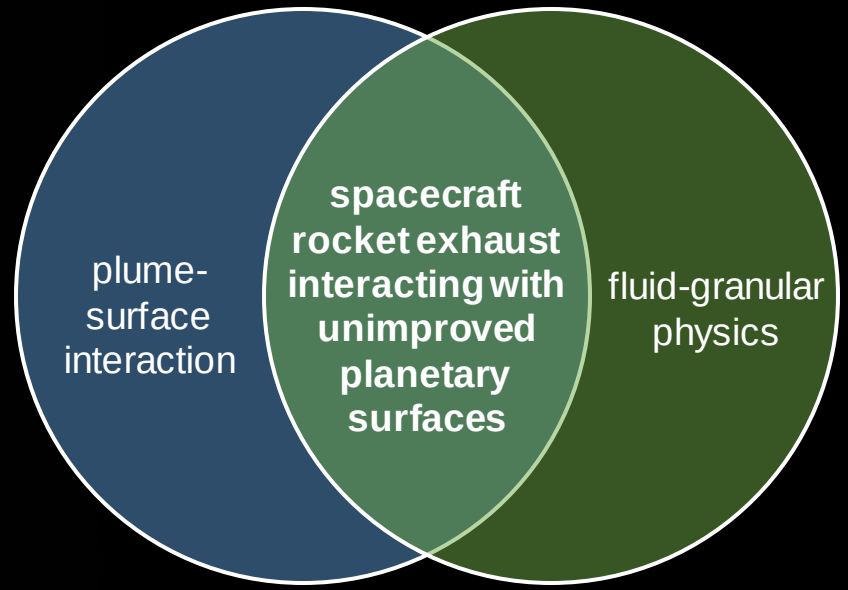
Ashley M. Korzun, Ph.D.

Langley Research Center

Introduction

*Rocket **Plume-Surface Interaction (PSI)** is a complex, multi-discipline problem that describes the lander environment due to the impingement of rocket exhaust onto the regolith of planetary bodies*



