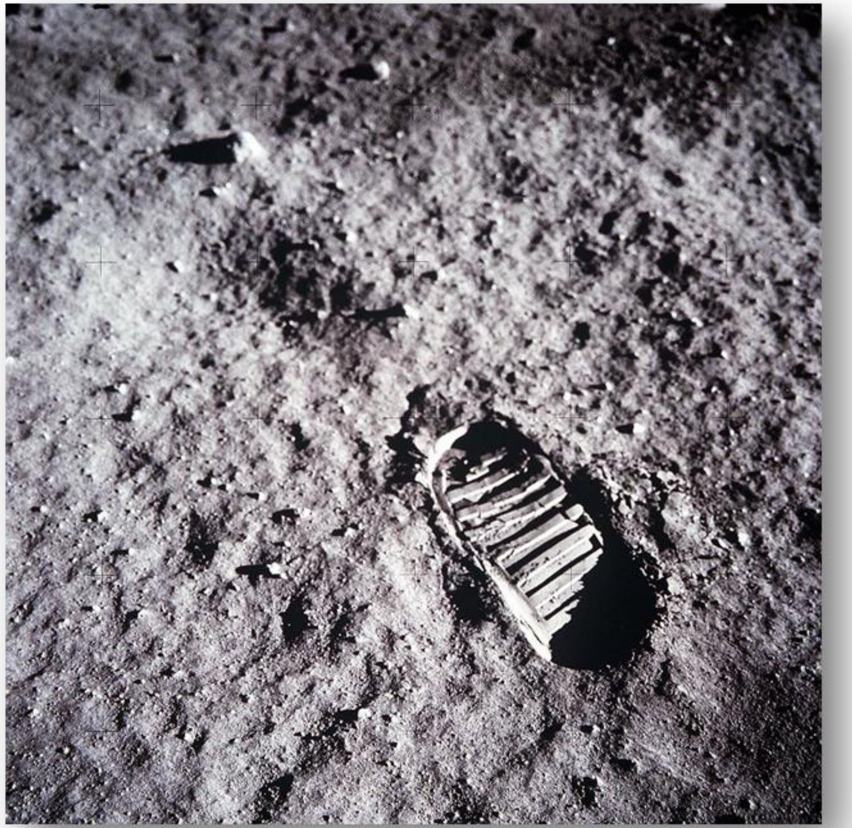
MANAGING THE PLUME EFFECT TO PROTECT LUNAR MISSIONS PAST, PRESENT & FUTURE

57th Session of the Scientific and Technical Committee
February 7, 2020

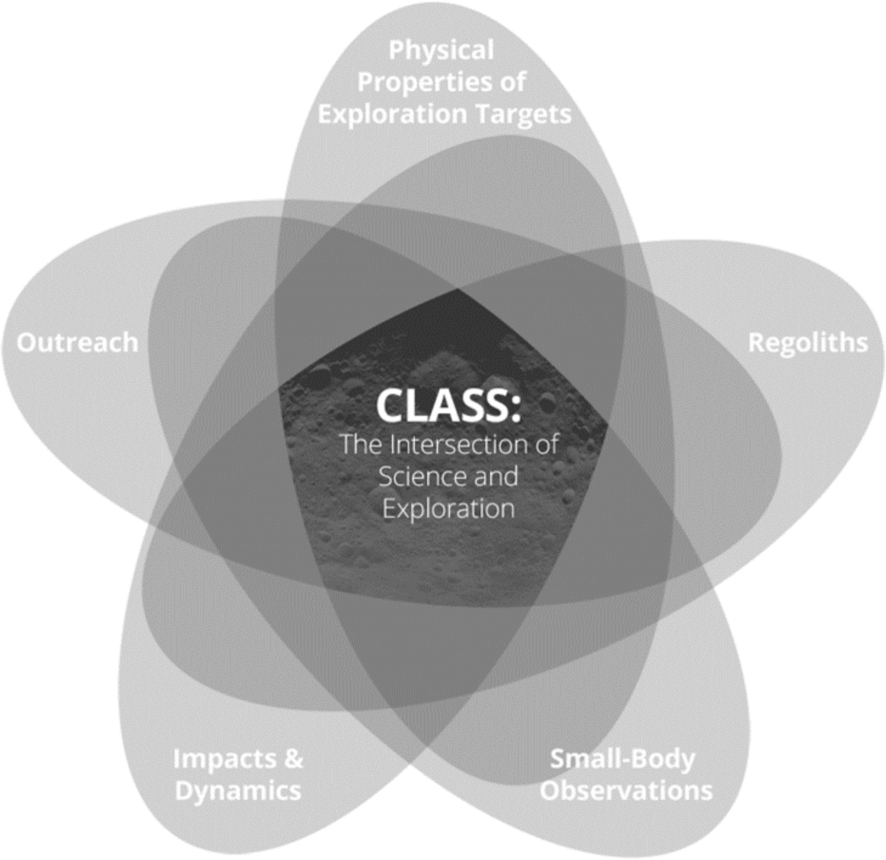
FOR ALL MOONKIND™



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 the exploration** and development and open the debate on equally pressing issues of property and resource extraction.



In lunar landings, a spacecraft the size of the Apollo Lunar Module will blow away more than a ton of soil, dust, and rocks at high velocity.

The **Center for Lunar and Asteroid Surface Science**, or **CLASS,** seeks to understand the physics of these effects so that we can predict and control them.

The CLASS team is composed of leading planetary scientists, geologists, geochemists, dynamicists, engineers, physicists and other researchers from across the world, and is headed by Prof. Daniel T. Britt at the University of Central Florida.

