National Aeronautics and
Space Administration

EXPLORE
MOON to MARS

Plume-Surface Interaction: Maturing Predictive Environments for Propulsive Landing on the Moon and Mars

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18th International Planetary Probe Workshop
July 8, 2021

Plume-Surface Interaction (PSI)

18 February 2021: Jezero Crater, Mars

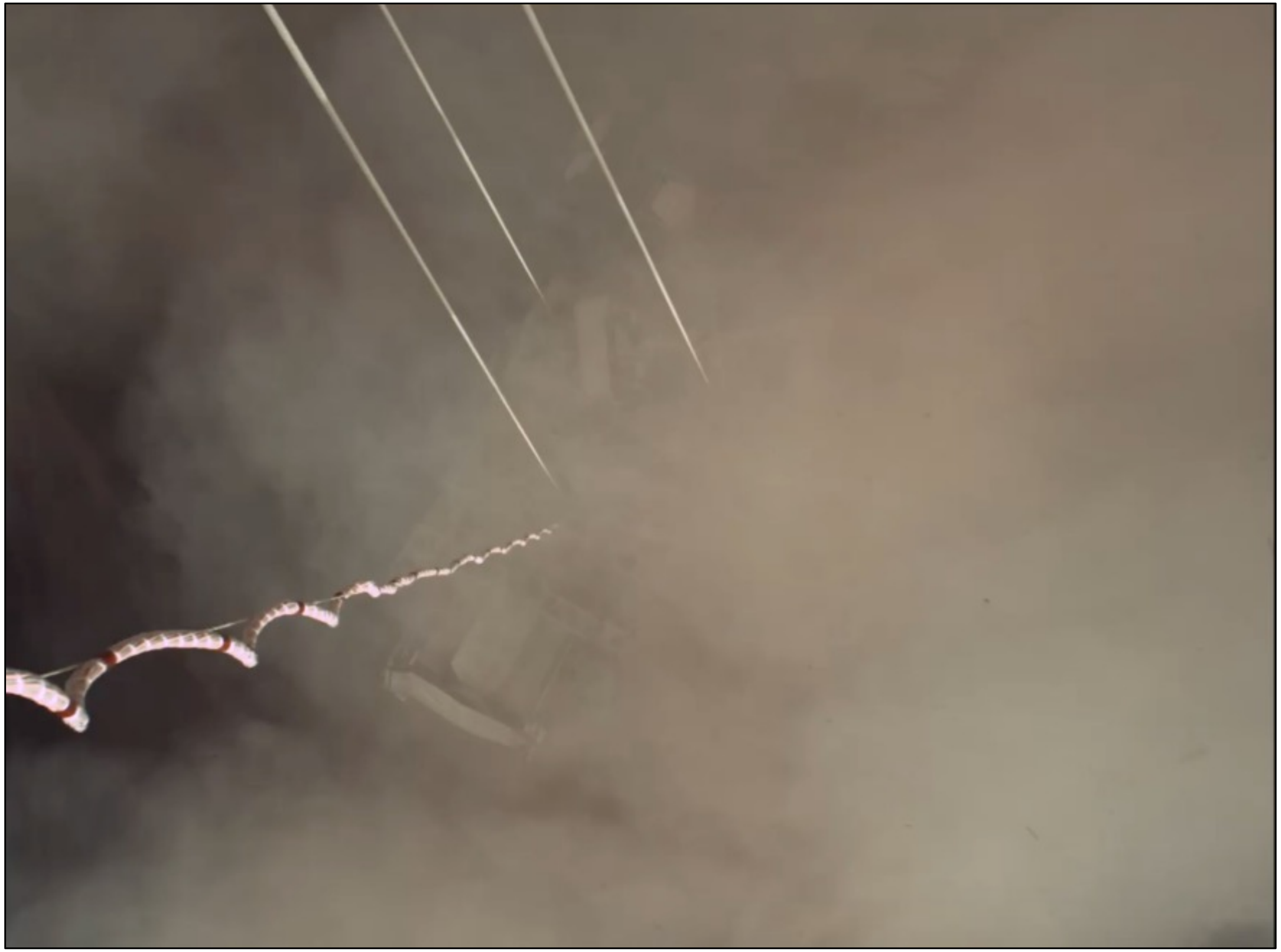
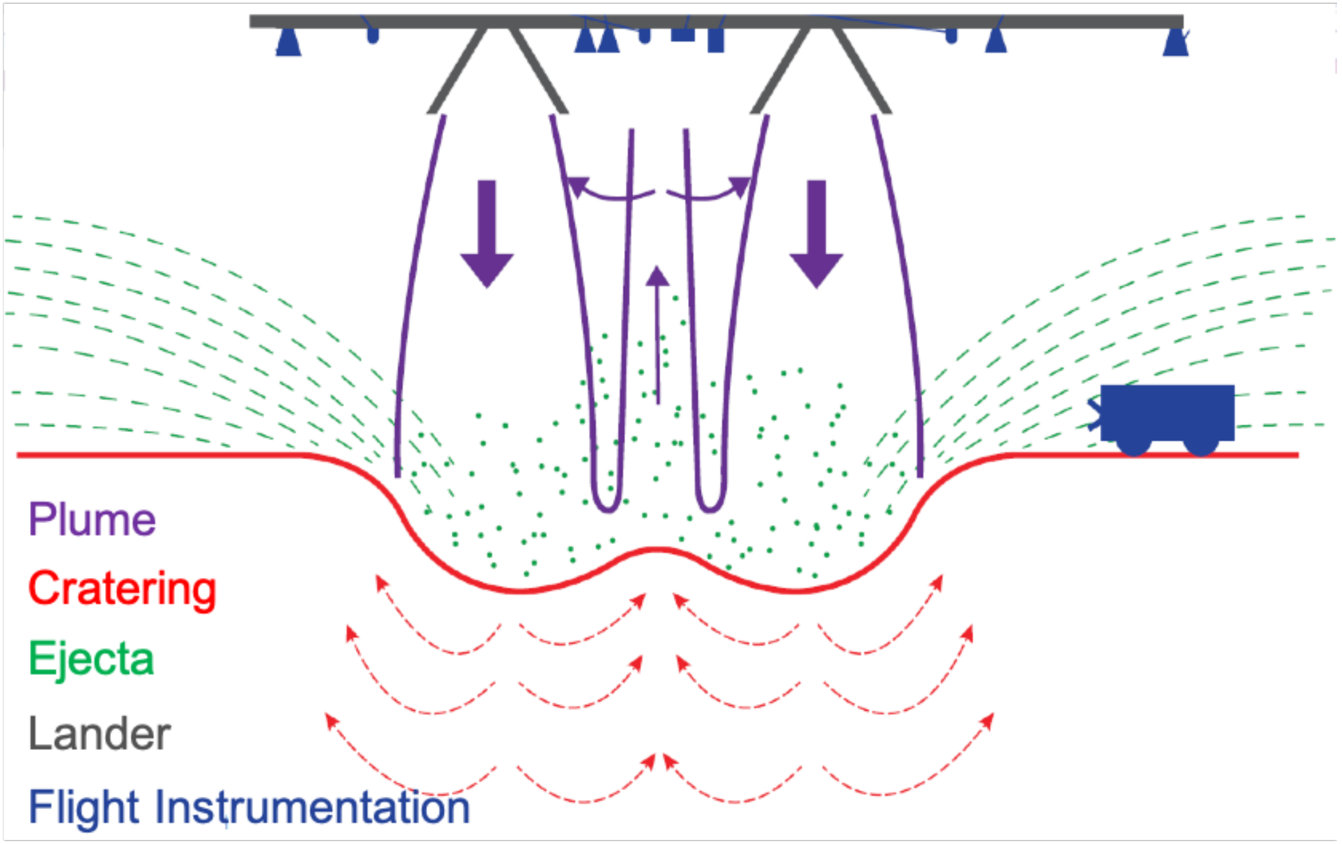