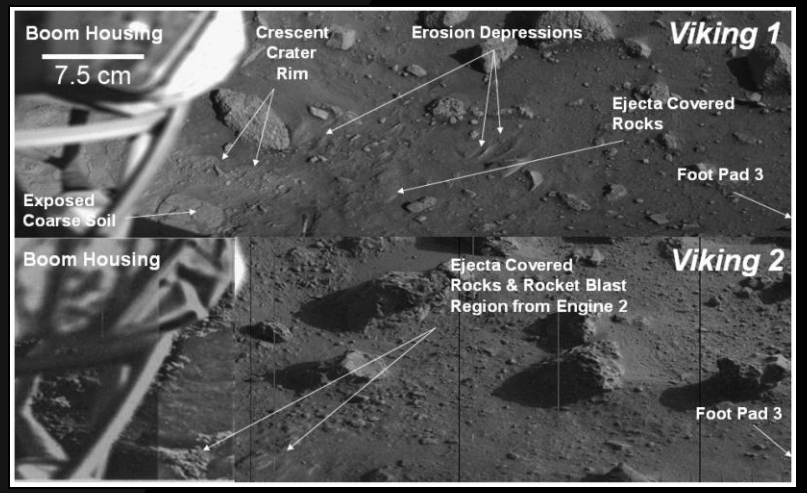


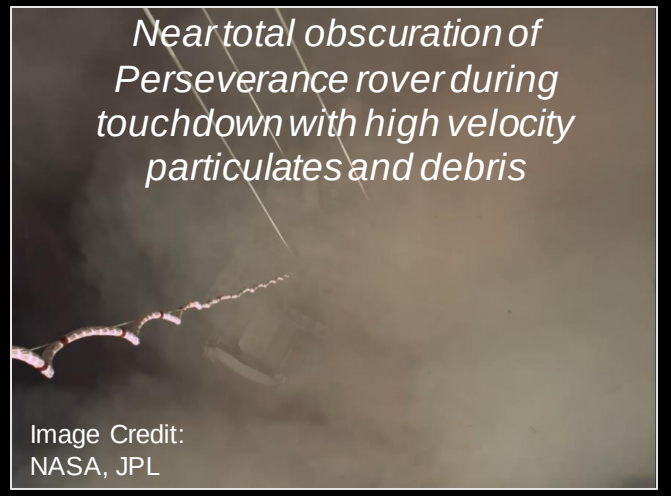
Risks Posed to Landers by PSI

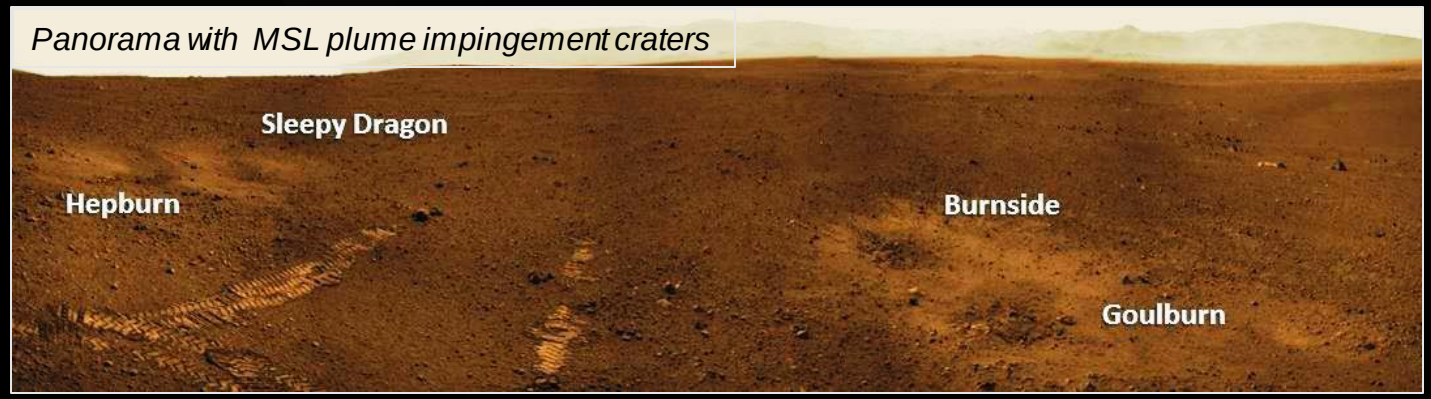
All propulsive landers experience PSI

An understanding of plume-surface interaction physics enables the ability to:

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







Risks Posed by PSI to Landers

"We've never lost a lander to PSI [yet]" is not an acceptable risk posture

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

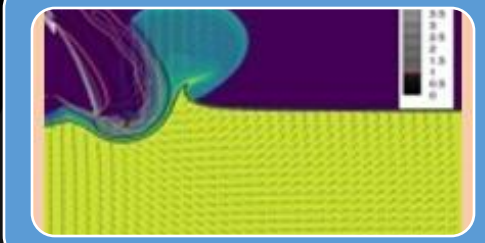
Visual Obscuration During Apollo 16 Landing (Metzger, 2010)

11-deg Tilt on Apollo 15 Lander (NASA)

Apollo flight experience cannot be extrapolated to lunar Human Landing Systems (HLS) for PSI → new data and modeling required

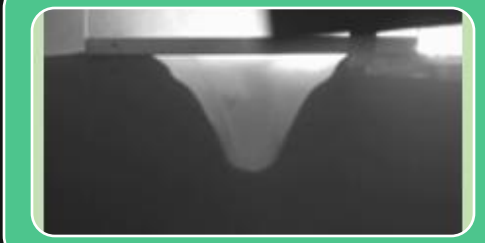
Reducing Risk from PSI

"Three-Legged Stool"



