MITIGATING LANDER PLUME EFFECTS WITH SPACE RESOURCES. P. T. Metzger[1] and D. T. Britt[2], [1] Florida Space Institute, University of Central Florida, 12354 Research Parkway, Suite 214, Orlando, Florida, 32826, USA, Philip.T.Metzger@ucf.edu, [2] Department of Physics, University of Central Florida, 4111 Libra Drive Physical Sciences Bldg., Orlando, Florida, 32826, USA, dbritt@ucf.edu

Introduction: Lunar lander engine exhaust blows soil, rocks, and dust at high velocity and will damage surrounding hardware such as lunar outposts, mining operations, or historic sites unless the ejecta are properly mitigated. The Center for Lunar and Asteroid Surface Science (CLASS) has established the CLASS Planetary Landing Team bringing together world-leading expertise in analyzing, modeling, and mitigating the problems of lander plume effects, along with representatives from the major commercial lander companies. Twenty years of research have developed a consistent picture of the physics of rocket exhaust blowing lunar soil, but significant gaps exist. No currently-available modeling method can fully predict the effects. However, the basics are understood well enough to begin designing countermeasures. To be low-mass, they must use lunar resources.

Understanding and Modeling the Physics: Our prior work characterized the different regimes of transport that can occur under various plume and planetary environment conditions [1-8]. While rocket exhaust can deeply crater Martian regolith, the lunar effects are largely restricted to surface scouring a few centimeters of looser material. Lunar regolith is highly compacted deeper than a few centimeters and the lack of an atmosphere to collimate the plume prevents abrupt pressure gradients from the surface that would otherwise cause the soil to deform into a crater. However, a possible exception may occur in the permanently shadowed regions where soil may be looser (as suggested by several lines of evidence) or with a larger lander on a soft crater rim.

Our team's prior work developed a model of lunar landing ejecta flux based on the available empirical data which predicts quantities of each particle size, their velocities, and impact angles for each location on the Moon, scaled by lander thrust-trajectory curve and distance to landing site [9,10]. We quantified several types of damage to neighboring hardware via analysis of the Surveyor III spacecraft that was sandblasted by the Apollo 12 landing [11] and by performing hypervelocity impacts of appropriate particle sizes and velocities onto additional materials. Based on this, Metzger wrote the relevant sections of NASA's document to protect the historic sites on the Moon. Recently, members of the CLASS team used Apollo data to derive a more accurate equation of soil ejection from the lander thrust-trajectory curve [12].

Mitigating via ISRU: Our results show plume ejecta are impossible to simply block with a berm or fence because particles colliding in flight 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. Berms can reduce ejecta damage, but full mitigation requires construction of a landing pad. CLASS team members have prototyped and studied technologies including sintering lunar regolith with microwaves, sunlight, and/or infrared radiation, application of polymers to regolith, the use of gravel and pavers, lunar concrete, and more. They have tested robotics for grading and compacting lunar landing zones. Our team members also tested 3D printing of regolith that can construct walls, and non-ISRU solutions such as deployment of inflatable blast barriers. Each method has drawbacks, so downselection to a set of complementary technologies is required.

Next Steps: We are pursuing three approaches to fully address the plume challenges. First, we are continuing research into the physics to close the gaps, leading to more predictive computer models. These will set better requirements for landing operations and landing pad construction. Second, we are testing and assessing each mitigation technology including sintering lunar regolith and other methods to create competent surfaces, robotics for bulldozing and berm-building, and the use of gravel or pavers. This will lead to a recommended downselection. Third, we are organizing a series of robotics competitions for landing pad construction technologies in conjunction with Machine Learning companies to further advance the necessary robotic capabilities.

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