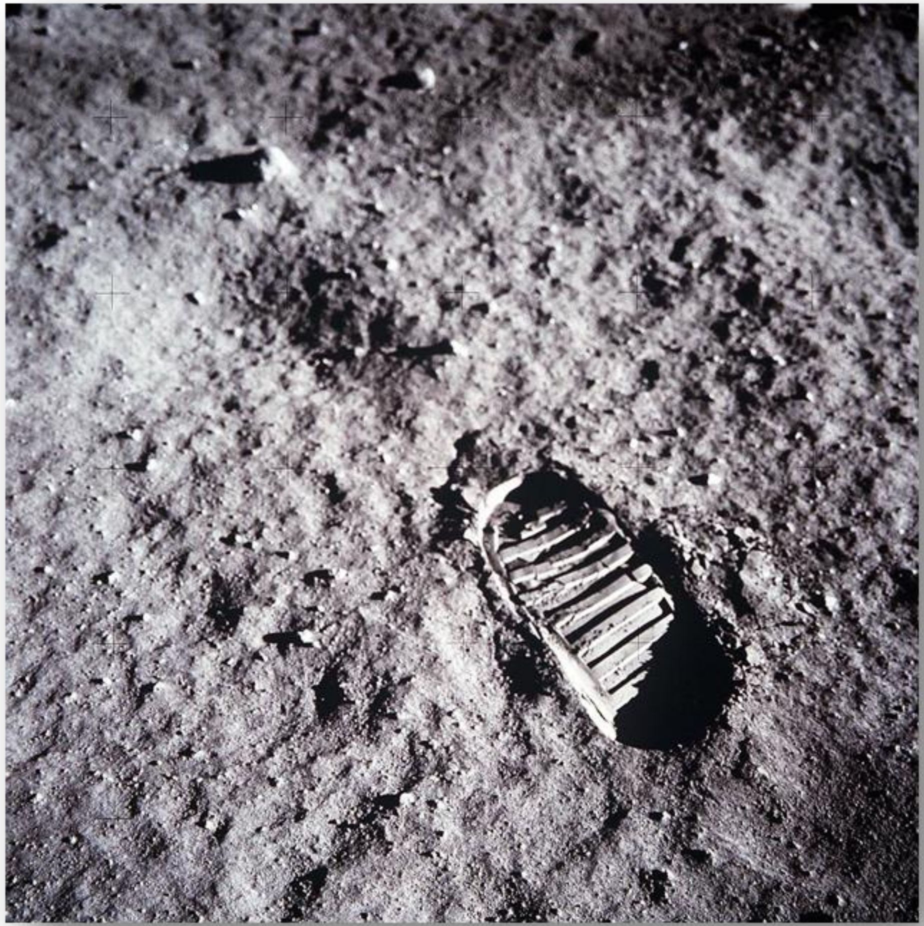
Managing the Plume Effect To Assure Sustainability Of Lunar Activities

59th Session of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space

Feb. 8, 2022

FOR ALL MOONKIND™



www.forallmoonkind.org

For All Moonkind is a non-profit organization that seeks to **protect and preserve human history and heritage** in outer space.

Our **entirely volunteer team** of space lawyers and policymakers are working to develop reasonable and practical protocols that will balance development and preservation and include systems to select, manage and study relevant sites.