Image Credit:
NASA, JPL

Plume-Surface Interaction (PSI)

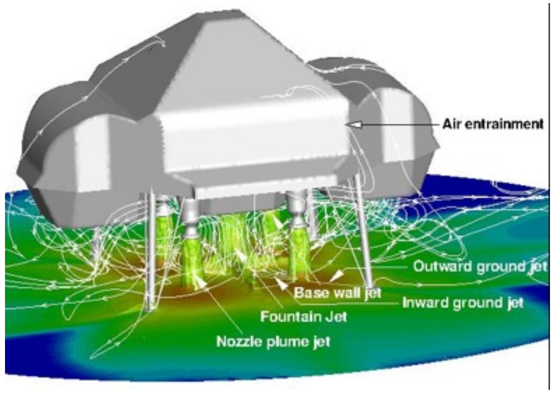
Rocket **plume-surface interaction (PSI)** is a multi-phase and multi-system complex discipline that describes the lander environment due to the impingement of hot rocket exhaust on regolith of planetary bodies.



Plume-Surface Interaction (PSI)

Plume Physics

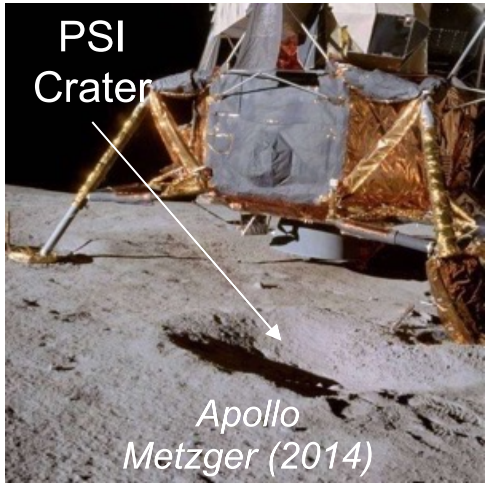
- Plume effects on the lander can lead to aerodynamic destabilization and high convective heating during powered descent and landing
- Apollo descent engine structural failure due to overpressure during touchdown



Wang, Ten-See (2019)

Erosion Physics

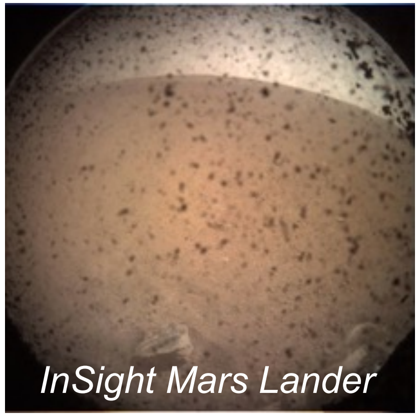
- Cratering can lead to destabilization of the lander upon touchdown and violate lander tilt requirements
- Apollo and InSight landers saw extensive cratering



