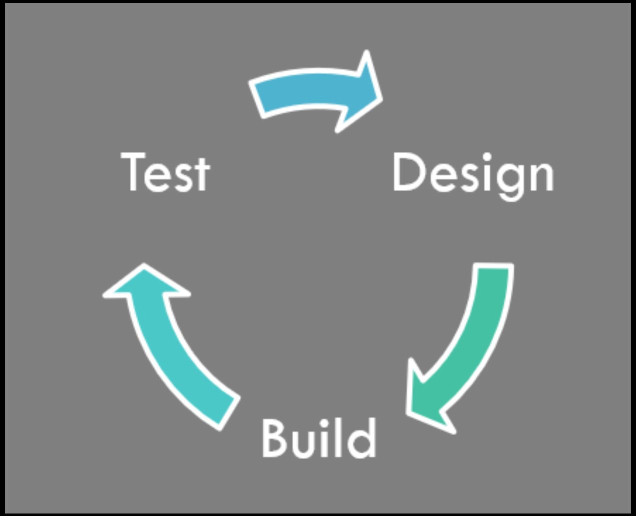
NASA

2021 Spaceport Summit

Lunar Spaceport: Construction of Lunar Landing & Launch Pads

Feb 23-25, 2021

Robert P. Mueller
Senior Technologist
Swamp Works
NASA Kennedy Space Center



SWAMP WORKS
NASA KENNEDY SPACE CENTER

“If you don’t land safely you don’t have a mission”

