PERCUSSIVE AND PNEUMATIC HEAT FLOW PROBE DEPLOYMENTS FOR LUNAR LANDERS.

K. Zacny[1], S. Nagihara[2], M. Hedlund[1], Z. Fitzgerald[1], [1]Honeybee Robotics, Pasadena, CA, zacny@honeybeerobotics.com; [2]Texas Tech University.

Introduction: The heat-flow probe directly addresses the goal of the Lunar Geophysical Network (LGN), which is to understand the interior structure and composition of the Moon [1]. The LGN consist of four small landers, that will deploy up to four instruments. Each lander weighs approximately 200 kg and includes a total payload mass of ~27 kg. The full cost of the six year mission in FY15 dollars is estimated at $903.7 million including reserves [2].

A key challenge for a heat-flow probe will be getting to a 3 m depth in order to measure the endogenic thermal gradient without being affected by fluctuations in the surface thermal environment of the Moon [3]. The Apollo 17 two heat flow probes reached 2.4 m.

To accurately measure endogenic heat flow, two measurements need to be acquired: the thermal gradient and the thermal conductivity. The thermal gradient is determined from temperature measurements at different depths. The thermal conductivity can be measured at the same depths as the temperature measurements by inserting heaters..

Heat-Flow Probe Concepts: We have been developing two highly innovative low mass and low power heat-flow probe systems [3, 4]. Each system consists of two parts: 1) a method of reaching 3 m depth in lunar regolith, and 2) a method of deploying thermal sensors.

Percussive Heat Flow Probe: The first system uses a percussive approach to hammer a small diameter cone penetrometer to >3 meter depth (Figure 1). Ring-like thermal sensors are deployed into the regolith every ~30 cm. The deployment rod is removed once depth is reached, maximizing measurement sensitivity by eliminating thermal path to lander except for the electrical tether. Penetration rate of the penetrometer can be correlated to regolith bearing strength and density; this added measurement would help with thermal conductivity correlation.

There are two critical aspects of this system: 1) penetrating highly compacted regolith to the required depth and 2) deploying thermal sensors. We have demonstrated both aspects and in turn verified successful operation of this method.

To verify penetration of the regolith, we devised an experiment whereby a rod with a cone at the end was driven into highly compacted JSC-1a lunar regolith simulant by a percussive hammer system. The density of the regolith was >1.9 g/cc which corresponds to a relative density, D_r, of >90%. All penetrometer designs reached ratget depth of 0.9 m depth, though with different speeds. The fastest, corresponding to 10 mm diameter cone, reached the bottom in a few tens of seconds while the slowest, corresponding to a 25 mm diameter cone, took 3 minutes. The size of the borehole must be traded against the difficulty of packaging sensors within borehole clearance constraints.

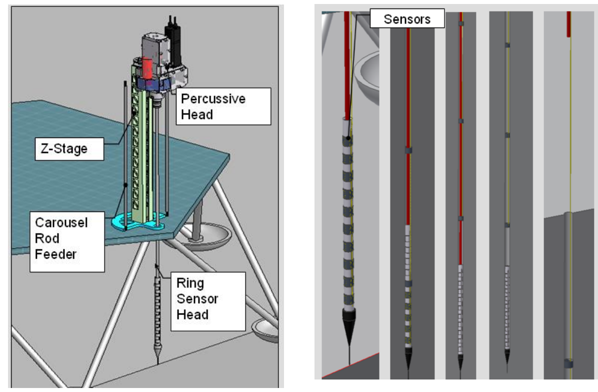

Figure 1. Percussive Penetrometer deployment of heat flow sensors. Upon reaching the depth, the rod is pulled out and sensors are left in a hole.