Apollo
Metzger (2014)

Ejecta Dynamics

- Ejecta dynamics lead to loss of instrumentation or function, damage to the lander/surrounding structure, lack of landing visibility and can spoof radar and NDL systems
- InSight initial loss of camera function and MSL sensor damaged

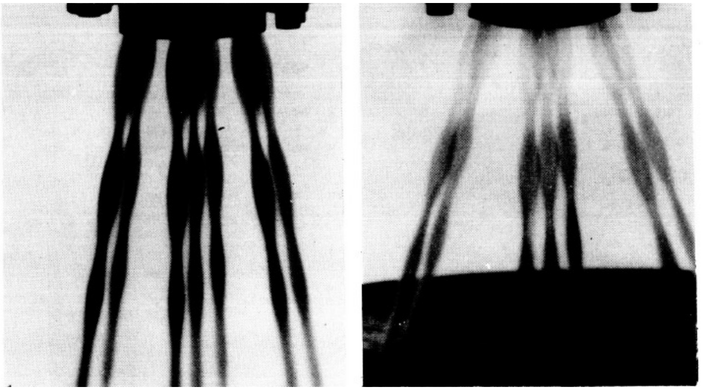


InSight Mars Lander

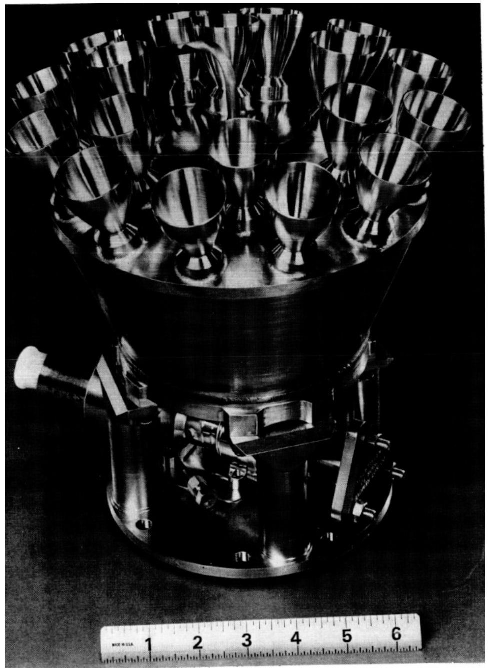
Technical PSI gaps lead to increased mission risks for lunar and planetary landers

Viking (1976)

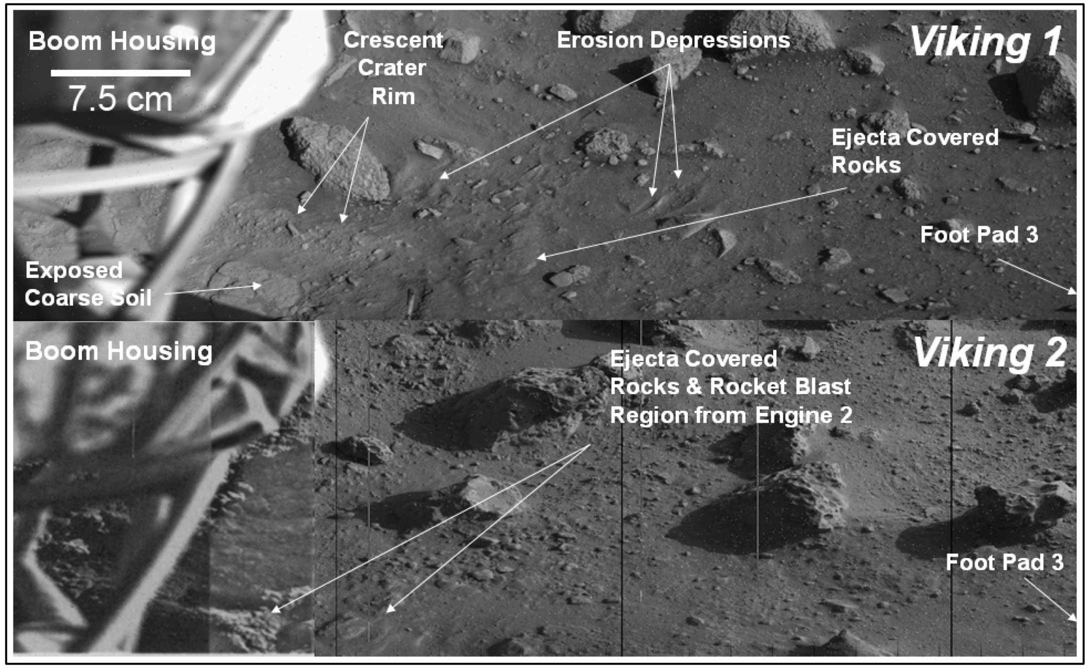
- Viking was concerned with PSI and conducted testing that is still heavily relied upon today
- Special 18-bell ‘showerhead’ nozzle developed to keep direct impingement pressure below 2 kPa