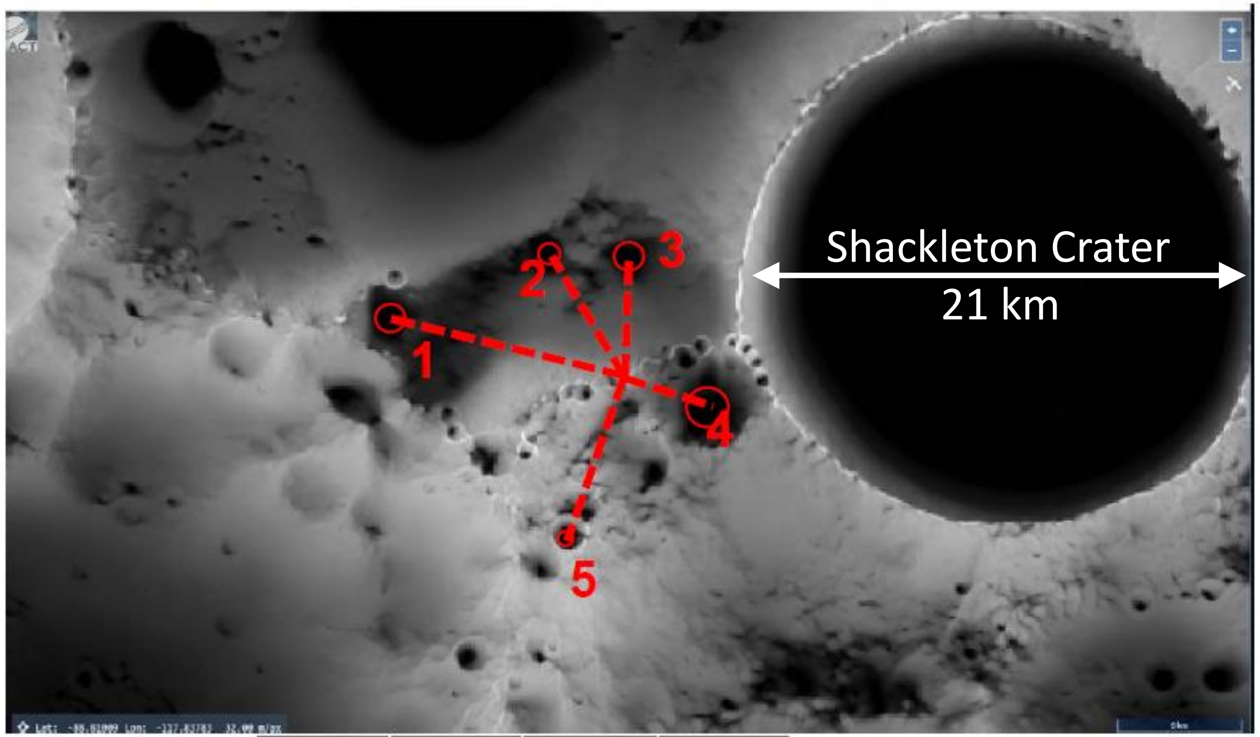
JAXA /Kaguya

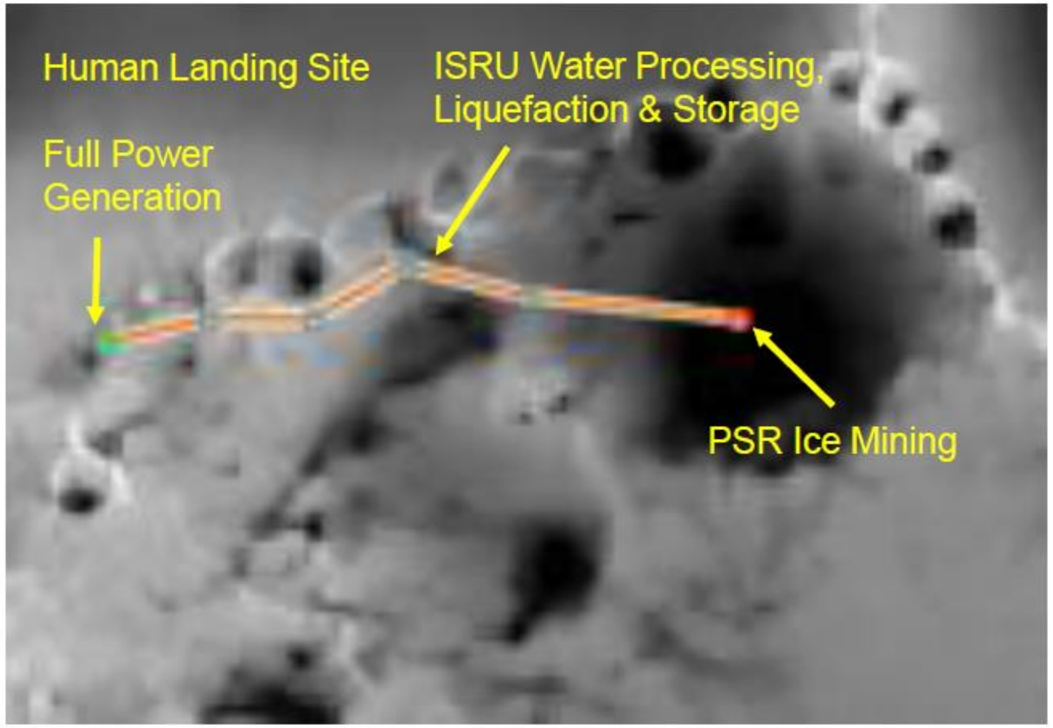
We are going to the Lunar South Pole

Landing Hazards & Lunar Dust Obscuration

Apollo 17

ISRU Ridge Site *Current Baseline



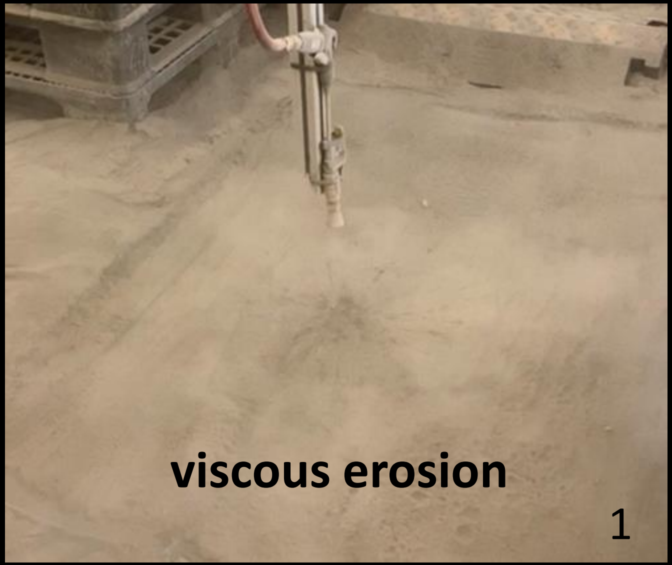


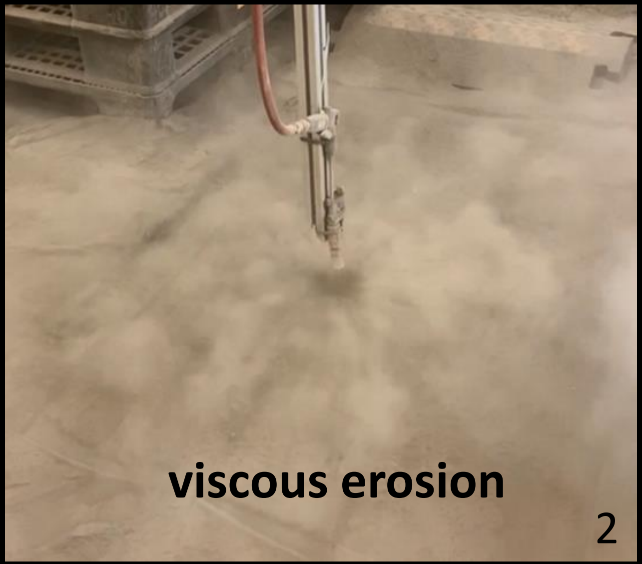
	Distance, m	Max Slope, deg	Approx. dia of PSR ice region, m
PSR 1	9105	14	1000
PSR 2	5654	19	500
PSR 3	4737	21	500
PSR 4	3500	16	1500
PSR 5	6688	21	500

