Rocket Plumes and Aeolian-like Bedforms in Regolith

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Introduction

Recent controlled lift-off and landings by Masten Space Systems' Xodiac rocket have produced some interesting, if not surprising, aeolian-like bedforms in the regolith simulant. Aeolian processes are evident on the Earth, Mars, and other planets and moons with sufficient atmosphere to generate wind, and with surficial particle size variations suitable for movement by the wind. Under Lunar conditions, all aeolian processes are related to plume effects. The studies examine regolith changes due to rocket plume effects toward a better understanding of landing surface improvements, geotechnical characteristics of the regolith (simulants), remote sensing characteristics of landing areas, and other tests.

Testing utilized ground to ground tests using the Xodiac rocket descending next to and over a regolith simulate. Aeolian bedforms were produced during the waning stages of the plume action, and offer insights to landing pad stability.

Plume Induced Aeolian-like Bedforms. Within the 40 second period of active plume dynamics, the following aeolian-like formations were created.

Most of the formations reflect deflation basin formation and deflation lag deposits, as seen in the photo as darker larger grains in shallow round to oval depressions ("*df*" Photo #3, 4 and 5).

As plume energy decreased, and erosion and formation of deflation basins concluded, the waning plume "wind" began forming parabolic dunes, crescent shapes with the open end pointing up-wind. This is evident in Photo #3, 4 and 5. Particle transport directions (away from the rocket) are shown as black arrows. Particle saltation and scouring created linear micro-channels parallel to particle transport directions and away from the rocket plume. Scouring around and undermining of pebbles created pedestals and features known as yardangs, which are elongate, wind-parallel ridges comprised of slightly coarser grain sizes (arrow-parallel micro-ridges shown as "*my*" in Photo #6). These seem to be created through overlapping processes from erosion during high plume energy, to rolling grains as that energy wanes, and then finer particle deposition roughly resembling miniature dunes. This type of "miniature dune" is a long, linear to asymmetrical feature forming parallel to the plume wind, and influenced by larger particle obstructions.

Dune formation occurred at incipient and moderately-well developed stages. Barchan-morphology dune formation was observed in much of the regolith simulant. Barchan dunes in nature form in a study wind environment where an abundance supply of sand is present. The waning stages of the rocket plume simulated this environment. Although the features are small, and poorly to moderately well developed, the dunes exhibit a steep slope on the face, and trailing walls away from the plume blast. These can be seen as "*bd*" in photos #3, #4m and #5.

The next set of photographs (Photos #5 and 7) shows (in the middle right of the left photo, and the enlargement of that area to the right) poorly formed transverse and irregular miniature or micro-dunes/ripples were partially formed perpendicular to the plume "wind" direction. Here the linear to incomplete crescent shapes, with the long-axis transverse to the plume wind direction, have formed through initial deflation, followed by deposition of particles as miniature dunes. These features formed in the waning stages of the plume life.

The plume modified surface features share similarities between Masten's Xodiac test and Change-5 lunar landing environment (Photo #8). The unconsolidated overburden has been removed resulting in a more compact layer with scattered larger pebbles.

Conclusions: Important Applications. These data illustrate the rapid development of regolith simulant aeolian-like bedforms during the very short life of a rocket plume. The aeolian-like features are observed as having formed on Earth and Mars. These features may prove to be useful in better understanding landing sites and landing pad stability.

Deflation lag deposits commonly undergo packing and the interlocking of grains. Such characteristics may be created to ensure more stable landing pad dynamics. Masten is continuing to investigate and document these features, and their utility in modeling landing pad variations created from plume energy. Particle transport, erosion and deposition influence the effectiveness of alumina-augmented landing pad reinforcement practices during landing events, and important focus of Masten's research and development.

Additionally, these data have potential applications in better understanding particle acceleration, diffusion, and stoppage under regolith mining conditions, which is another focus of Masten's research and development.