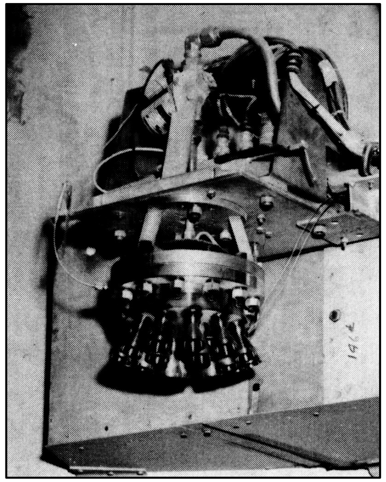


Columnated plumes at different cant angles with 7-bell Viking engine



18-bell Viking landing engine





Viking landing engine PSI test at White Sands Test Facility

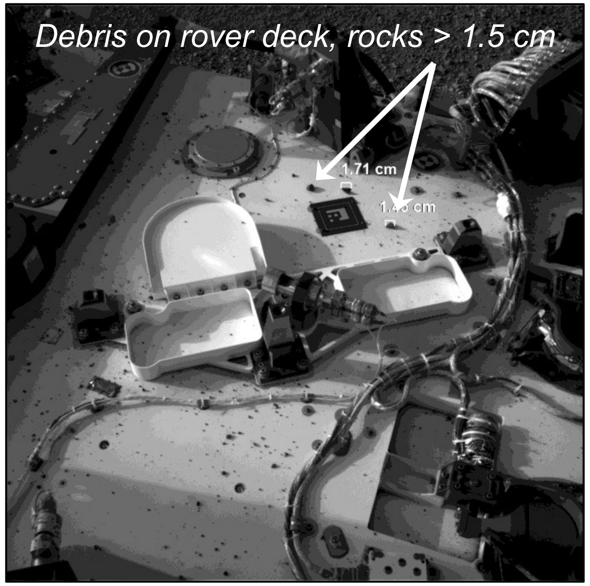
Image Credits:

(1) Romine, G., Reisert, T., and Gliozzi, J., “Site Alteration Effects from Rocket Exhaust Impingement During a Simulated Viking Mars Landing”, NASA CR-2252, 1973.

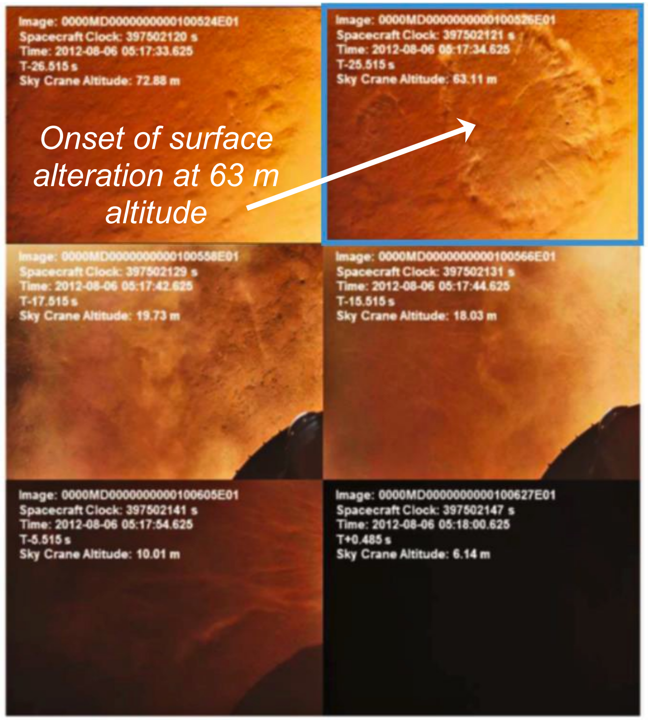
(2) Mehta, M., “Plume-Surface Interactions due to Spacecraft Landings and the Discovery of Water on Mars”, Ph.D. Dissertation, Univ. of Michigan, 2010.

Mars Science Laboratory (2012)

- Skycrane designed to mitigate PSI effects and damage to science payload
- Surface erosion observed to begin at ~ 63 m above the surface
- Crater depth estimates range from 5 to 20 cm before exposing bedrock
- Damaged wind sensor (hypothesized to be damaged by PSI)



Debris on rover deck, rocks > 1.5 cm



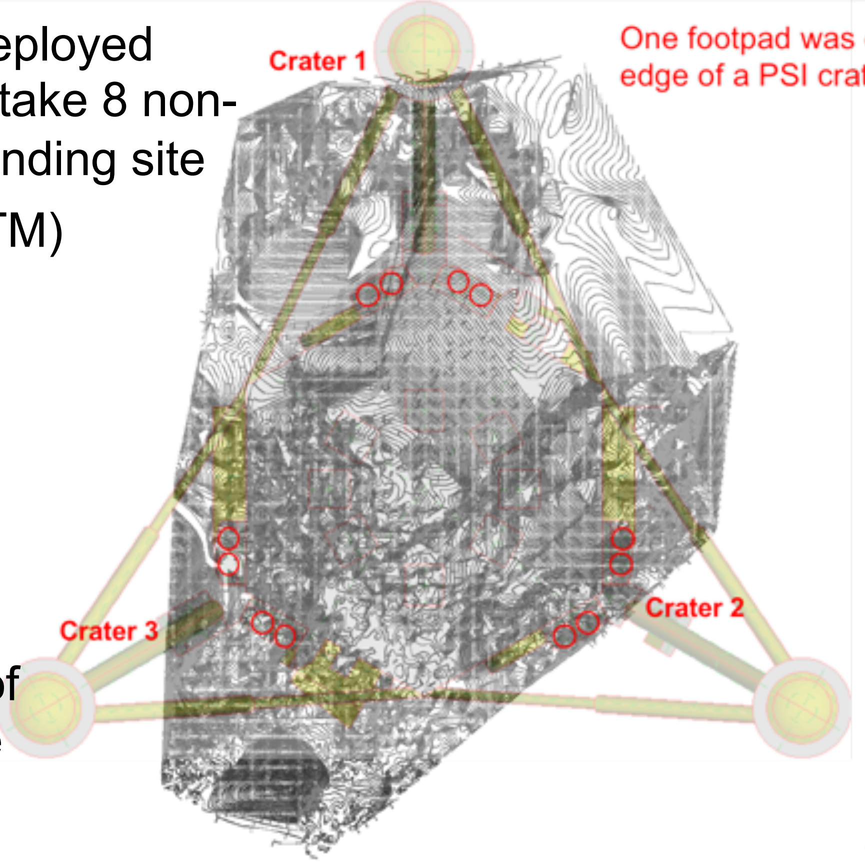
MARDI images showing progression of surface alteration