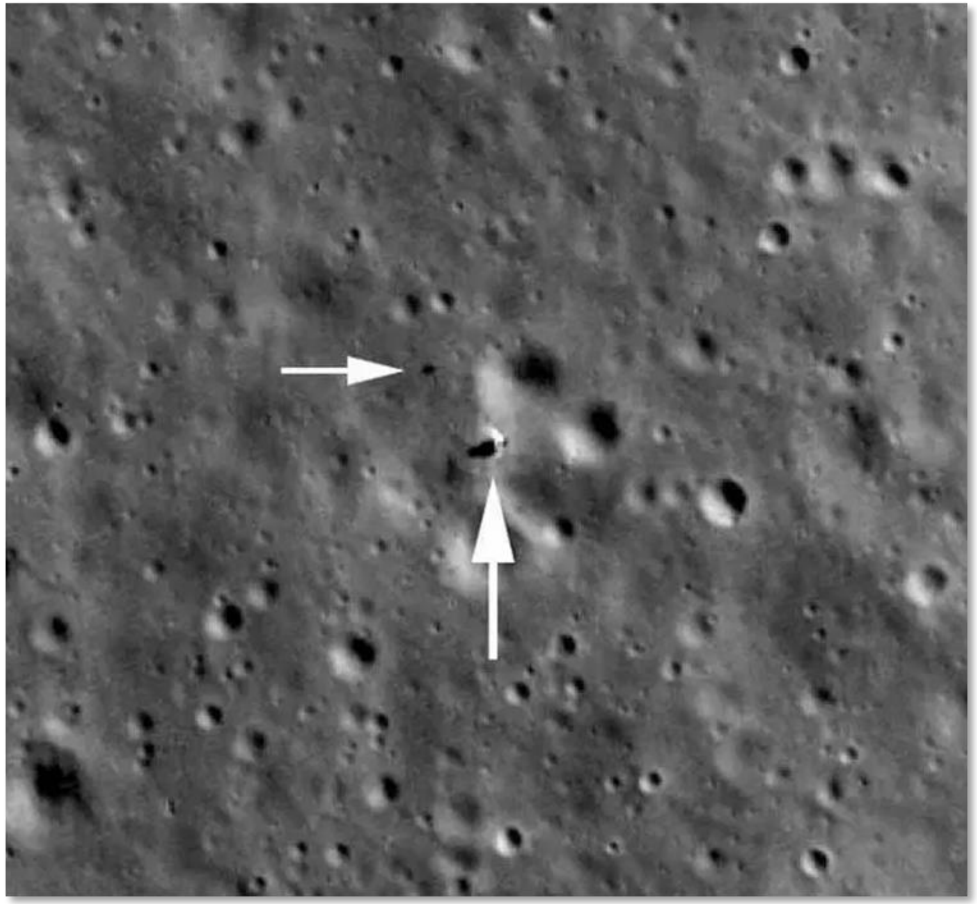


Image of Yutu-2 taken from Lunar Reconnaissance Orbiter.

For All Moonkind and **CLASS** seek to **promote sustainable lunar missions**, consistent with the **Guidelines for the Long-term Sustainability of Outer Space Activities** recently agreed upon by the Committee on the Peaceful Uses of Outer Space.

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.

"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:

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.

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, and inhalation and irritation."