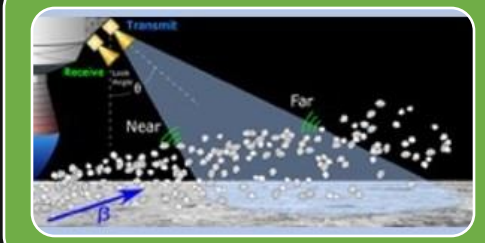
Modeling & Simulation

- Fills in testing and data gaps
- Large uncertainty, current tools need quantitative validation



Experimental Data

- Varying levels of fidelity
- Better control, instrumentation

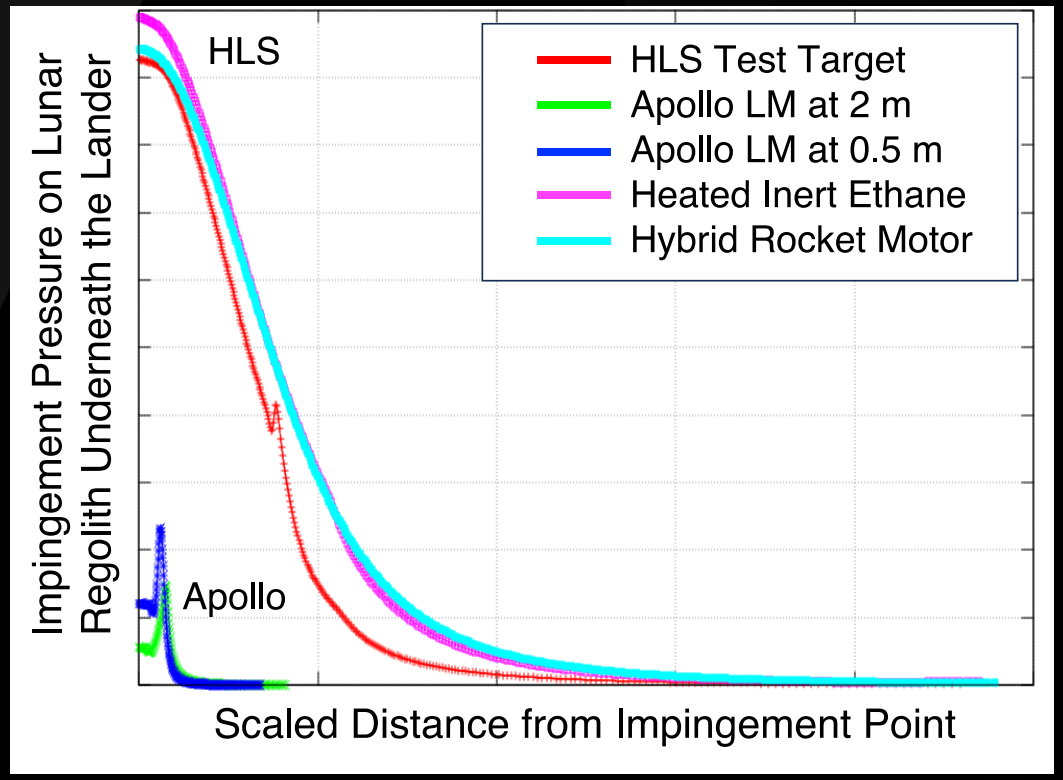


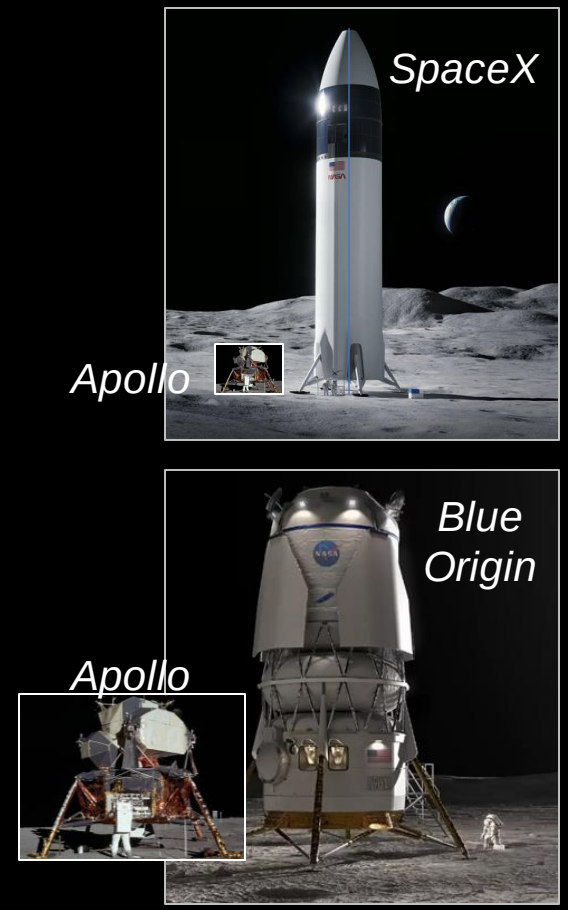
Flight Data

- Ground truth
- Limited opportunities, data

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