Panorama with MSL plume impingement craters

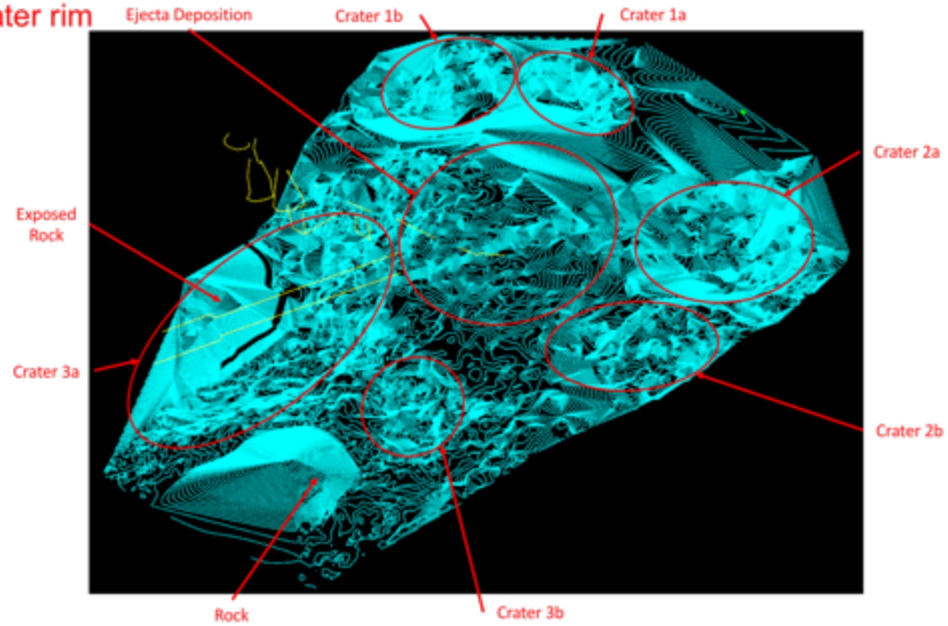
Image Credits:
(1) Bradford, E., Rabinovitch, J., and Abid, M., "Regolith Particle Erosion of Material in Aerospace Environments", IEEE, 2019.
(2) Vizcaino, J. and Mehta, M., "Quantification of Plume-Soil Interaction and Excavation due to the Skycrane Descent Stage", AIAA 2015-1649, 2015.

InSight (2018)

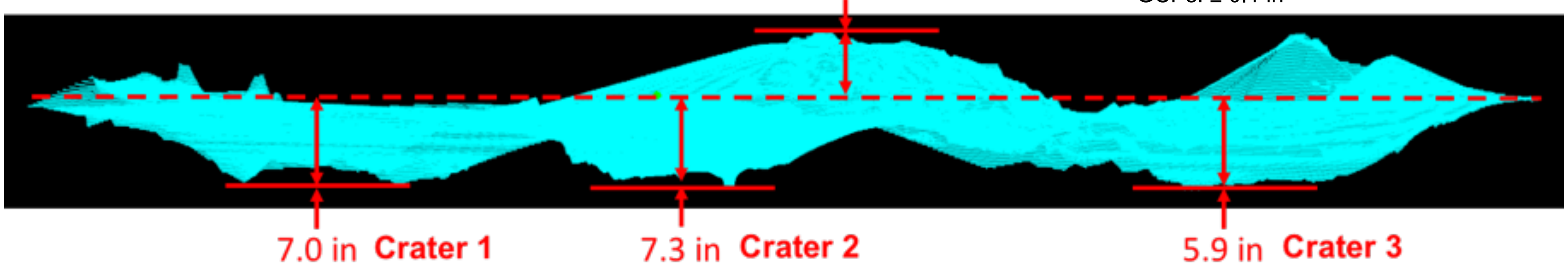
- InSight's Instrument Deployed Camera (IDC) used to take 8 non-stereo images of the landing site
- Digital Terrain Map (DTM)
- Crater volume
- Erosion rate
- Avg. crater diameter:
  - 20 inches wide
  - 7 inches deep
- One footpad on edge of crater rim – could have led to a ~5º tilt of the lander