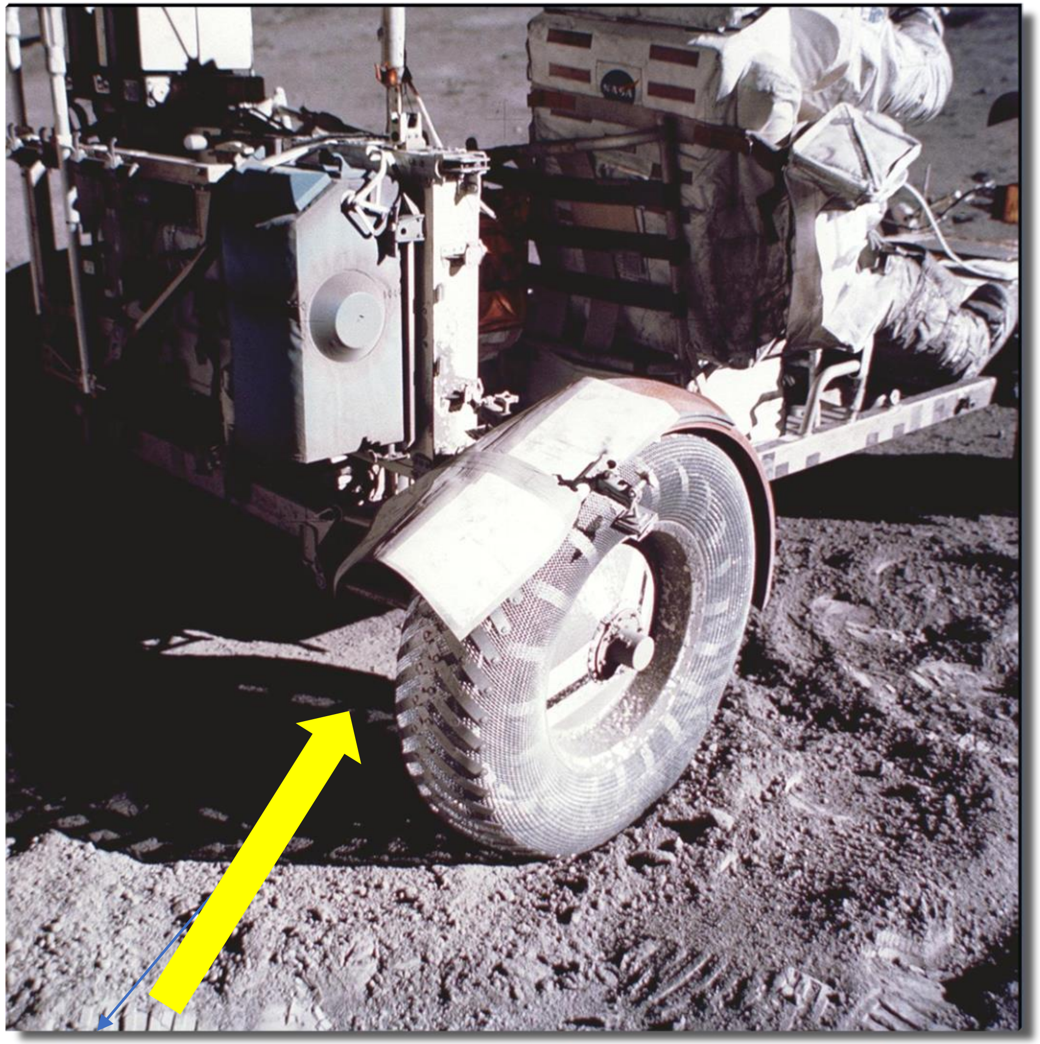
In so doing, we seek to **promote responsible and sustainable exploration and development of space**.

FOR ALL MOONKIND™

The LTS Guidelines define the sustainability of outer space activities as the ***ability to maintain the conduct of space activities indefinitely into the future*** in a manner that realizes the objectives of ***equitable access to the benefits*** of the exploration and use of outer space for peaceful purposes, in order to meet the needs of present generations while preserving the outer space environment for future generations.

UN Doc. A/74/20
UN Doc. A/AC.105/C.1/L.366

FOR ALL MOONKIND™



Stiff plasticized maps were taped together and fastened by clamps to patch a broken fender of the Apollo 17 Lunar Roving Vehicle (LRV).

"I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon.
I think we can overcome other physiological or physical or mechanical problems except dust."

Gene Cernan

Lunar regolith is the **layer of unconsolidated rocks, pebbles, and dust** that exists on the lunar bedrock. The particles are sharp and angular in nature, resulting in a much more abrasive material than their terrestrial counterparts

Regolith **is also adhesive**, both mechanically and electrostatically. **Mechanical adhesion** occurs because of the barbed shapes of the grains of dust. **Electrostatic adhesion** is caused by the charging of objects by various sources, such as solar wind plasma and photoionization.

