PERCUSSIVE DIGGING APPROACH TO LUNAR EXCAVATION AND MINING.

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Introduction: Terrestrial earth-moving machines such as bulldozers, bucket wheel excavators etc., rely on shear force to break up and excavate the soil and softer rocks. They use hydraulic systems which have inherent advantages, over electromechanical systems including the ability to generate larger forces, small size, simplicity, robustness etc. Another advantage that terrestrial earth moving machines have is their large weight, reaching hundreds of tons and more. This approach will not be feasible on the Moon, not only because of lower gravity (1/6th that of the Earth's), but also because of large launch costs ($50k-$100k to place 1kg on the Moon).

The requirements for regolith moving such as trenching, clearing, building berms, habitat shielding for lunar outpost development and ISRU are in the range of thousands of tons [1]. A system that is most effective, robust, and efficient will potentially save billions of dollars.

Percussive Digging Approach: The solution to the problem of low excavator mass in low gravity environment is to use a percussive digging approach [2]. A scoop with a percussive actuator can dig deeper and faster with force that is much lower than a corresponding non-percussive scoop. This directly translates into lighter excavator, and in turn billions of dollars saved by not launching heavier systems. Apart from much higher efficiencies, percussive and vibratory systems will enhance particle discharge into the bin (the scoop can be vibrated during the regolith discharge cycle to speed up the discharge of particles). Other applications include vibrating blades/plows like the one attached to the Chariot rover in the most recent field test at Moses Lake, WA. Vibrating surfaces reduce sliding friction between the blade and soil particles, and in turn forces and power required to move regolith . The impulse magnitude and frequency can be tuned relative to soil strength to further improve efficiency.

There is, of course, always a trade off. In the case of a percussive system, the trade-off is between the additional energy to drive the actuator and the additional mass that would be required in the absence of the percussive system. However, in the trade between more mass and more energy, energy wins since it can be harvested from the Sun.

Testing of Percussive Approach: In the ambient tests the percussive digger breadboard was attached to a linear slide which was mounted on an aluminum frame (Figure 1). The percussive digger deployment scheme used weights and pulleys to passively apply a constant weight-on-bit throughout an individual test. The weight-on-bit was adjustable for any given test by changing the stack of weights. A laser rangefinder mounted to the side of the linear slide was used to obtain penetration rate data.

All tests were run at 2.7 Joules per blow and at full speed (1750 bpm.) All tests used a Lunar Surveyor-style scoop as a soil penetrator.

Three soils were used: GRC-1, GRC-3 and JSC-1a. For each soil, two densities were tested, and for each density at least two iterations of both the percussive digger and the static penetrator were run.

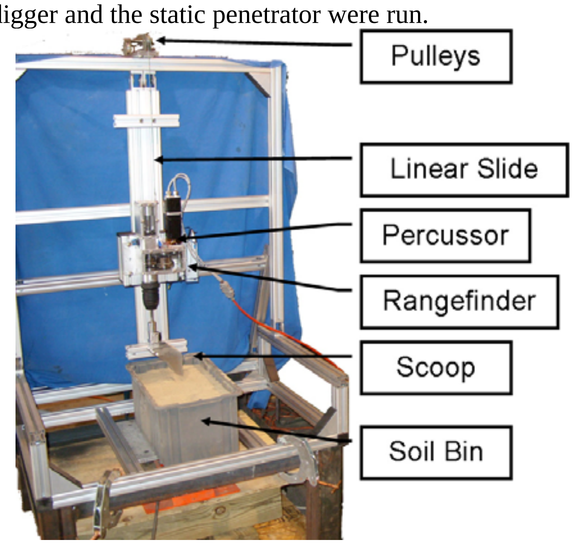

Figure 1. Percusssive digger set-up.

Results: The results have shown that that the Surveyor-like scoop could be pushed 80 mm into compacted JSC-1a with 250N force. In low density JSC-1a, the same scoop could be pushed 100 mm with 170 N force. The same scoop with a percussive actuator could be pushed into both fluffy and dense soils with only 5N of force. This represent a ratio of forces in the range of 45. Thus, with a percussive scoop, the weight of an excavator can be up to 45 smaller.

References: [1] Mueller, R. and King, R., Trade Study of Excavation Tools and Equipment for Lunar Outpost Construction, STAIF 2008; [2] Zacny, K. et al., Novel Approaches to Drilling and Excavation on the Moon, AIAA-2009-6431, Space 2009.