New study addresses how lunar missions will kick up moondust

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A look at the Apollo 12 landing site. Astronaut Alan Bean is shown working near the Modular Equipment Stowage Assembly (MESA) on the Apollo 12 Lunar Module (LM) during the mission's first extravehicular activity (EVA) on Nov. 19, 1969. Credit: NASA

Before the end of this decade, NASA plans to return astronauts to the moon for the first time since the Apollo Era. But this time, through the Artemis Program, it won't be a "footprints and flags" affair.

With other space agencies and commercial partners, the long-term aim is to create the infrastructure that will allow for a "sustained program of lunar exploration and development." If all goes according to plan, multiple space agencies will have established bases around the South Pole-Aitken Basin, which will pave the way for lunar industries and tourism.

For humans to live, work, and conduct various activities on the moon, strategies are needed to deal with all the hazards—not the least of which is the lunar regolith (or "moondust"). As the Apollo astronauts learned, moondust is jagged, sticks to everything, and can cause significant wear on astronaut suits, equipment, vehicles, and health.

In a new study by a team of Texas A&M engineers, regolith also poses a collision hazard when kicked up by rocket plumes. Given the many spacecraft and landers that will be delivering crews and cargo to the moon in the near future, this is one hazard that merits close attention.

The study was conducted by Shah Akib Sarwar and Zohaib Hasnain, a Ph.D. Student and an Assistant Professor (respectively) with the J. Mike Walker '66 Department of Mechanical Engineering at Texas A&M

University. For their study, Sarwar and Hasnain investigated particle-particle collisions for lunar regolith using the "soft sphere" method, where Newton's equations of motion and a contact force model are integrated to study how particles will collide and overlap.

This sets it apart from the "hard sphere" method, which models particles in the context of fluids and solids.

While lunar regolith ranges from tiny particles to large rocks, the main component of "moondust" is fine, silicate minerals with an average size of 70 microns. These were created over billions of years as the airless moon's airless surface was struck by meteors and asteroids that pounded much of the lunar crust into a fine powder.

The absence of an atmosphere also meant that erosion by wind and water (common here on Earth) was absent. Lastly, constant exposure to solar wind has left lunar regolith electrostatically charged, which means it adheres to anything it touches.

When the Apollo astronauts ventured to the moon, they reported having problems with regolith that would stick to their suits and get tracked back into their lunar modules. Once inside their vehicles, it would adhere to everything and became a health hazard, causing eye irritation and respiratory difficulties.

But with the Artemis missions on the horizon and the planned infrastructure it will entail, there's the issue of how spacecraft (during take-off- and landing) will cause regolith to get kicked up in large quantities and accelerated to high speeds.

As Sarwar related to Universe Today via email, this is one of the key ways lunar regolith will be a major challenge for regular human activities on the moon:

"During a retro-propulsive soft landing on the moon, supersonic/hypersonic rocket exhaust plumes can eject a large quantity (108–1015 particles/m^3 seen in Apollo missions) of loose regolith from the upper soil layer."

"Due to plume-generated forces—drag, lift, etc.—the ejecta can travel at very high speeds (up to 2 km/s). The spray can harm the spacecraft and nearby equipment. It can also block the view of the landing area, disrupt sensors, clog mechanical elements, and degrade optical surfaces or solar panels through contamination."

Data acquired from the Apollo missions served as a touchstone for Sarwar and Hasnain, which included how ejecta from the exhaust plume from the Apollo 12 Lunar Module (LM) damaged the Surveyor 3 spacecraft, located 160 meters (525 ft) away. This uncrewed vehicle had been sent to explore the Mare Cognitum region in 1967 and characterize lunar soil in advance of crewed missions.

Surveyor 3 was also used as a landing target site for Apollo 12 and was visited by astronauts Pete Conrad and Alan Bean in November 1969.

The damage was mitigated by the fact that Surveyor 3 was sitting in a crater below the landing site of the Apollo 12 LM. Another example is the Apollo 15 mission that landed in the Hadley–Apennine region in 1971. During the LM's descent, astronauts David R. Scott and James B. Irwin could not see the landing site because their exhaust plume had created a thick cloud of regolith above it.

This forced the crew to select a new landing site on the rim of Béla, an elongated crater to the east of the region. The LM could not achieve a balanced footing at this site and tilted backward 11 degrees before stabilizing itself.

Research conducted since these missions took place led to the conclusion that collisions between regolith particles likely caused the scattering. As Sarwar indicated, these examples illustrate how disturbed regolith can become a hazard, especially where other spacecraft and facilities are positioned nearby:

"The above two examples from the Apollo era were not severe enough to jeopardize mission success. But future Artemis (and CLPS) missions will take place on the lunar south pole, where the soil is assumed to be significantly more porous/weak than the equatorial and mid-latitude Apollo landing regions."

"Also, Artemis landers are expected to deliver much larger payloads than Apollo and therefore require more thrust to slow down. As a result, deep cratering can happen (not seen in Apollo) due to rocket exhaust plumes and blow the regolith at much higher angles than those seen previously (~1-3 degrees above ground)."

In accordance with the long-term goals of the Artemis Program, NASA plans to build infrastructure around the southern polar region to allow for a "sustained program of lunar exploration and development." This includes the Artemis Base Camp, consisting of a foundation surface habitat, a habitable mobility platform, a lunar terrain vehicle (LTV), and the Lunar Gateway in orbit.

"As such, protecting humans, structures, or nearby spacecraft from the hazards of lunar regolith particles is of paramount concern," said Sarwar.

Similar research has shown how clouds of regolith caused by landing and take-off could also pose a hazard to the safe operation of the Lunar Gateway and lunar orbiters. These threats have driven considerable research into how lunar dust can be mitigated during future missions. As noted, Sarwar and Hasnain used the soft sphere method to evaluate the risks posed by particle-particle collisions:

"In this method, adjacent particles are allowed to overlap each other by a tiny amount, which is taken as an indirect measure of the deformation expected in a real particle-particle collision. This overlap value, along with relevant material properties of lunar regolith, is then used in a spring-dashpot-friction slider representation to calculate forces in each collision event. The inelasticity involved in a collision is varied from completely inelastic to highly elastic."

"Our results reveal that highly elastic collisions between relatively large regolith grains (~100 microns) cause a significant portion of them to eject at large angles (some can fly out at ~90 degrees). The rest of the grains are, however, contained in a small-angle region (

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