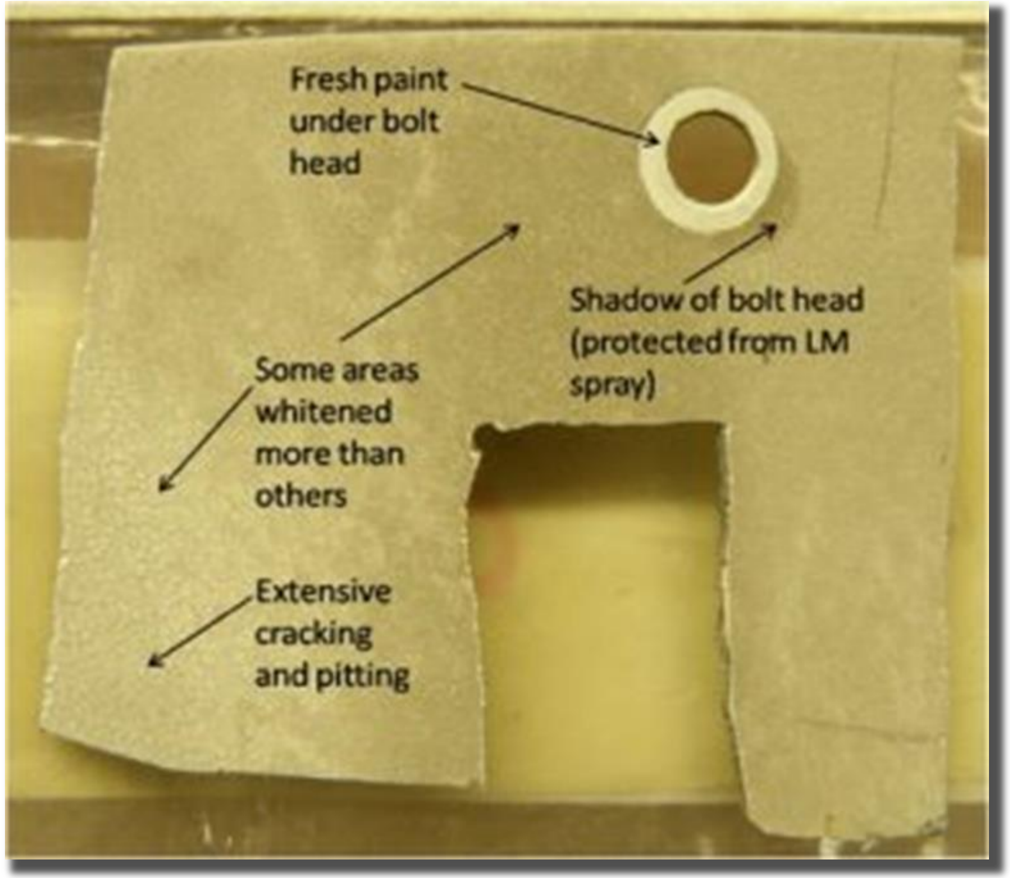
FOR ALL MOONKIND™

In 1967, Apollo 12 landed near Surveyor 3 – astronauts brought a piece back. Almost all of the exposed surfaces on the camera retrieved from Surveyor III were at least partially covered with a layer of lunar dust.

The camera's exterior surface seemed to be **fading and** had a series of shadows that provided a direct indication that lunar dust was responsible for a major part of the observed discoloration.

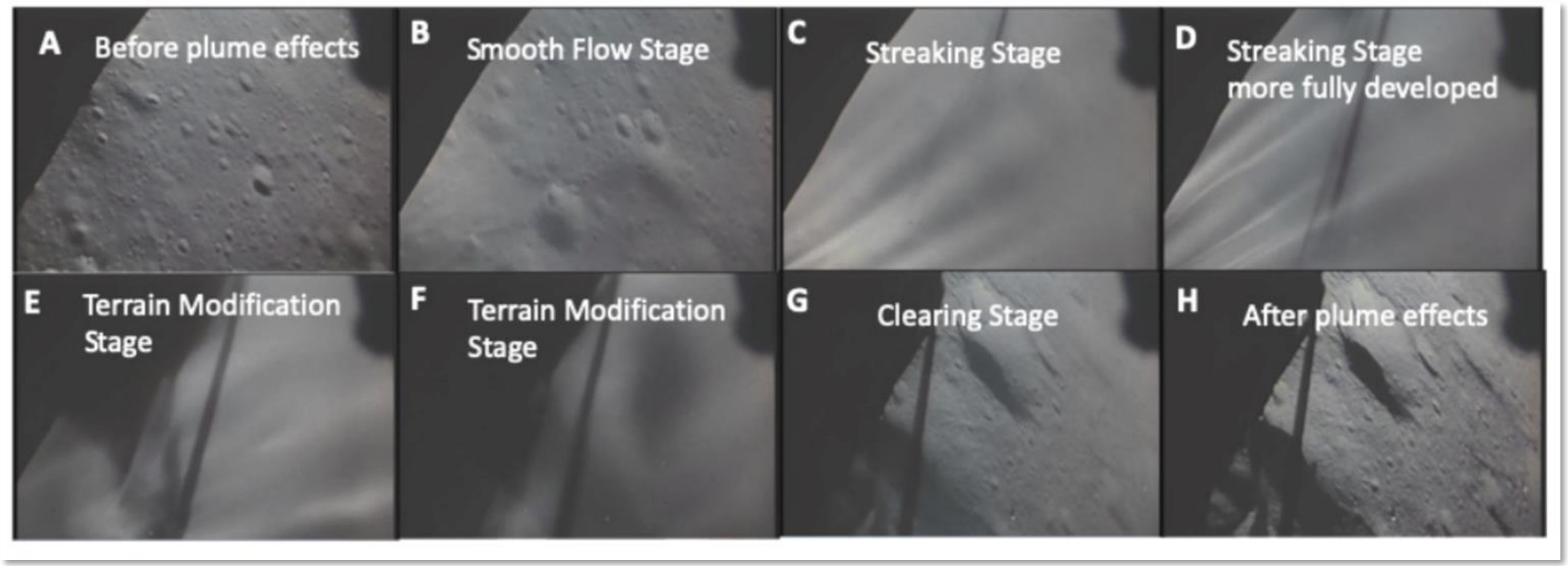
The surface of Surveyor III had **hundreds of pits**, or micro-craters, from the impact of high-velocity soil particles.