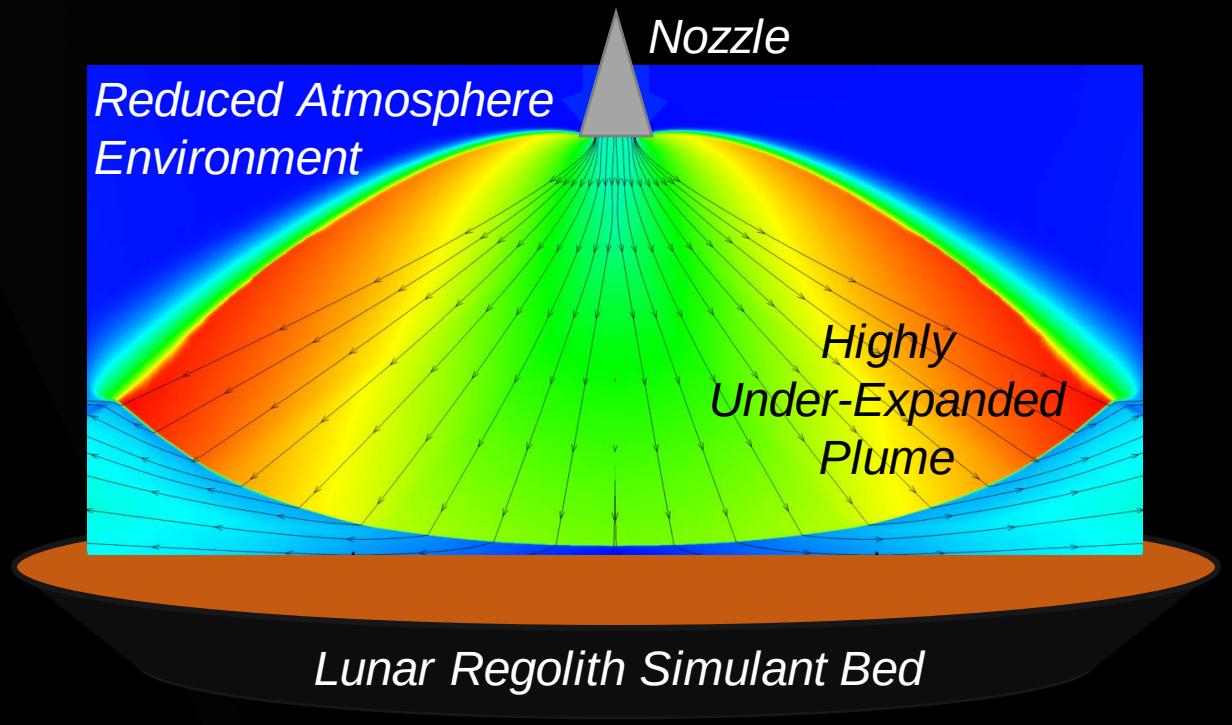


HLS Lander Concepts

PSI Test Concept for HLS Risk Reduction

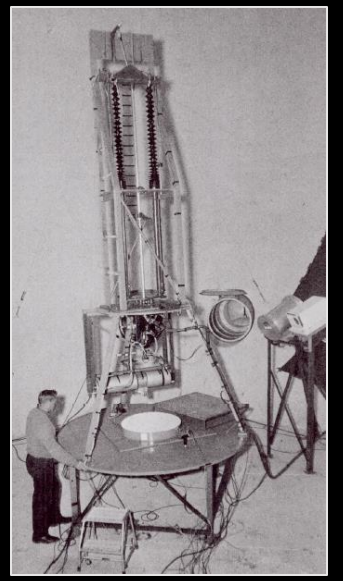
<u>Objective</u>: To reduce risk to the HLS lander(s) through acquisition of lunar-relevant ground test data to quantify and reduce uncertainty in PSI predictions through improvements to and validation of modeling capabilities