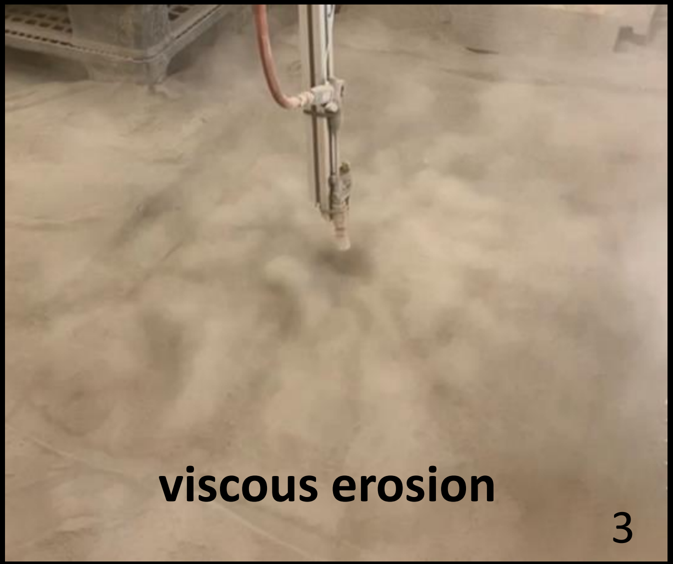
	Distance, m	Max Slope, deg	Approx. dia of PSR ice region, m	Ridge Longitude	Ridge Latitude	PSR Longitude	PSR Latitude
PSR 1 straight	6600	20	1000	-137.34 (222.64)	-89.45	-116.94	-89.38
PSR 4 straight	6500	18	1500			-158.79	-89.57
PSR 4 Ridgeline	6850	15	1500			-158.73	-89.58

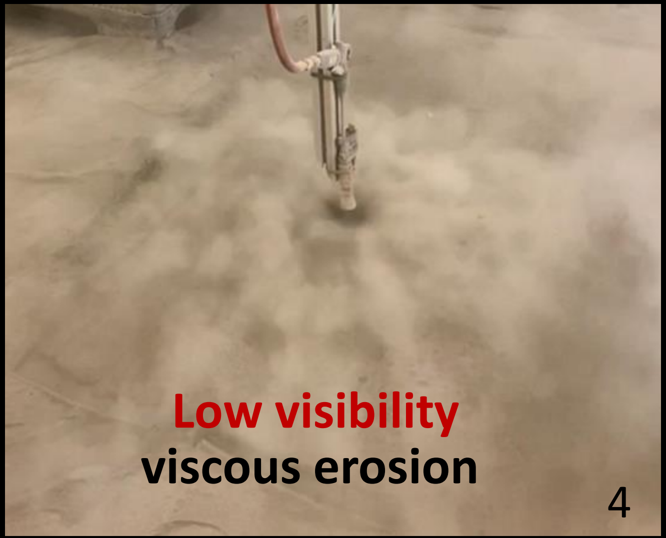
NASA Oxygen & Water Production Architectures for Early Reusable Lander, Lunar ISRU Workshop, Sanders et al, 7/2019