The spacecraft had **pinholes** where sand grains penetrated the paint and cracks that radiated away from the pinholes.



Damage to Surveyor III

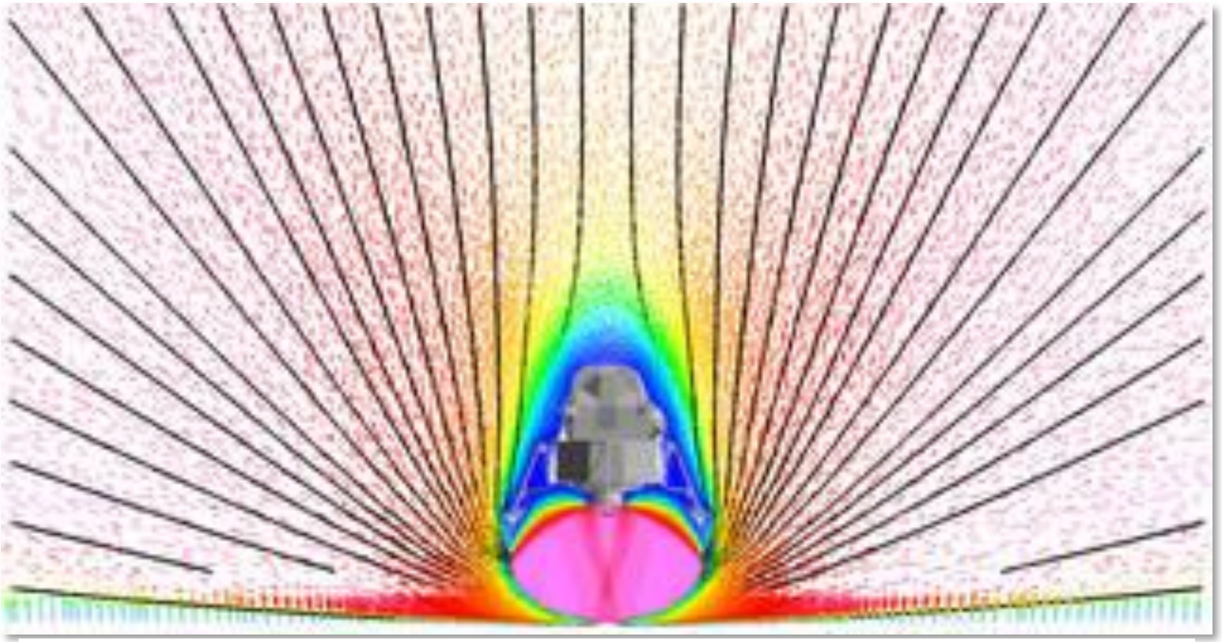
FOR ALL MOONKIND™



Stages of rocket exhaust ejecta beneath an Apollo Lunar Module. In smooth and streaking flow stages, ejecta is mainly in a sheet **1-3 degrees above horizontal**, although some individual streaks are at higher angles. In terrain modification stage much of the ejecta is lofted into higher angles **exceeding 15 degrees.**

Credit: Metzger, P., Smith, J., Lane, J., Phenomenology of soil erosion due to rocket exhaust on the Moon and the Mauna Kea lunar test site. Journal of Geophysical Research: Planets 116, no. E, 2011.

FOR ALL MOONKIND™



Apollo Lunar Module plume impingement at a distance of 5 m above the landing surface. Image shows plume gas velocity vectors colored by velocity magnitude (blue = low, magenta = high) as well as streamlines indicating the strong upward flow direction under vacuum conditions.
Credit: NASA

Rocks and larger particles may directly damage equipment.