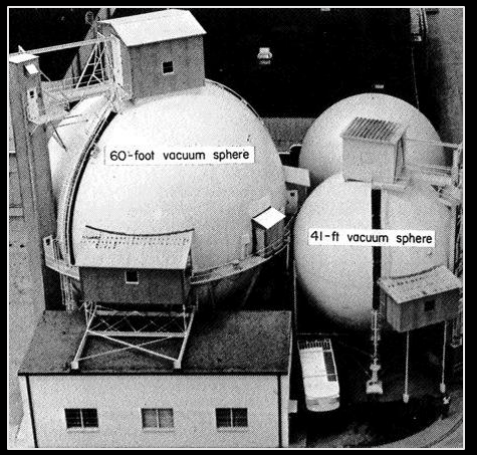
- Target scaled flight conditions and an Apollo condition
- Parameters:
  - Nozzle height above regolith
  - Plume total pressure
  - Plume mass flow rate
- Target 30 runs per propulsion type:
  - Inert Ethane: June – Sept 2024
  - Hybrid Motor: Jan – Apr 2025



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)

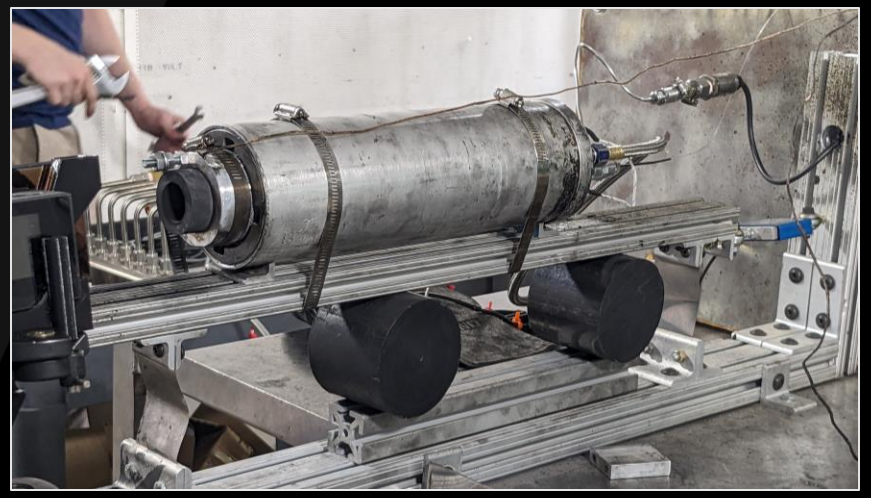




60-ft Vacuum Sphere (NASA LaRC)