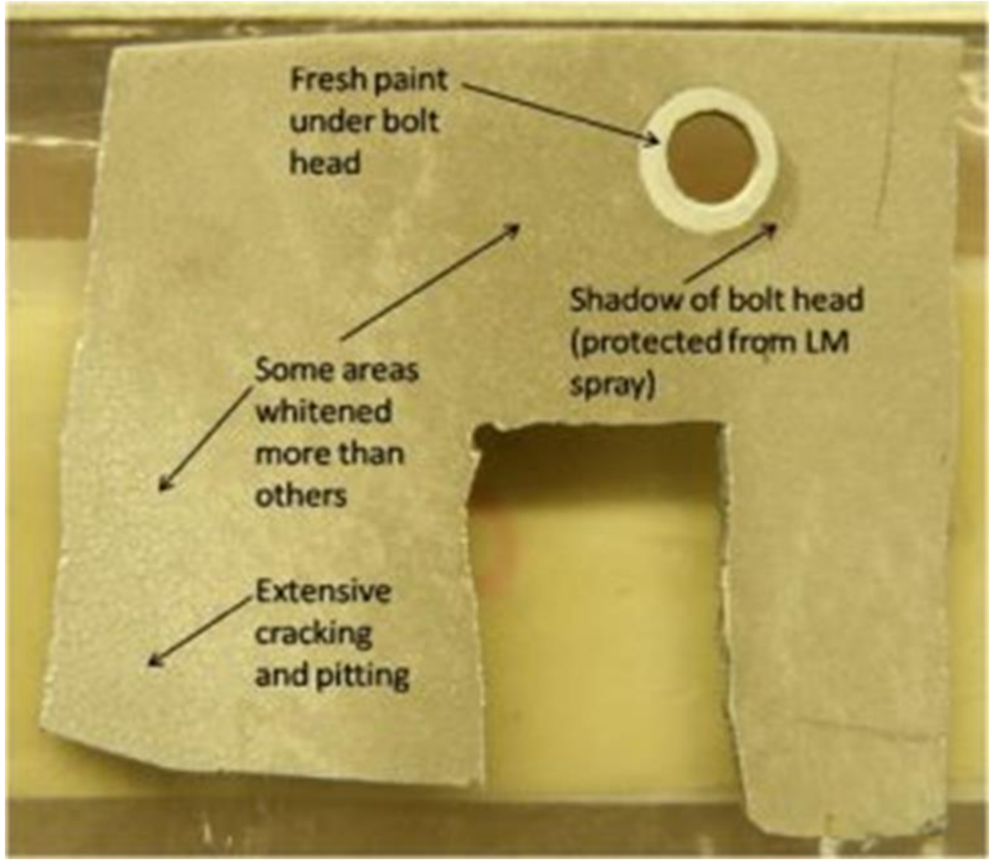
Damage to Surveyor III

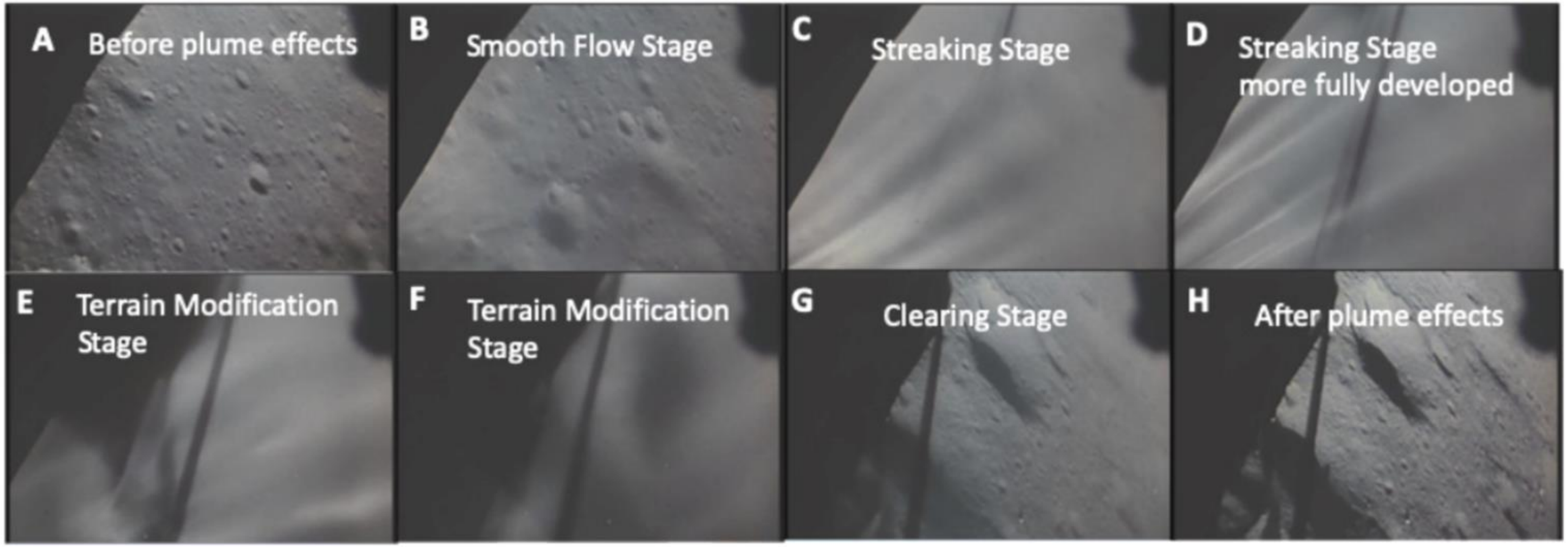
In 1967, Apollo 12 landed near Surveyor 3 – astronauts brought a piece back. Almost all of the exposed surfaces on the camera retrieved from Surveyor III were at least partially covered with a layer of lunar dust