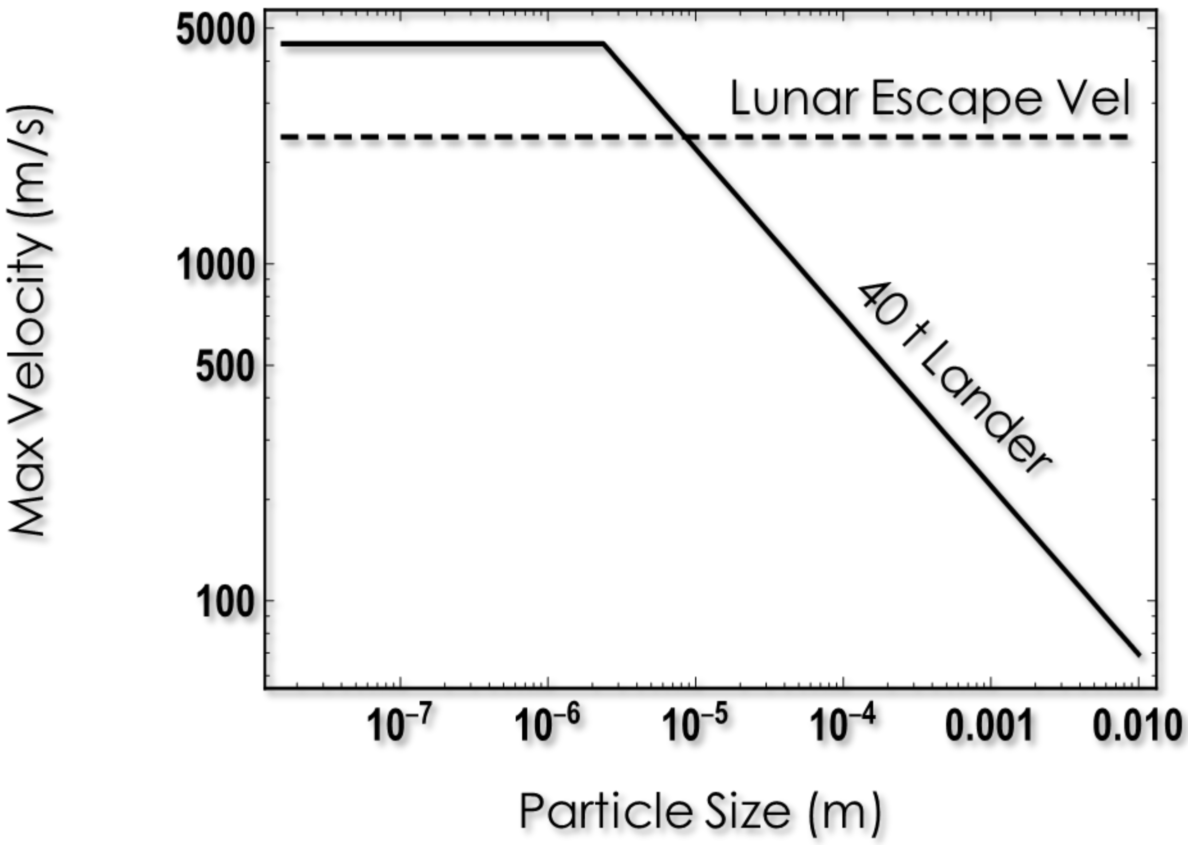
Dust coating is a precursor to myriad other problems including:

- vision obscuration
- false instrument readings
- dust coating and contamination
- loss of traction
- clogging of mechanisms
- abrasion
- thermal control problems
- seal failures

Announced Missions to the Lunar Surface & Lunar Orbit as of February 2022

2022	LunaH-Map - Early 2022 - Lunar Orbiting CubeSat **(USA)** Lunar Ice Cube - Early 2022 - Lunar Orbiting CubeSat **(USA)** Lunar InfraRed imaging (LunIR) - Early 2022 - Lunar Flyby and Technology Test CubeSat **(USA)** OMOTENASHI - Early 2022 - Lunar Lander CubeSat **(Japan)** EQUULEUS - Early 2022 - L2 Orbit Lunar CubeSat **(Japan)** IM-1 - Early 2022 - Lunar Lander **(USA)** CAPSTONE - NET March 2022 - Lunar Navigation Test Orbiter **(USA)** Luna 25 - May 2022 - Lunar Lander **(Russia)** Pathfinder Lunar Orbiter - 1 August 2022 - Lunar Orbiter **(South Korea)** Prime 1 - December 2022 - Lunar Lander **(USA)** Peregrine Mission 1 - 2022 - Lunar Lander **(USA)** SLIM - 2022 - 2023 - Lunar Lander **(Japan)** Hakuto-R (Mission 1) – Late 2022 – Lunar Lander **(ispace)** Rashid – Late 2022 – Lunar Lander **(UAE)** Peregrine – Late 2022 – Lunar Lander **(Astrobotic)** Nova-C – Late 2022 - Lunar Lander **(Intuitive Machines)**
2023	XL-1 Lander - 2023 - Lunar Lander **(USA)** Chandrayaan-3 – 2023 – Lunar Lander **(India)** VIPER - Late 2023 - Lunar South Pole Rover **(USA)**
2024 & beyond	Chang'e 7 - 2024 - CNSA (China) Lunar Survey Mission **(China)** Chang'e 6 - 2024 - CNSA (China) Lunar Sample Return Mission **(China)** Lunar Trailblazer - 1 February 2024 - Lunar Orbiting Small Satellite **(USA)** Chang'e 8 - TBD - CNSA (China) Lunar Technology Test **(China)** Beresheet 2 - 2024 - SpaceIL and IAI (Israel) Lunar Lander **(Israel)**