Propulsion Elements – Rocket Plume Simulant

- Highly under-expanded exhaust plume matching absolute peak and radially scaled distributions for surface impingement pressure and shear
- Firing durations: 4-6 seconds per test run
- PSI testing using two separate propulsion elements
  - Inert, heated ethane plume (Purdue Univ.)
  - GOX/ABS hybrid rocket motor (Utah State Univ.)
  - Thrust < 50 lb_f

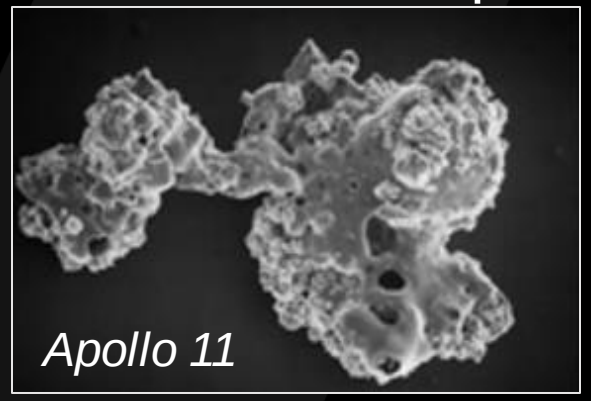


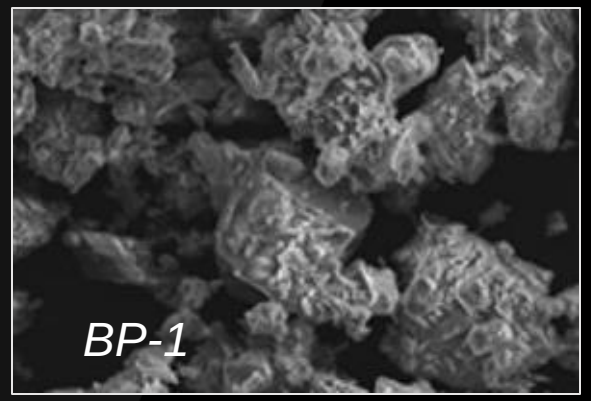
98 mm GOX/ABS Hybrid Motor (Utah State)

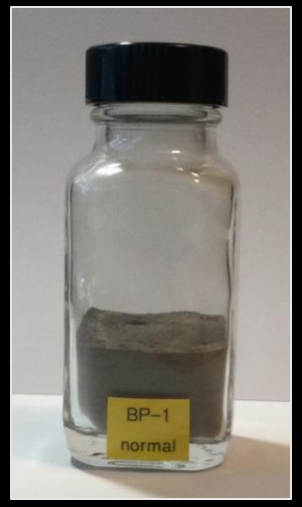
Portable Ethane Cart (NASA SSC / Purdue)

Lunar Regolith Simulant

- BP-1 crushed basalt lunar regolith simulant with similar geotechnical properties to HLS landing sites at the lunar South Pole
- Handling, preparation, and hardware design requires drying, venting, PPE, and specialized procedures for use







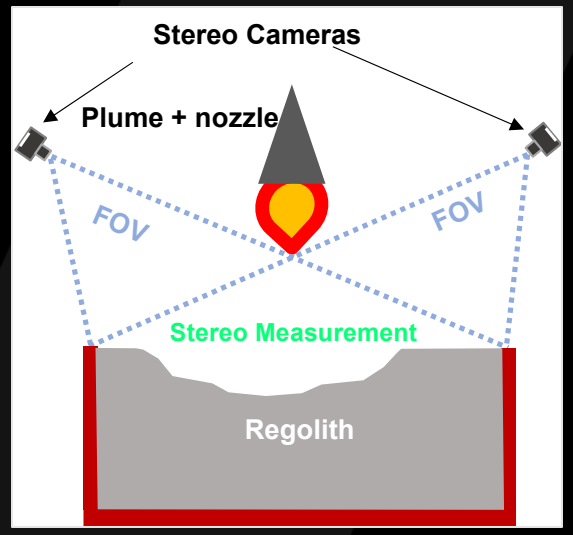
Cohesiveness of BP-1 (NASA KSC)