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





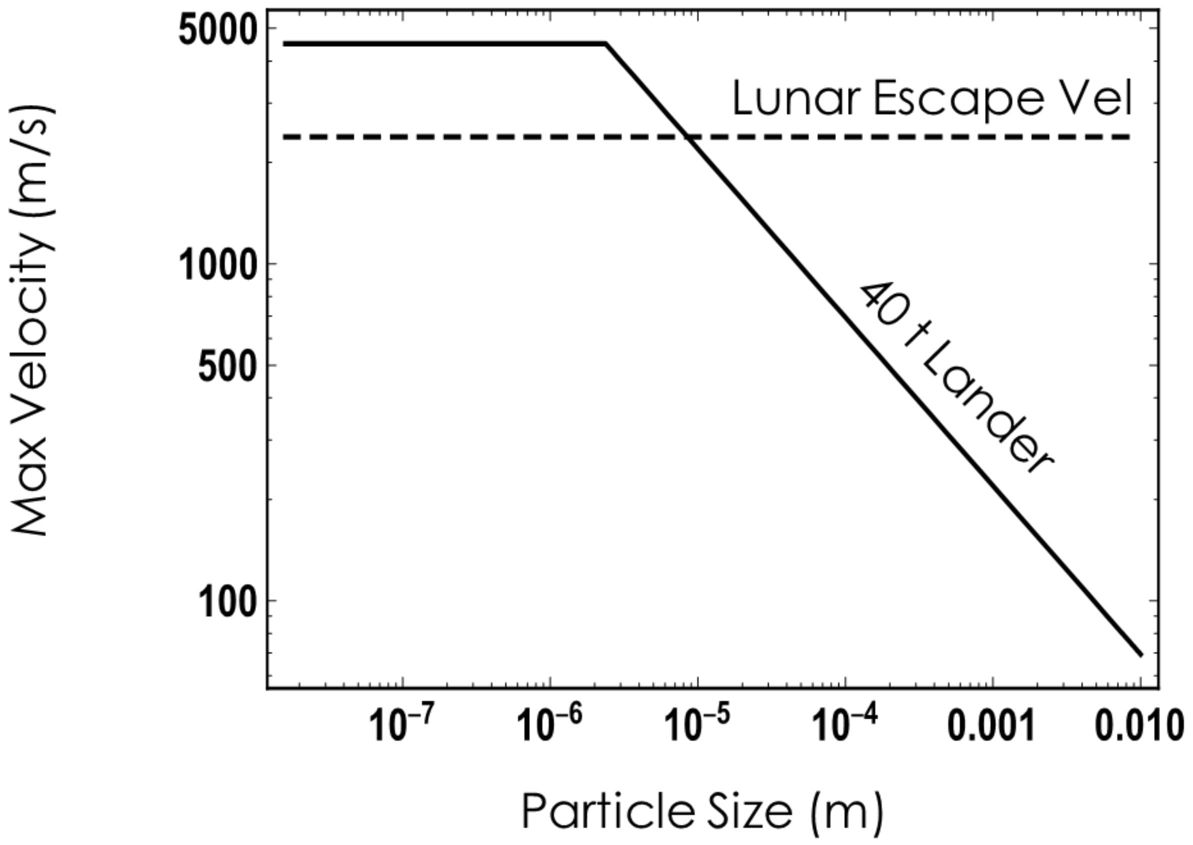
Stages of rocket exhaust ejecta beneath an Apollo Lunar Module. In smooth and streaking flow stages, ejecta is mainly in a sheet **1-3 degrees above horizontal**, although some individual streaks are at higher angles. In terrain modification stage much of the ejecta is lofted into higher angles **exceeding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

***Ultimately,
the fact is that no matter where a vehicle lands on the Moon, it will produce ejected particles of varying sizes that will impact at great distances.***

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



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.

