ROCKETM – A PROPULSIVE EXCAVATION SYSTEM FOR THE MOON AND MARS. T. Vazansky[1], J. Slavik[1], and C. Luken[1], [1]Astrobotic Technology, Propulsion & Test Department (1572 Sabovich Street, Mojave, CA 93501, travis.vazansky@astrobotic.com).

Introduction: The RocketM system (**R**esource **O**re **C**oncentrator using **K**inetic **E**nergy **T**argeted **M**ining) is designed for efficient extraction of surface and subsurface material on non-terrestrial planetary bodies. A dome is sealed to the regolith surface, creating a volume that holds pressure, and a small rocket thruster within the collection dome fires into regolith to liberate the material (Figure 1). The ejected regolith is then collected within the dome and conveyed to processing equipment. The RocketM system has been developed through Phase 1 of NASA's Break the Ice Challenge and an SBIR (Small Business Innovative Research), Phase 1 contract (NASA SBIR 2022 Phase I Solicitation).

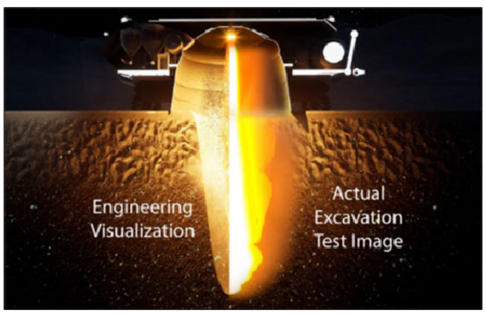

Figure 1: RocketM dome showing active rocket cratering and excavation

System Overview: RocketM takes advantage of plume-surface interaction (PSI) deep cratering phenomena to excavate granular material. When a rocket exhaust plume is close enough to a loose surface (such as the surface regolith of the Moon and Mars), the plume stops scouring the surface and starts digging vertically. By harnessing the kinetic energy of a rocket exhaust plume in a deep cratering scenario, sub-surface material can be excavated without the abrasion and tool wear seen in traditional excavation techniques, and as this report will show, with minimal thermal energy input to the extracted material or surrounding area. Additionally, the excavated material will necessarily be pneumatically transported after excavation, enabling on-site beneficiation via a system like Aqua Factorem [1].

RocketM uses a small rocket engine mounted at the top interior of a dome. The dome assembly is then mounted to a rover mobility platform and is driven to a desired excavation area. The dome is then lowered so that its edge is sealed to the regolith surface (Figure 2). The rocket fires into the regolith surface, creating a crater, and material is collected within the dome.

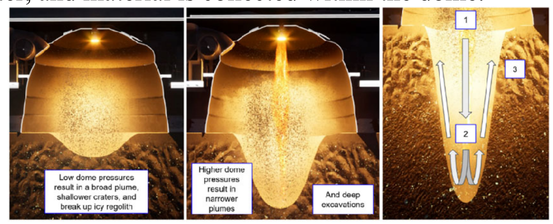

Figure 2: Visualization of RocketM mining process

Test Program: To test this mining concept, a prototype dome was fabricated and mounted to Astrobotic's PSI test stand. A live rocket engine was then used to fire into icy regolith and excavate material.

Dome Fabrication. The team was able to design the dome system around off-the-shelf domes (made from industrial cooking woks) which matched the rocket-to-regolith distance and crater diameter seen in previous plume-surface interaction studies conducted by Astrobotic (Figure 3). The concept for the dome used redirection of the plume gas with suspended ejecta in order to slow the gas and separate some of the larger ejecta particles from the plume gas. This redirection and collection was accomplished by an inner dome, collection tray, and outer dome (Figure 4). The dome was instrumented to record data about the exhausting plume gas and pressure environment inside of the dome. Once a test fire was completed, the rocket engine and dome could be removed from the collection tray and the total collected ejecta could be weighed and analyzed for water content.