Vented Prototype Regolith Bin Design (NASA KSC)

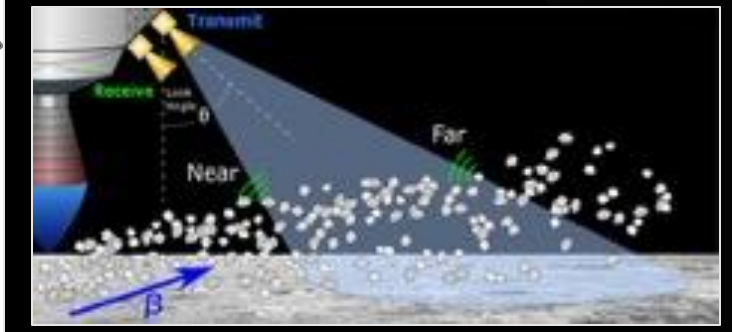
Instrumentation and Diagnostics

Primary

- Capture erosion onset; transient and final surfaces in 3D
- Ejecta energy measurements at discrete locations
- Direct measurement of facility and propulsion conditions



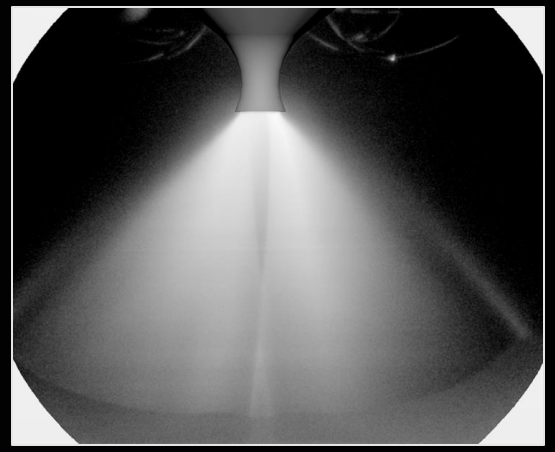
SCALPSS (NASA LaRC)



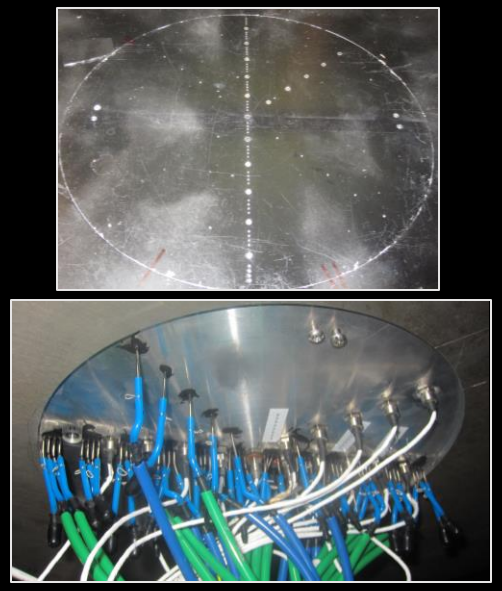
mm-Wave Doppler Radar (NASA KSC)

Secondary

- Direct quantitative verification of plume impingement conditions (pressure, shear)
- Plume flow visualization and characterization