Cold Gas Testing Video: GMRO* lab - KSC









*Granular Mechanics & Regolith Operations (GMRO)

~100 psi (689.5 kPa) compressed air

Cold Gas Testing Crater: GMRO* lab - KSC

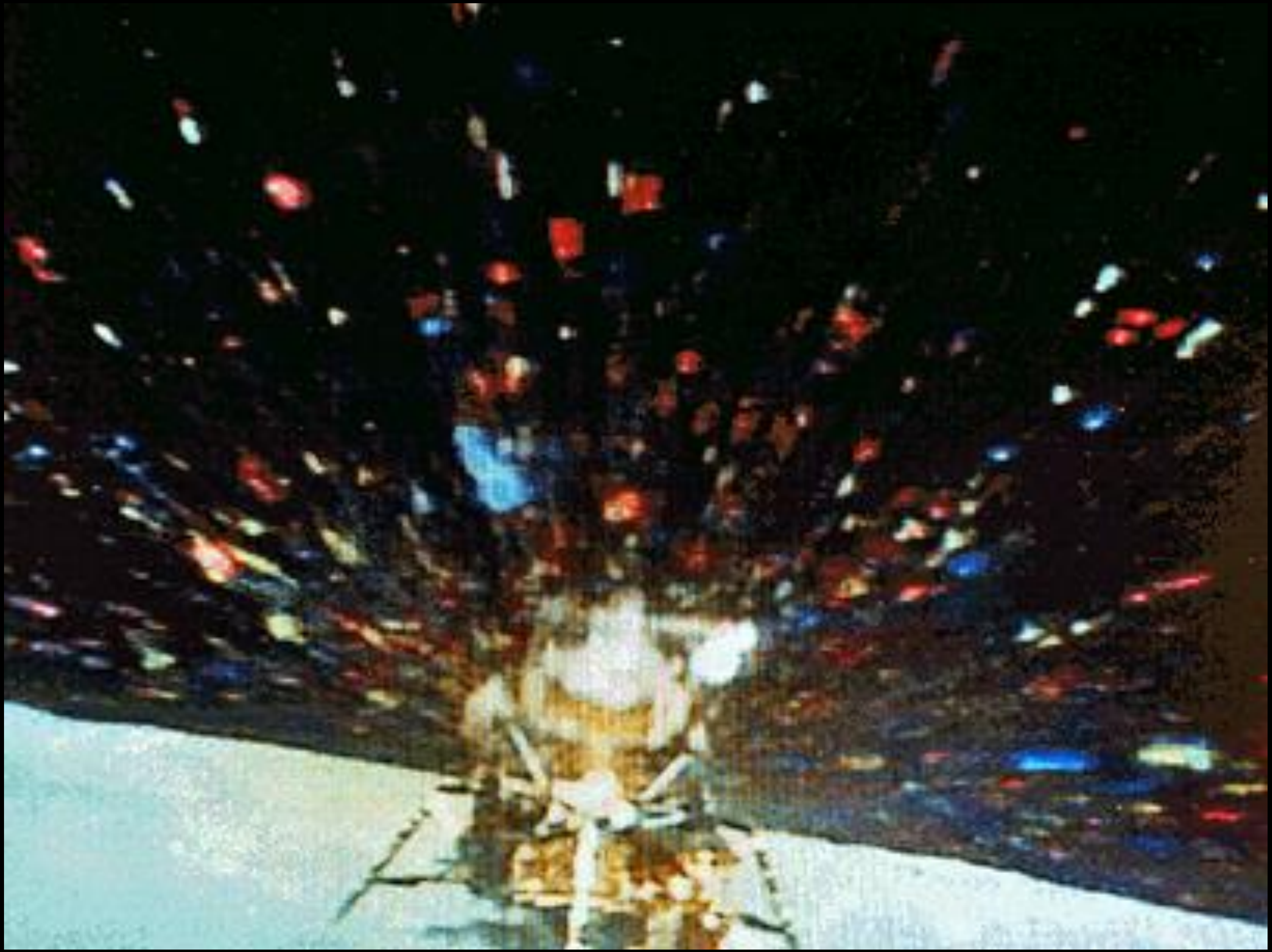
After the Test

*Granular Mechanics & Regolith Operations (GMRO)