CLASS Center for Lunar & Asteroid Surface Science

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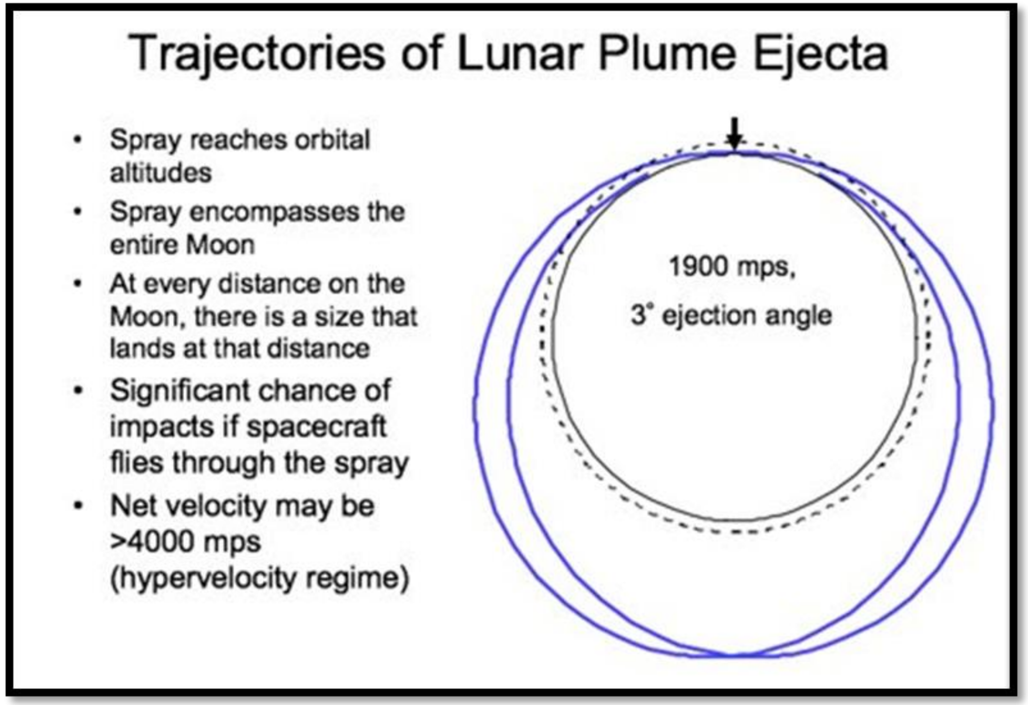
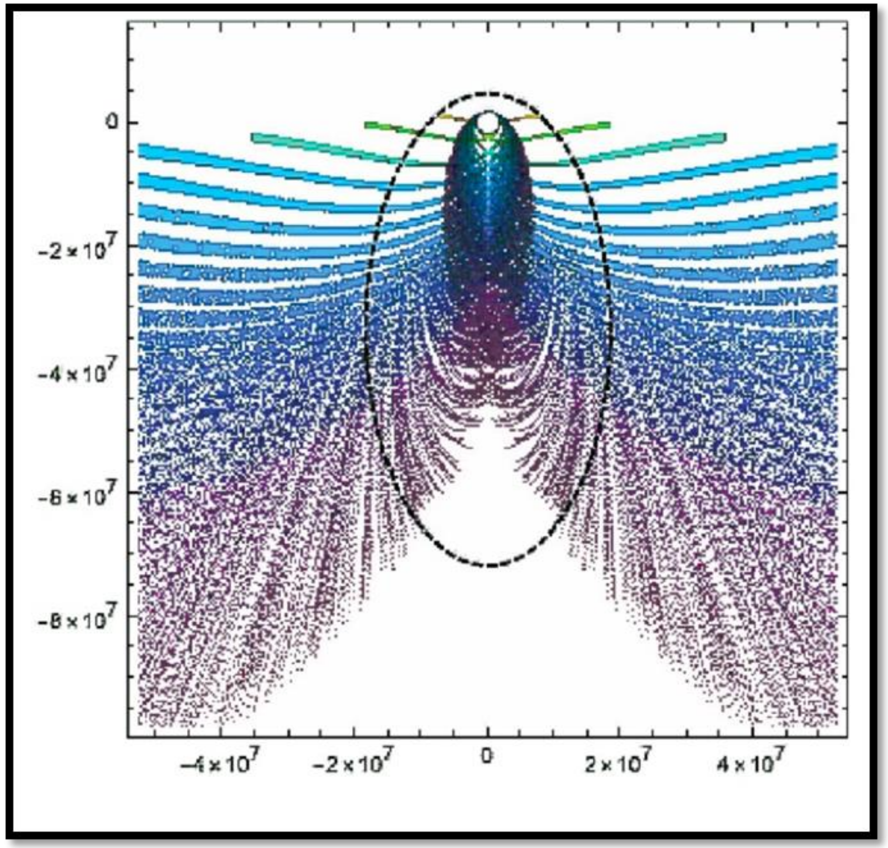


Black circle: circumference of the Moon. Black arrow: where the Lunar Module landed. **Dashed circle:** altitude of the orbiting Command and Service Module during the Apollo missions. **Blue circles:** ejected from the landing of the Lunar Module.