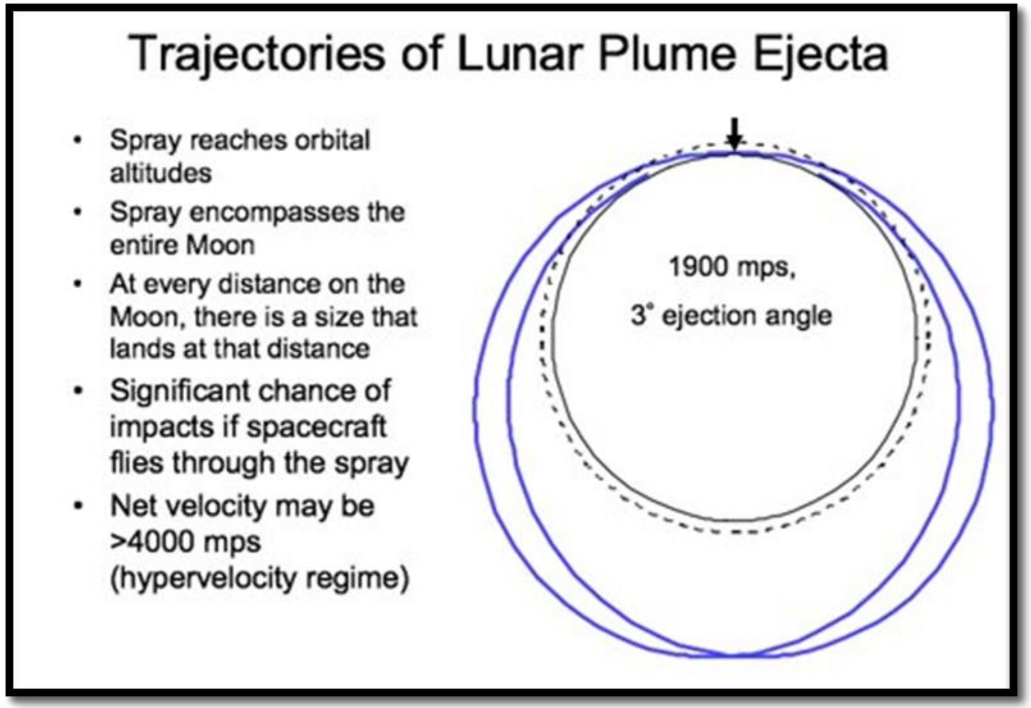
FOR ALL MOONKIND™



Credit: P. T. Metzger, Dust Transport and Its Effects Due to Landing Spacecraft, The Second NASA Engineering and Safety Center Workshop on the Impact of Lunar Dust on Human Exploration, 2020.

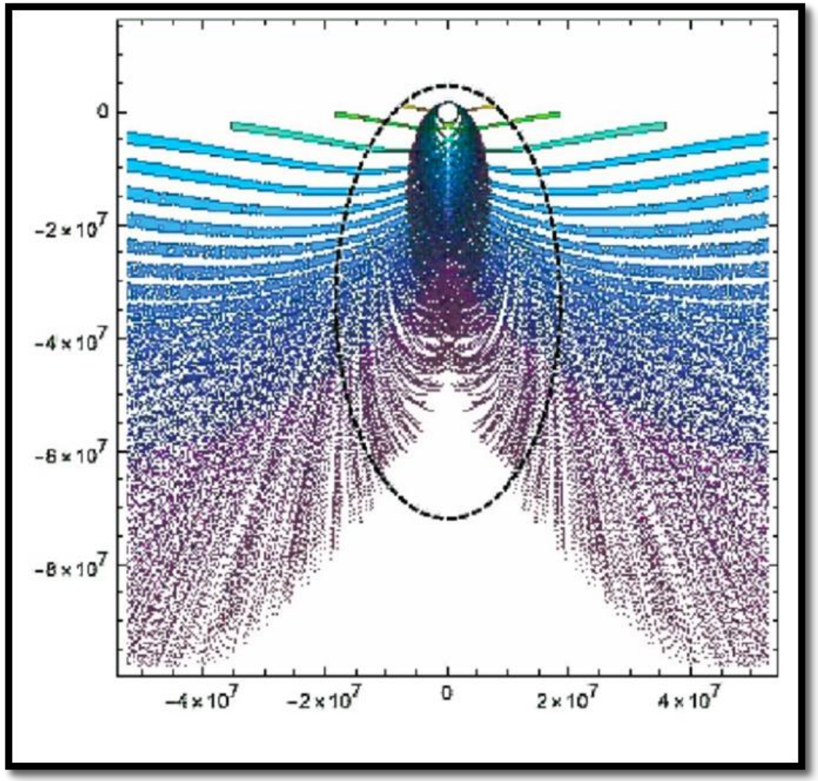
Model of maximum ejecta velocities as a function of lunar soil particle size.