Collimated Plume during Morpheus Flight at Kennedy Space Center

Falcon 9 plume
with under-expanded
nozzle in upper
atmosphere

Source: SpaceX



Apollo 16 Launch
(NASA PHOTO: s72-35613)

Lunar Landing Considerations

- **Topography** (tipping angle, hazards, craters, boulders, rocks, ejecta shielding)
- **Lighting** (Pilot view, camera sensor view)
- **Regolith Reflectance** (LIDAR, RADAR)
- **Thermal** (long shadows, CTE stresses)
- **Seismic** (structural integrity of landing site)
- **Geotechnical** (regolith conditions, bearing strength, surface dust)
- **Over Flight Path** (cannot fly over base for safety)
- **Navigational Aids** (Visual targets, retro-reflectors, active beacons)
- **Rocket engine thrust** (mass of lander, landing conops, height from surface, duration of operation)
- **Plume Surface Impingement Ejecta** (landing visibility, damage to base assets & orbital assets)
- **Plume Surface Impingement Cratering** (hazard to vehicle, liberates regolith & dust)
- **Plume Surface Impingement Blast Ejecta** (Explosion Ejecta)
- **Proximity to Regions of interest** (Science, ISRU)
- **Proximity to Habitat / Base** (Commuting burden)
- **Access via traverses** (EVA and mobility platforms, direct vs. distance made good)
- **Artemis Accords** (principle of due regard, safety zones, de-confliction)

Lunar Landing / Launch Pads

Goal: Mitigate lunar surface hazards

Pad Solution: Prepare the landing site to remove rocks & grade surface

Goal: Eliminate liberation of regolith dust particles & avoid surface cratering

Pad Solution: Emplace a rocket engine gas plume barrier on the regolith surface

Lunar Landing / Launch Pads (LLP)
Notional Preliminary Requirements
(To be Reviewed)

- The LLP terrain shall have a slope of < 5^{o}
- The LLP terrain shall be cleared of rocks > 20 cm diameter
- The LLP shall withstand gas temperatures of 3,000^{o} – 4,000^{o} C
- The LLP shall withstand gas velocities of 2,000 – 3,000 m/s
- The LLP shall withstand a maximum shear stress of 3000 Pa
- The LLP shall support landing within 100m of a given point
- The LLP shall have good visibility for pilots and sensors before and during landing
- The LLP shall withstand the launch environment during ignition

Lunar Landing / Launch Pads Concepts

LLP Structure Concepts
Minimal Preparation
Existing Topography
Compacted Regolith Surface
Bedrock Surface
Ice Surface
Rock Piles
Surface Stabilization Applications
Regolith Bags
Ice Bladders
Pavers
Metallic Plates
Deployable Structures
Direct Emplacement of Sintered Structures
Direct Emplacement of Polymer Concretes
Direct Emplacement of a Concrete Pad

Off Earth Landing and Launch Pad Construction – A Critical Technology for Establishing a Long-Term Presence on Extraterrestrial Surfaces
Nathan J. Gelino, Robert P. Mueller, Robert W. Moses, PhD, James G. Mantovani, PhD, Philip T. Metzger, PhD, Brad C. Buckles, Laurent Sibille, PhD
To Be pubished at ASCE Earth & Space Conference, April 2021 (COVID-19 delay)

Conclusions

- Lunar launch and Landing must be safe to have a successful mission
- There are many hazards on the lunar surface
- These hazards must be mitigated to ensure a safe landing and launch
- Site Preparation can shape the topography by moving regolith
- Regolith and rocks can be moved by robotic mobility with implements
- A landing/launch pad can prevent rocket plume regolith ejecta and cratering
- The Artemis accords may require a landing/launch pad