Large Vehicle Lunar Landing Surface Interaction and In-Situ Resource Based Risk Mitigation: Landing & Launch Pads

Robert P. Mueller[1] and Nathan J. Gelino[2]
National Aeronautics & Space Administration (NASA), Kennedy Space Center, Florida 32899, USA

Kyle L. Dixon[3]
National Aeronautics & Space Administration (NASA), Kennedy Space Center, Florida 32899, USA

Laurent Sibille[4]
Southeastern Universities Research Association (SURA), Kennedy Space Center, Florida 32899, USA

Bruce T. Vu[5]
National Aeronautics & Space Administration (NASA), Kennedy Space Center, Florida 32899, USA

A key capability required for the exploration of planetary bodies is the ability to land on the surface. Previous work performed by NASA and other institutions has primarily focused on landing small spacecraft on planetary surfaces and the associated small-to-medium thrusters required for the soft landing. In the case of human exploration—particularly the establishment of long duration exploration and habitation outposts—the ability to land large landers, such as the SpaceX Starship, is necessary.

These larger landing systems require the use of more powerful engines, with higher engine exhaust temperatures and higher landing loads. Understanding the excavation of material by the engines, as well as the potential for the landing legs to sink into the subsurface, is key in ensuring reliable and safe landings. A further improvement in landing reliability can be achieved by constructing landing / launch pads, especially with in-situ resources.

Some material excavation by the plume is inevitable, leaving at least a portion of the surface scoured and uneven under the lander and ejecting regolith particles and rocks at very high velocities. One possible solution would be to robotically build landing / launch pads (ideally autonomously) at the destination using in-situ materials. In this case, the first one or few landers will need to land on unimproved surfaces at higher risk; however, they would bring the required equipment to build the landing pads with mostly local resources, thus increasing the reliability of safe landing for subsequent larger landers. A number of methods to build in-situ landing and launch pads have already been developed. These methods include no or some addition of required

[1] Senior Aerospace Technologist & Principal Investigator, NASA Kennedy Space Center, Swamp Works, AIAA Professional Member
[2] Aerospace Technologist, NASA Kennedy Space Center, Swamp Works
[3] Aerospace Technologist, NASA Kennedy Space Center, NE-l5.
[4] Senior Technology Development Scientist, ISRU Subject Matter Expert, NASA Kennedy Space Center, Swamp Works, AIAA Associate Fellow
[5] Analyst, NASA Kennedy Space Center, NE-L6

binder additives to the local regolith material, different processing approaches and result in varying landing pad strengths.

A sub-scale rocket engine plume, was used to simulate some of the conditions of a landing on the Moon to assess the effectiveness of various materials for an in-situ built landing pad, The GO2/GCH4 rocket engine fired on 1m^2 area coupons of representative pad materials. The results will allow continued development towards materials that satisfy the landing pad properties required for the effective risk reduction and increased reliability for landing people and equipment on the lunar surface.

This work contained two parts: (1) computer modeling of a large rocket engine plume interacting with regolith on the Moon, using the Granular Gas Flow Solver (GGFS) provided by CFD Research Corporation as well as other computational fluid dynamics codes (CFD) such as Loci/CHEM. (2) Developing landing/launch pad materials that could be used for in-situ construction on the lunar surface in the future, to mitigate the calculated effects of a large vehicle rocket engine landing and launching on the Moon.

The resulting computed values of plume impingement surface temperature, stagnation pressure, gas velocity, shear stress and heat flux were then matched as closely as possible in the Earth's atmosphere in a sub-scale rocket engine GO2/CH4 test which was provided by Masten Space Systems in Mojave, California. The rocket engine was mounted on a test stand with vertical translation capabilities so that the landing operations of a lander could be simulated (Figure 1).



Figure 1: Masten Space Systems rocket engine vertical translation test stand

The pad materials test coupons were placed at the surface of a large bin containing simulated lunar basalt regolith and subjected to a test firing as shown in Figure 2. The results of this testing will be presented with related findings, analysis and discussion.

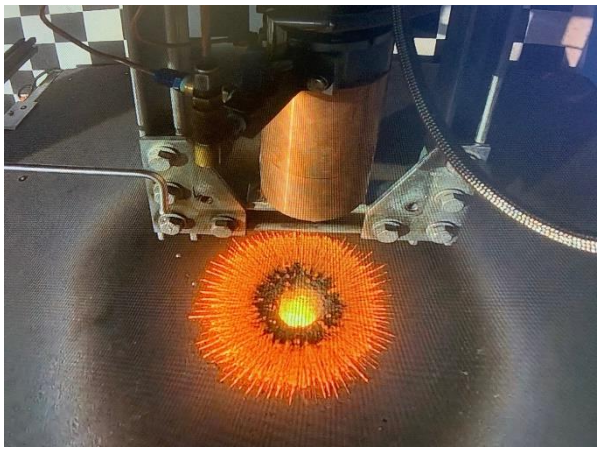


Figure 2. Ablative polymer regolith paver shortly after terrestrial rocket engine testing with a collimated plume which is not representative of lunar vacuum conditions

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