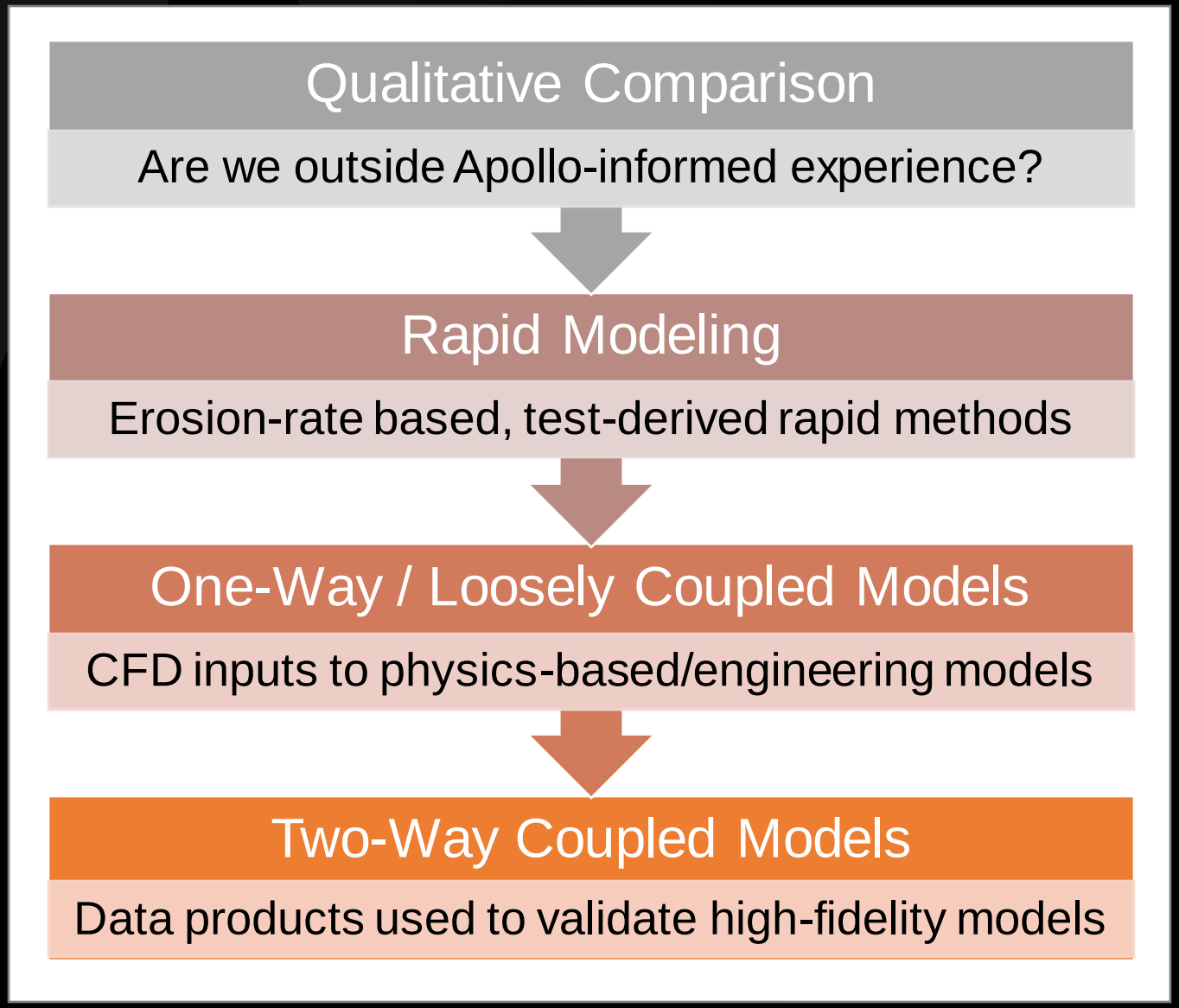
PLIF Plume Flow Visualization (NASA LaRC)



Instrumented Impingement Plate (NASA LaRC/MSFC)

*Will also have passively collected data for dust (witness plates, coupons and mechanisms with special coatings)

Data Use for Risk Reduction



Summary

- PSI poses risks to *all* propulsive landers, as well as nearby surface assets and infrastructure
- PSI testing will reduce risk to HLS lunar landers operating outside of environments and experience from Apollo
- Targeted PSI testing of this type was last conducted using vacuum facilities for the Apollo and Viking programs