PNEUMATIC DRILLING FOR THE LUNAR LASER RANGING REFLECTOMETER ARRAY. D. Currie[1], K. Zacny[2], [1]University of Maryland, [2]Honeybee Robotics Spacecraft Mechanism Corp. (zacny@honeybeerobotics.com).

Introduction: The Lunar Laser Ranging Retroreflector Array for the 21st Century (LLRRA-21) in combination with a Lunar Laser Ranging (LLR) program within the International Laser Ranging Service (ILRS) should provide extensive new information on the lunar interior, General Relativity and cosmology. Since Apollo, the ground stations improved the ranging accuracy by 200x and now the Apollo arrays provide a significant limitation of the LRR accuracy. While the LLRRA-21 package can provide 100x improvement, to achieve 10 µm ranging performance, we must anchor the CCRs to a thermally stable mass. During the day/night lunar cycle, the regolith will rise and fall by almost 500 µm. Yet, it is estimated that the thermal variation 1 m below the surface is < 0.1°C.

Deploying CCR Pneumatic Drilling: Lunar regolith below the first 10-20 cm is highly compacted and highly cohesive [1]. The only way a probe can move forward is if it can remove the regolith from underneath or if it has enough energy to crush/pulverize the regolith, re-compact it and push it to the side.

The pneumatic penetration approach relies on excavating the soil by displacing it (moving it out of the hole with gas). In vacuum, 1g of gas can loft 6000 g of soil [2]. The gas could be provided from the lander propulsion system, which uses compressed Helium to pressurize tanks. This Helium is vented to vacuum upon touch down. But in our case, it could be used to penetrate to 1m depth.

When penetrating lunar regolith, the penetrometer may also run into a rock. The probability of running into a rock with a diameter twice or greater than that of the penetrometer cone (in our case ~2.5cm or less) in 5m depth is only 1%. [3]

The pneumatic system is the game-changer for subsurface access. The extremely low mass and volume required to reach 1m, along with very simple penetration method allow the CCR to remain in a variety of payload architectures. The low mass and power cost of such a system may result in higher risk tolerance because it does not come at a large cost with respect to other payload elements.

Laboratory Tests: In these tests 1inch diameter cone was pushed 2inches into compacted JSC-1a with 100lb force before penetration ceased (Figure 1). However, when gas was injected below the cone (via injector holes in the cone) the vertical thrust force was reduced to zero (the rod was falling into the hole under its own weight).

Field Tests: We performed tests in lunar analog: Mauna Kea tephra, HI (Figure 2). The experiment included a hollow rod with a cone at the bottom and CCR on top. A pneumatic line (from air compressor) was connected to the side of the rod. Prior to testing, we measured soil strength using geotechnical tool – a rod with a load cell on top and the same diameter cone as in CCR. We found it takes >130lbs to manually push the cone into the soil to ~0.5m depth. When the pneumatic line was opened the rod almost fell into the subsurface with little push. We estimate the push force must had been <5lbs.

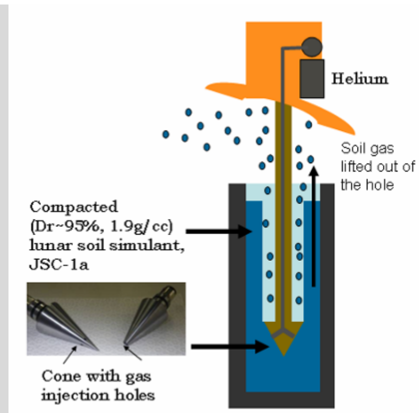

Figure 1. Pneumatic spear approach for excavating holes in granular materials.

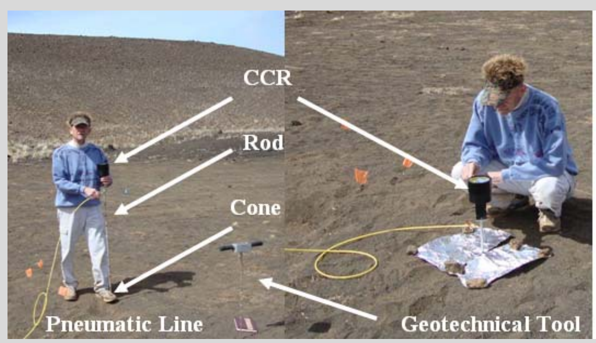

Figure 2. CCR deployed pneumatically in Mauna Kea, HI tephra (lunar analog). Left: the system before deployment. Right: system after deployment.

References: [1] G. H. Heiken, et al., Lunar Sourcebook, 1991. K. Zacny et al., Novel Method of Regolith Sample Return from Extraterrestrial Body Using a Puff of Gas, Paper #1082, IEEE Aerospace conference, 2010. [3] Carrier, D., The four things you need to know about the geotechnical properties of lunar soil, Lunar Geotechnical Institute, 2005.