One footpad was on the edge of a PSI crater rim

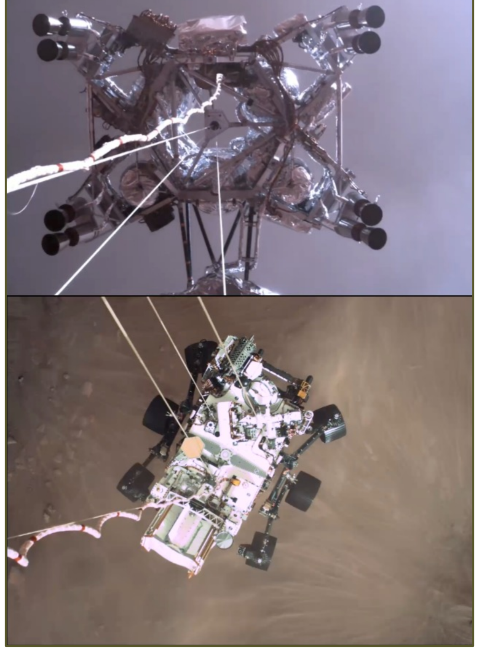


Length scale accuracy based on comparisons with GCPs: ± 0.1 in



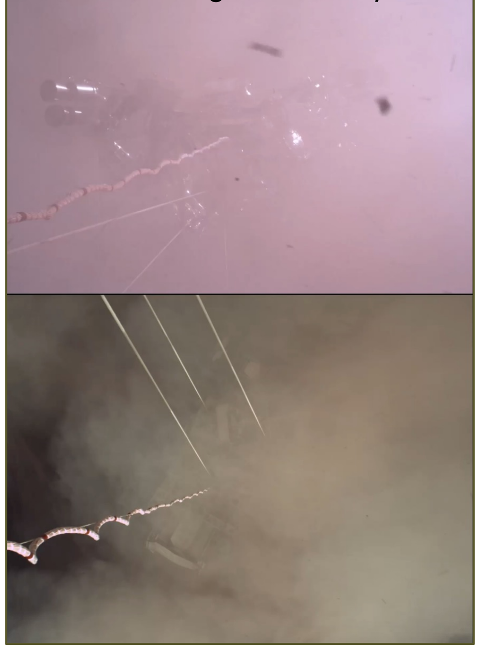
Mars2020 (2021)

- Similar to MSL, M2020 also used the Skycrane to mitigate PSI effects
- For the first time, data from uplook and downlook cameras on the descent stage and rover provided visualization of PSI

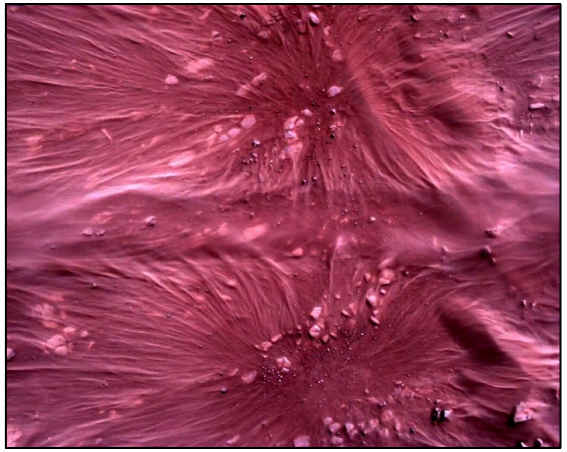


Dust lofting as rover is lowered towards the surface

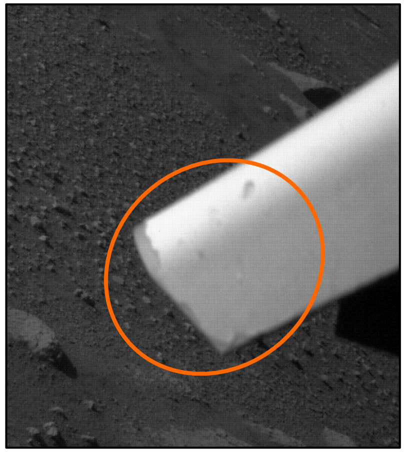
Nearly complete visual obscuration of the rover by touchdown



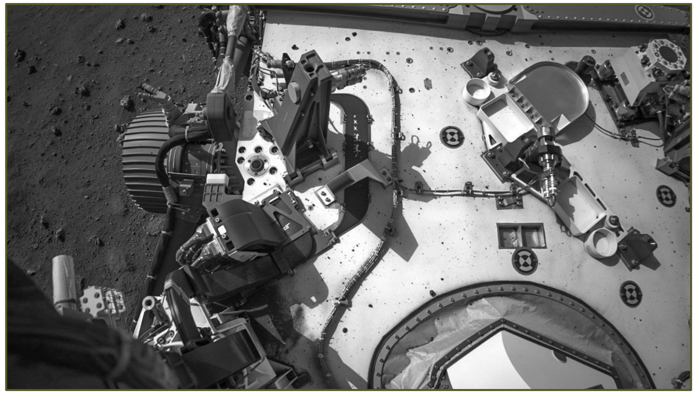
Skycrane begins to depart and dust begins to dissipate