This simulation indicates that particles up to 10 µm can be ejected completely off the Moon.



Black circle: circumference of the Moon. Black arrow: where the Lunar Module landed.
Dashed circle: altitude of the orbiting Command and Service Module during the Apollo missions.
Blue circles: ejecta from the landing of the Lunar Module.

Credit: Jeffrey Montes, et. al., Pad for Humanity: Lunar Space as Critical Shared Infrastructure, Proceedings of the 17th International Conference on Engineering, Science, Construction & Operations in Challenging Environments, 2020.



Physics-based computer simulation of ejecta caused by a 40mT lunar lander.
Tiny circle: Moon.
Ellipse: Near Rectilinear Halo Orbit of the Lunar Gateway. Ejecta crosses the Gateway orbit such that Gateway will pass through the ejecta several times before it is dissipated by solar wind.

FOR ALL MOONKIND™

As lunar activity looks to move beyond short-duration, self-contained science missions, the potential for damage or mission failure caused by high-velocity ejecta, combined with the potential for geopolitical confrontations over these effects, suggests that a solution must be developed.

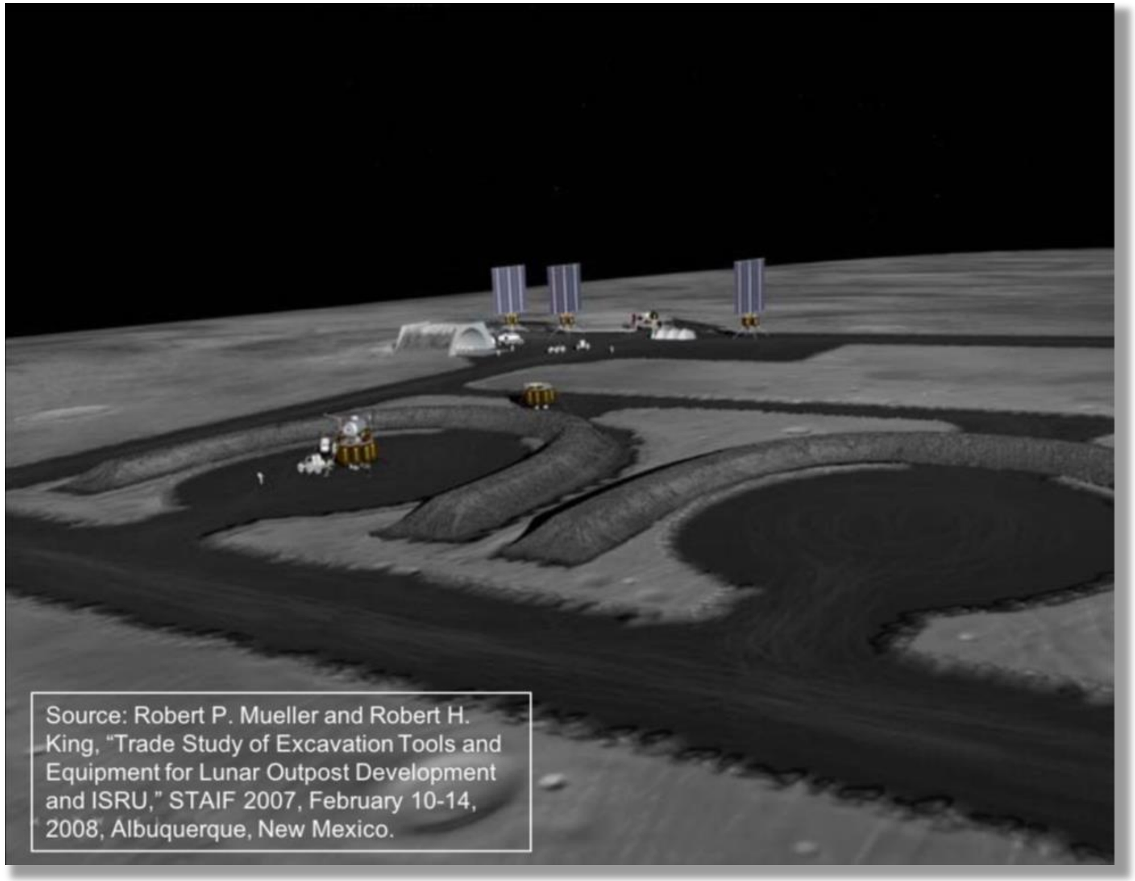
There are multiple ideas for the mitigation of the plume effect, including:

- constructing berms
- implementing safety zones and
- creating landing pads

When using berms alone, particles colliding in flight are likely to scatter over the barriers. Larger particles like rocks loft over barriers and arc down the other side, scattering the particles in lunar vacuum.