Source: 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 (forthcoming).



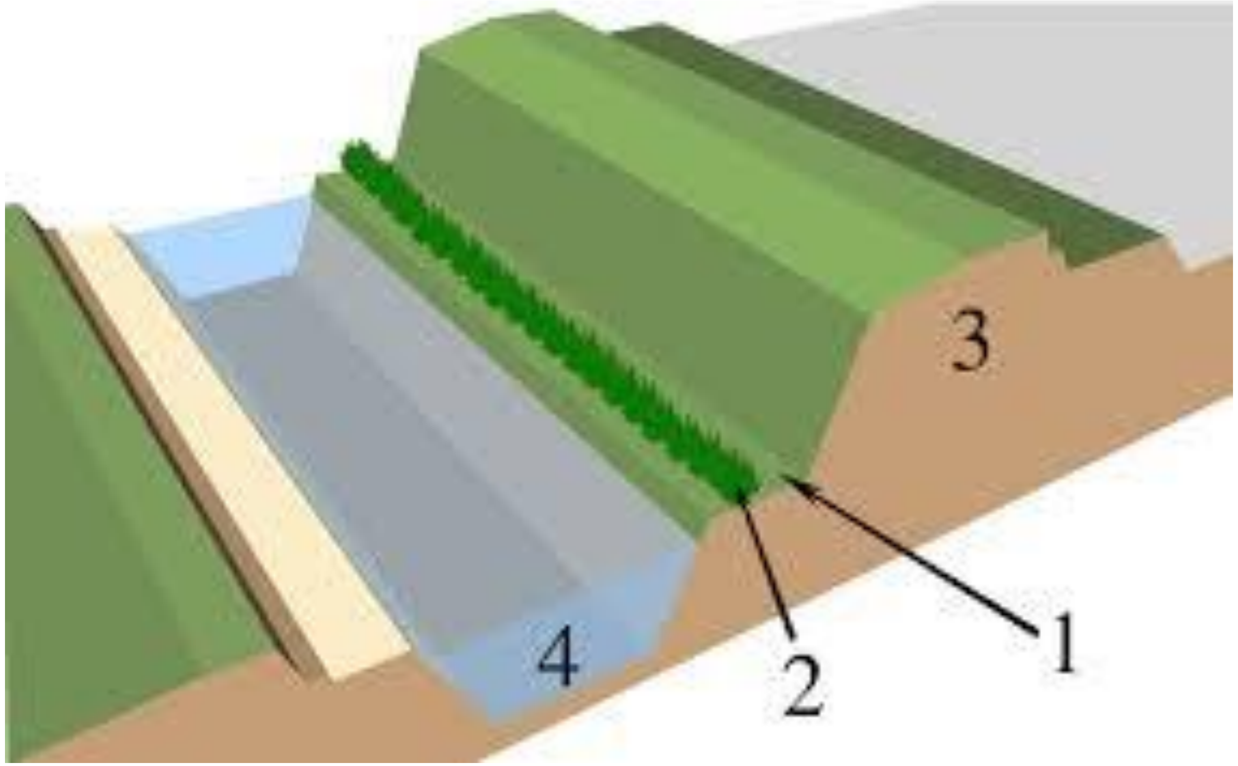
Physics-based computer simulation of ejecta caused by a 40mT lunar lander. **Tiny circle**: Moon. **Ellipse:** Near Rectilinear Halo Orbit of the Lunar Gateway. Ejecta crosses the Gateway orbit such that Gateway will pass through the ejecta several times before it is dissipated by solar wind.

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.

We have already heard from several delegations this session that we should contemplate safety zones.