Mars Lander Engine surface impingement and flow patterns



Paint erosion on the RIMFAX instrument



Debris on the Perseverance rover deck

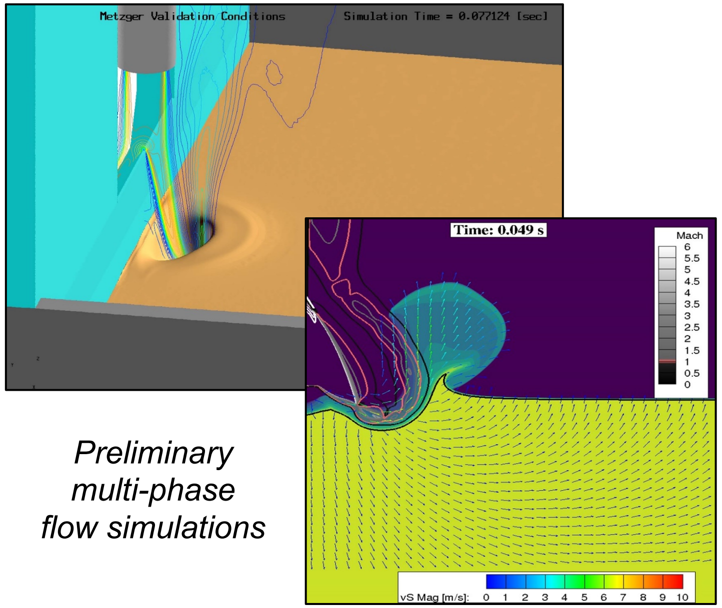
Image Credit:
NASA, JPL

Langley Research Center

NASA's PSI Project

Computational Modeling & Simulation

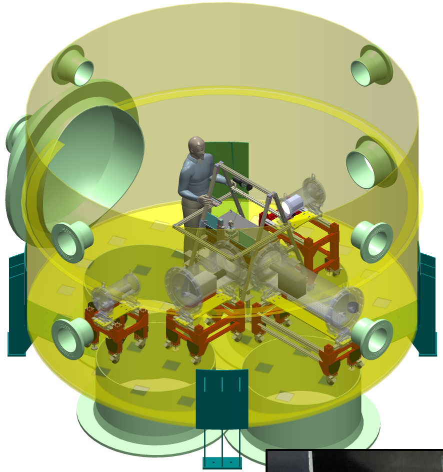
- Plume flow in low-pressure environments
- Effect of mixed continuum/rarefied flow on erosion and ejecta
- Regolith particle phase modeling
- Gas-particle interaction modeling



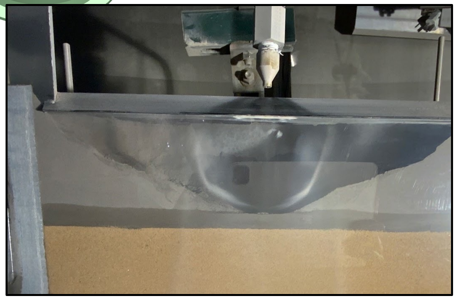
Preliminary multi-phase flow simulations

Ground Testing

- NASA MSFC TS300 sub-scale, inert gas regolith test
- NASA GRC ISP flight-scale hot-fire regolith test



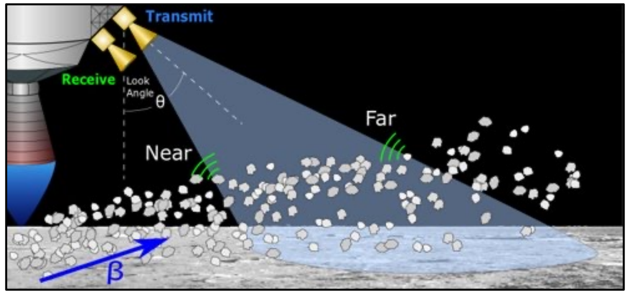
MSFC TS300 test setup



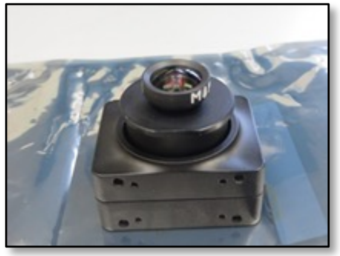
BP-1 crater generated under near-vacuum ambient pressure

Flight Instrumentation

- Improve TRL in relevant testing:
  - Stereo camera (SCALPSS)
  - mm-wave doppler radar
- 3D flight reconstruction with photogrammetry