Safety zones can be defined as buffer zones in which operational safety requires consultations between Parties to avoid harmful interference and related risks. While safety zones may reduce some of the risks associated with the plume effect, when used alone, they are insufficient to dispel the visual landing hazards.

FOR ALL MOONKIND™



Landing pads are a kind of armor for the lunar surface in that they **protect the ground** from the highly destructive force of the exhaust plume.

Practically speaking, this **prevents the ground from becoming a spray of high-velocity projectiles** that would necessitate armor for surrounding assets.

Investing in this lunar infrastructure early is critical for cost control, asset safety and programmatic durability. These landing pads should be the result of **international collaboration**; established in internationally agreed locations that afford requisite access to locations as indicated by further exploration and analysis of the resources on the Moon.

FOR ALL MOONKIND™

For All Moonkind believes that nations engaged in – or whose nationals are engaged in – activities on the Moon have a **legal obligation** to **mitigate the potentially devastating effects** of lunar ejecta.

Beyond the responsibilities imposed by the Outer Space Treaty & the Liability Convention, the **LTS Guidelines** tell us that we, as the international community, must take steps towards mitigating the risks associated with the conduct of outer space activities so that present benefits can be sustained, and future opportunities realized.

A/74/20

II. Guidelines for the long-term sustainability of outer space activities

A. Policy and regulatory framework for space activities

Guideline A.1

Adopt, revise and amend, as necessary, national regulatory frameworks for outer space activities

1. States should adopt, revise and amend, as necessary, national regulatory frameworks for outer space activities, taking into account their obligations under the United Nations treaties on outer space as States responsible for national activities in outer space and as launching States. When adopting, revising, amending or implementing national regulatory frameworks, States should consider the need to ensure and enhance the long-term sustainability of outer space activities.

2. With the increase in outer space activities by governmental and non-governmental actors from around the world, and considering that States bear international responsibility for the space activities of non-governmental entities, States should adopt, revise or amend regulatory frameworks to ensure the effective application of relevant, generally accepted international norms, standards and practices for the safe conduct of outer space activities.

3. When developing, revising, amending or adopting national regulatory frameworks, States should consider the provisions of General Assembly resolution 68/74, on recommendations on national legislation relevant to the peaceful exploration and use of outer space. In particular, States should consider not only existing space projects and activities but also, to the extent practicable, the potential development of their national space sector, and envisage appropriate, timely regulation in order to avoid legal lacunae.

4. States, in enacting new regulations, or in revising or amending existing legislation, should bear in mind their obligations under article VI of the Outer Space Treaty. Traditionally, national regulations have been concerned with issues such as safety, liability, reliability and cost. As new regulations are developed, States should consider regulations that enhance the long-term sustainability of outer space activities. At the same time, regulations should not be so prescriptive as to prevent initiatives addressing the long-term sustainability of outer space activities.

Guideline A.2

Consider a number of elements when developing, revising or amending, as necessary, national regulatory frameworks for outer space activities

1. When developing, revising or amending, as necessary, regulatory measures applicable to the long-term sustainability of outer space activities, States and international intergovernmental organizations should implement international obligations, including those arising under the United Nations space treaties to which they are party.

2. In developing, revising or amending, as necessary, national regulatory frameworks, States and international intergovernmental organizations should:

(a) Consider the provisions of General Assembly resolution 68/74, on recommendations on national legislation relevant to the peaceful exploration and use of outer space;

(b) Implement space debris mitigation measures, such as the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, through applicable mechanisms;

54 V.19-06077

FOR ALL MOONKIND™

Guideline A.1 provides that given the increase in space activities by both governmental and non-governmental actors from around the world, and considering that States bear international responsibility for the space activities of non-governmental entities, **States should adopt, revise, or amend regulatory frameworks to ensure the effective application of relevant, generally accepted international norms, standards and practices for the safe conduct of outer space activities.**

Guideline A.3 provides that States should **encourage each entity** conducting space activities to **develop specific requirements** and procedures **to address the safety and reliability of outer space activities** under the entity's control and assess all risks to the long-term sustainability of outer space activities associated with the space activities conducted by the entity and **take steps to mitigate such risks to the extent feasible**.

FOR ALL MOONKIND™

We look to the Moon as a **testing ground** for deeper exploration. And yet all of our efforts could be **fatally threatened** by the existence of the lunar dust, and the **destructive impact** lunar landings can have over the entire lunar surface, and even lunar orbit. The development and establishment of **shared landing pads** may be the **only way** to adequately address this devastating issue.

Thank you

Michelle Hanlon // Co-Founder
Michelle@forallmoonkind.org

Bailey Cunningham // Project Manager: Space Law
Bailey@forallmoonkind.org

https://www.forallmoonkind.org

FOR ALL MOONKIND™