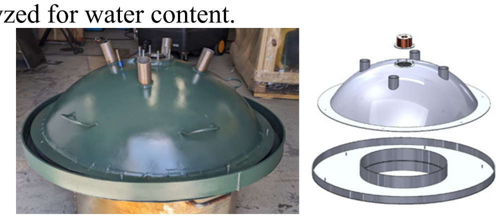

Figure 3: Assembled dome (left) and CAD (right)

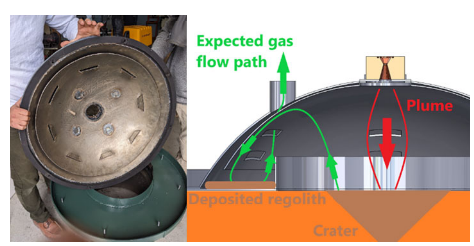

Figure 4: Dome interior (left) and illustration of expected gas flow path during testing (right)

Test Setup. Testing of the rocket-dome assembly was accomplished using Astrobotic's PSI test stand. The stand uses a 100 lbf rocket engine mounted above a regolith simulant bin to generate and observe PSI effects. For RocketM, the engine interfaced with the top of dome, and the dome was pressed into the regolith surface (Figure 5). To demonstrate ice collection, various types of frozen regolith were prepared using water and liquid nitrogen (Figure 6). This included cemented icy regolith with frozen water and regolith combined into one cohesive matrix, and discrete icy regolith with frozen ice particles distributed among the granular material.

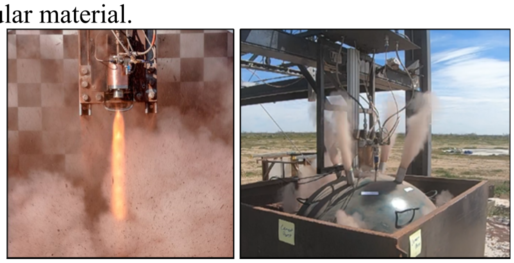

Figure 5: PSI Test Stand during general PSI testing in separate SBIR program (left); RocketM dome during hot fire test (right)

Figure 6: Chilling icy regolith with liquid nitrogen

Test Results – Ice/Water Transport. Liquid water in regolith was seen in the collection tray after the icy regolith testing. This phenomenon was hypothesized by the RocketM team, because the majority of the energy transferred by the rocket engine is kinetic energy. Transporting liquid water validates that all water is not vaporized in the plume. The team had theorized that ice crystals would also be seen in the collection plate, however, this was not observed. The time between freezing the regolith and making the measurements and observations of the crater typically lasted 30 minutes in sunny 80° F weather. This time scale and weather decreased potential of seeing transported ice in the collection tray.

Test Results – Ice/Water Excavation. Figure 7 shows total propellant used versus the amount of excavated ice/water. The excavated ice/water mass was calculated based on mass percentage of the regolith in this testing. Mass flow (g/s) was normalized to total propellant used in each test. This was compared to the mass of water excavated per crater. Figure 7 shows that the RocketM system is mass positive, which means it can excavate more lunar water ice than propellant used in the process. The average ratio is 3.2 times the ice excavated to propellant used with a maximum ratio of 3.95. In future iterations of the RocketM design, exhaust gases could be captured and recycled, further improving the efficiency of the RocketM system.

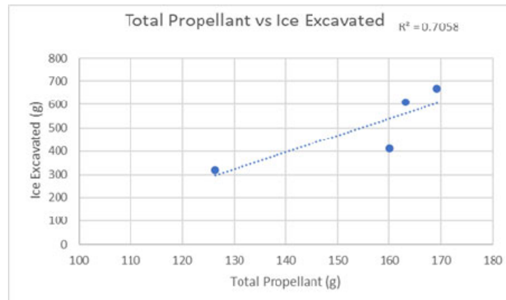

Figure 7: Total propellant vs. Calculated water excavated

Remaining Work: Future work on RocketM would develop collection and beneficiation systems that will take in and process the excavated material. Also, optimal thrust levels will be validated through further hot fire testing, and the percentage of volatiles lost through the dome seal during the excavation process needs to be determined. Finally, RocketM will be integrated with a rover mobility platform that can traverse the rugged lunar terrain and access areas containing icy regolith.

Conclusion: The Phase I SBIR program successfully demonstrated that water/ice can be collected by using a rocket plume to induce deep cratering in icy regolith deposits. That process is proven to be mass positive since ~3.2 times more ice is collected than propellant expended. Considering these initial results, RocketM holds the potential to be a key contributor to the future lunar ecosystem.

References: [1] Metzger, P. T., Sapkota, D., Fox, J., & Bennett, N. (2021). Aqua Factorem: Ultra Low Energy Lunar Water Extraction. Final report, NASA Innovative Advanced Concepts (NIAC) Phase I, NASA grant, (80NSSC20K1022). Available: https://fsi.ucf.edu/philip-metzger-ph-d/. [Accessed Mar. 22, 2024].