mm-Wave Doppler Radar

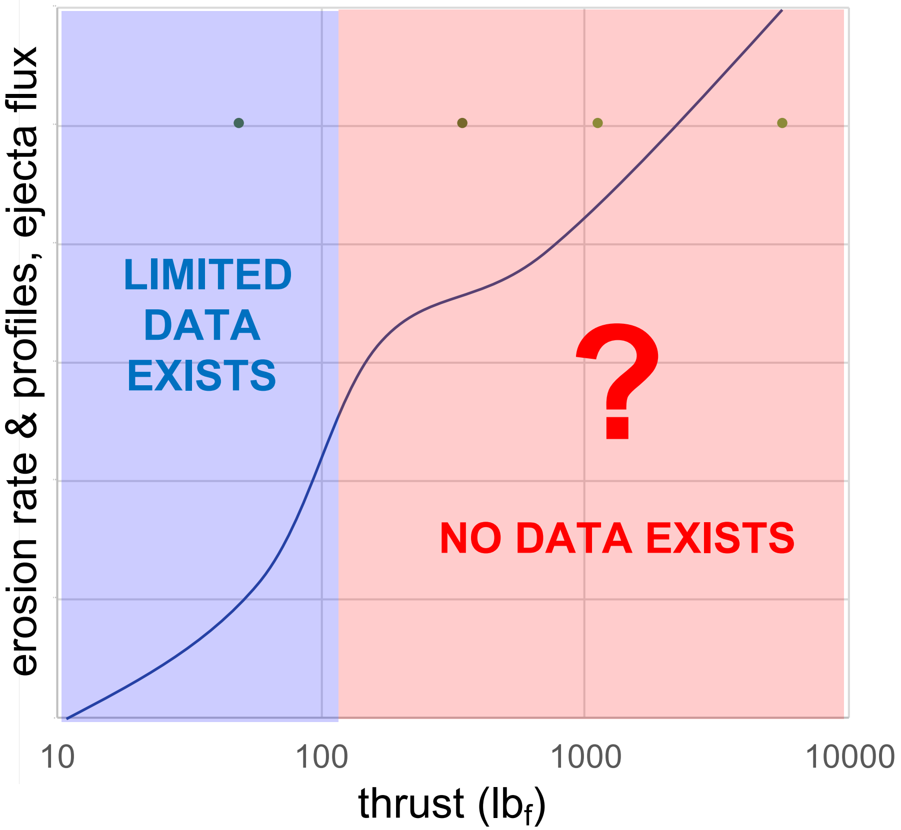


SCALPSS

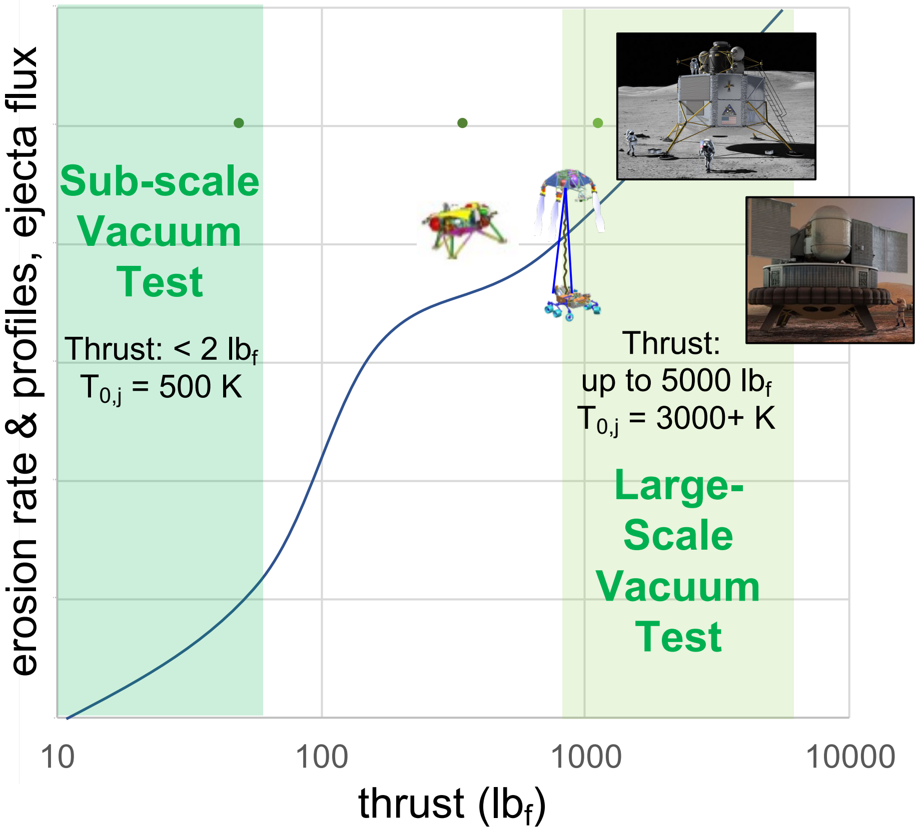
Langley Research Center

Need for Relevant Test Data

Current Situation



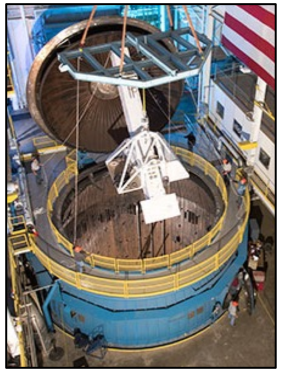
PSI Project



These two ground tests are the first opportunity since Viking to obtain flight-relevant PSI data through controlled, well-characterized ground testing

Sub-scale Inert-gas Test

Large-scale Hot-fire Test



- Relevant ground test data are necessary to validate predictive tools and quantify uncertainty in predictions: *qualitative* → *quantitative environments and impacts*
- No direct measurements of flight-scale data presently exist to inform large-scale landing systems

All propulsive landers are affected by PSI

- It's E, D, ***and L***: When landing paradigms change, PSI returns to the risk list
- Sustainable exploration necessitates looking beyond immediate, near-field vehicle effects
- Lunar landing experience will directly feed forward to Mars

Looking Ahead

- Two posters on PSI and a presentation on the EDLCAMs in the EDL Tech session at IPPW (July 20)
- Multiple special sessions on PSI and dust at upcoming 2022 AIAA SciTech Forum
- Sub-scale ground test beginning in July 2021; large-scale ground test in late 2023
- SCALPSS flight data from Nova-C lunar lander in early 2022

Questions?

Collaborators:

NASA Marshall Space Flight Center
NASA Kennedy Space Center
NASA Langley Research Center
NASA Glenn Research Center
Jet Propulsion Laboratory
Johns Hopkins University
University of Michigan
University of Central Florida
University of California - Davis