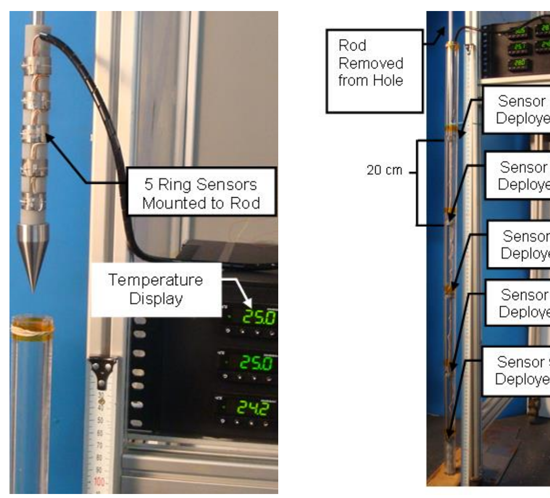

Figure 2. Prototype Sensor deployment. Left: Sensors mounted near percussive rod tip deployed into a hole (clear acrylic tube); Right: 5 ring sensors deployed every 20 cm to 1 meter depth.

A sensor deployment scheme was developed whereby sensors were placed on the outside of the penetrometer rod and were deployed in a "top-down" scheme (Figure 2). Once the penetrometer reached depth for a given sensor, the sensor was deployed via a burn wire and the penetrometer was lowered to a next position. For this 1m demonstration system, sensors were released from the penetrometer rod at 20 cm, 40 cm, 60 cm 80 cm, and 100 cm.

Pneumatic System*:* The second system uses a pneumatic (gas) approach to lower the temperature and thermal conductivity sensors attached to a lenticular (bi-convex) tape to >3 meters (Figure 3). The system is a revolutionary innovation as it has extremely low mass, volume, and simple deployment.

Figure 3. Pneumatic heat flow probe uses compressed helium gas to advance below the regolith surface.

The deployment mechanism (Figure 3) spools out a glass fiber composite stem downward. The stem ends with a cone and needle probe. The stem forms a hollow cylinder of approximately 1.5 cm diameter – slightly smaller then the diameter of the cone. The stem advances cone into the regolith, while gas jets are emitted from the sides of the cone. The gas jets essentially blow the regolith from underneath the cone and in turn create a deeper hole for the probe to advance to. A short and thin thermal needle probe attached to the cone tip measures temperatures and thermal conductivities of the regolith. This is achieved by stopping the gas jets and pushing the probe into the intact rgolith beneat the cone. After the stem reaches the required 3 m depth, the temperature sensors embedded along the stem continue monitoring thermal gradient.

Helium gas, used for pressurizing liquid propellant and typically vented once on the surface, can be scavenged from the lander propulsion system, making the thermal probe system lighter. Should spacecraft helium not be available, a simple gas delivery system may be added specifically for the heat flow probe. Honeybee demonstrated that 1 gram of N2 at 5 psia can lift 6000g of JSC-1a in lunar conditions (vacuum, 1/6g). Thus, only a small amount of gas would be required to penetrate to 3 m.

The system was tested in compacted JSC-1A lunar simulant placed within a large bin inside a vacuum chamber. A depth of 1 m was reached less than one minute. During this time 5 grams of nitrogen gas at 400 kPa was used.

The probe was also deployed in NU-LHT-2M lunar highlands simulant placed in a bin within a vacuum chamber. The probe reached ~2 m depth in appromxiatel 2 minutes. The probe was also used to demonstrate stop-and-go operation.

Acknowledgments: This work was supported by NASA SBIR and PIDDP programs.

References: [1] National Research Council (2011), Vision and Voyages for Planetary Science in the Decade 2013-2012, National Academies Press, p. 423. [2] Shearer C. and Tahu, G. (2011) Mission Concept Study: Lunar Geophysical Network, National Academies Press, p. 40. [3] Science Definition Team for the ILN Anchor Nodes, ILN Final Report (2009). [4] Zacny (2013), Pneumatic and Percussive Approaches for Heat Flow Probe Deployment on Robotic Lunar Missions, Earth, Moon, and Planets, Vol 111, Issue 1-2; [5] Nagihara (2013), Compact, Deep-Penetrating Heat Flow Probe for Small Lunar Landers, Abstract 1252, 44th LPSC, 18-22 March 2013, Houston, TX