PERCUSSIVE DIGGING TOOL FOR LUNAR EXCAVATION AND MINING APPLICATIONS. K. Zacny, J. Craft, J. Wilson, P. Chu, and K. Davis. [1]Honeybee Robotics Spacecraft Mechanism Corporation (zacny@honeybeerobotics.com)

Introduction: The extraction of top surface and also of highly compacted material on the lunar surface is critical to the success of long term utilization of resources for the production of oxygen, water and other consumables needed for propulsion and life support systems as well as for other 'civil' engineering applications such as building berms, roads, trenches etc. The ISRU will become even more critical if the lunar polar craters are found to contain water ice. Apollo data clearly indicates highly compacted soil at shallow depths [1] on the lunar surface, for which there is no existing experience in effective excavation under the vacuum and partial gravity environment there.

Percussive Digging Tool: 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 system which has inherit advantages (over electromechanical systems) that include ability to generate larger forces, small size, simplicity, robustness etc. Another advantage that terrestrial earth moving machines have includes their large weight reaching hundreds of tons and more. This will not be possible on the Moon, which with its lower gravity of 1/6th that of the earth's, would require similarly capable excavation systems to be 6 times heavier. The solution to this problem is to use percussive/vibratory approach [2]. A scoop with a percussive actuator can dig deeper and faster with force that is at least 25 times lower than corresponding non-percussive scoop. This directly translates into 25 times lighter excavator and in turn money saved by not launching heavier systems. Apart from much higher efficiencies, percussive and vibratory system 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/ploughs 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 particles and soil and in turn forces and power required to move the regolith. There are many other applications where transfer of regolith takes place. Note also that the impulse magnitude and frequency can be tuned relative to soil strength to improve efficiency even further.

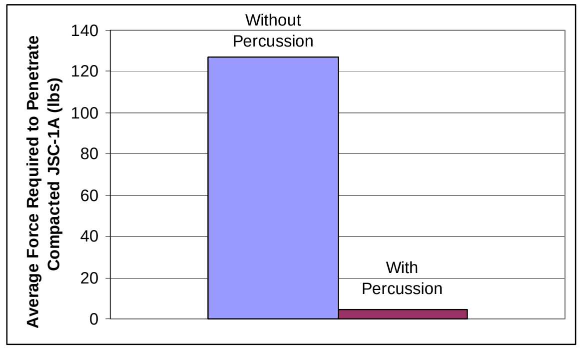

Figure 1. Preliminary test shows that percussion dramatically reduces the reaction loads necessary to penetrate compacted JSC-1a.

Honeybee has developed a percussive shovel for use on the military's Man-Transportable Robotic Systems such as iRobot's PackBot and Foster Miller Talon. Due to their light weight, these robots can provide only limited reaction force for digging and hence lessons learned from using these platforms can be directly applicable to the Moon, where lunar gravity leads to the reduction of the system weight as compared with that on Earth by 1/6th. The mass of the Talon is 60kg while that of the PackBot is 30kg.

Honeybee's digging tool design is a novel approach ideally suited for lunar applications to defeat compacted regolith. By using the impact energy imparted by a reciprocating hammer transferred through the scoop to defeat the target material, the need for large reaction loads from the vehicle is minimized. As with all space-flight systems, mass is at a premium. A system which does not rely solely on the vehicle's weight and traction to react against forces required to break-up and penetrate the soil will provide a distinct advantage over other such systems, especially in a microgravity environment such as the moon.

References: [1] Carrier, W. D., and Mitchell, J. K. (1989) "Geotechnical engineering on the Moon", De Mello Volume, Editora Edgard Blücher Ltda., São Paulo, pp. 51-58. [2] Klosky, J.L., et al. (1996), Proc. Space V, Engineering, Construction, and Operations in Space '96, ASCE, 2, 903-909.

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