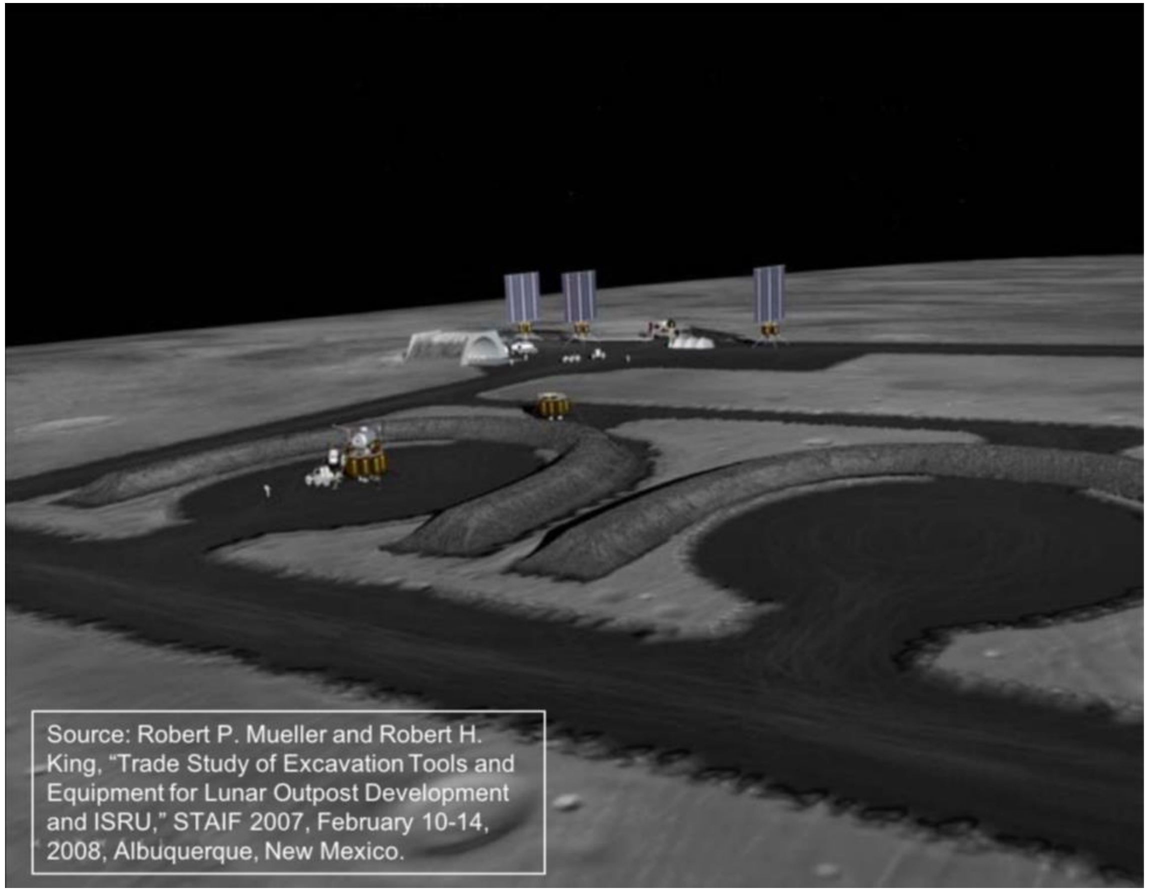
But zones are simply not enough because the perimeter required to assure safety may be extreme.

Safety zones do little to dispel the visual landing hazards also created by the plume effect.



Additionally, it has been suggested that lunar ejecta could be blocked using berms, fences or similar barriers. However, particles colliding in flight will scatter over the barrier. Also, larger particles like rocks loft over the barrier and arc down into the other side, and the berms themselves scatter the particles in lunar vacuum.

Shared Lunar Landing Pads



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.

In the absence of this surface armor, all individual surface systems around the touchdown site will need to be protected, and thus more massive, undermining a mass-efficient mission architecture.

For All Moonkind and **CLASS** believe 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.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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;

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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.

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Thank you.