Development of Compact, Modular Lunar Heat Flow Probes

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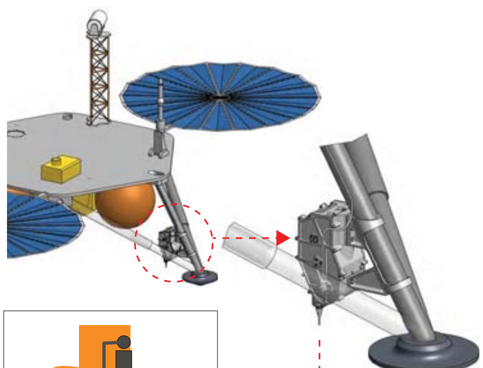
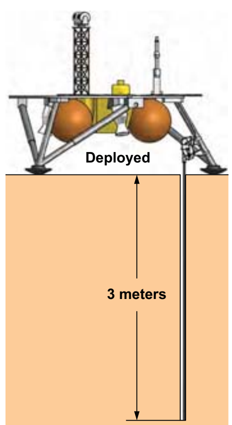
Narrative

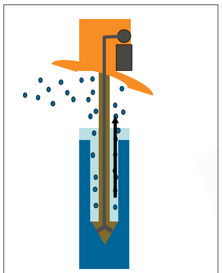
Geothermal heat flow measurements are a high priority for the future lunar geophysical network missions recommended by the latest Decadal Survey [1] and previously the International Lunar Network [2]. Because the lander for such a mission will be relatively small, the heat flow instrumentation must be a low-mass and low-power system. The instrument needs to measure both thermal gradient and thermal conductivity of the regolith penetrated. It also needs to be capable of excavating a deep enough hole (~3 m, [2]) to avoid the effect of potential long-term changes of the surface thermal environment [3, 4]. The recently developed pneumatic excavation system [5] can largely meet the low-power, low-mass, and the depth requirements. The system utilizes a stem which winds out of a pneumatically driven reel and pushes its conical tip into the regolith. Simultaneously, gas jets, emitted from the cone tip, loosen and blow away the soil.

The thermal sensors consist of resistance temperature detectors (RTDs) embedded on the stem and an *in-situ* thermal conductivity probe attached to the cone tip. The thermal conductivity probe consists of a short 'needle' (2.4-mm diam. and 15- to 20-mm length) that contains a platinum RTD wrapped in a coil of heater wire. During a deployment, when the penetrating cone reaches a desired depth, it stops blowing gas, and the stem pushes the needle into the yet-to-be excavated, undisturbed bottom soil. Then, it begins heating and monitors the temperature. Thermal conductivity of the soil can determined from the rate of temperature increase with time. When the measurement is complete, the system resumes excavation until it reaches the next targeted depth.

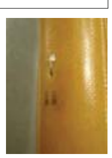
The Pneumatic Heat Flow System

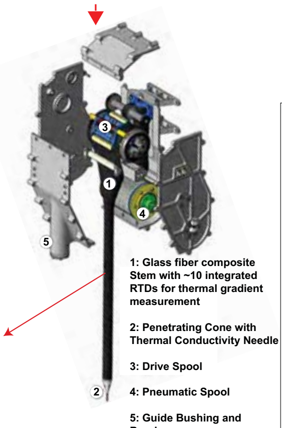




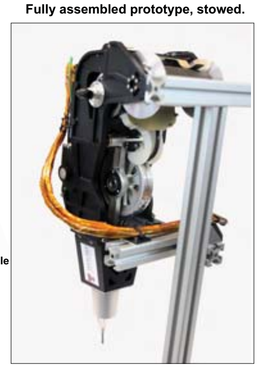


The penetrating cone emits gas jets and blows the soil away, while it is being pushed down by the stem.





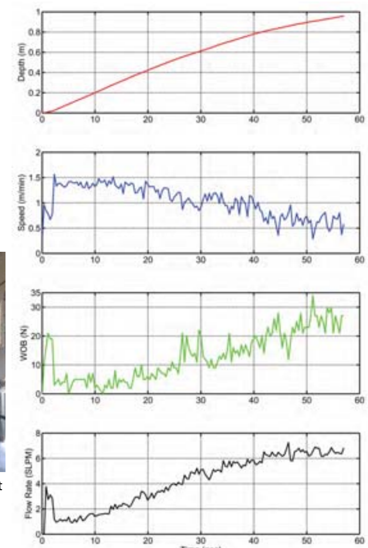
Fully assembled prototype, stowed.



Excavation Test: 1 m into *JSC-1A* lunar simulant in near vacuum

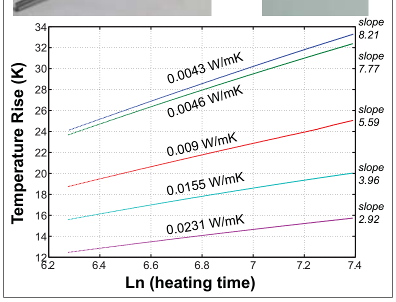
The latest prototype of the heat flow probe has been tested successfully in excavating one meter into JSC-1A lunar regolith simulant in a vacuum chamber (4 Torr). The probe reached the 1-m target depth in less than a minute, using 5 grams of Nitrogen gas pressurized at 400 kPa, while weight on bit (WOB) was kept under 30 N most of the time.

3-m excavation test in preparation



In-situ Thermal Conductivity Probe

A prototype of the thermal conductivity system has been fabricated and tested with the lunar simulant JSC-1A in a vacuum chamber. Side-by-side measurements of the current system and a commercial thermal conductivity probe (*Decagon TR-1*) were carried out at chamber pressures ranging from 0.0014 to 744 Torr. The simulant was compacted before the measurements. At pressures lower than 0.1 Torr, thermal conductivity of JSC-1A is nearly constant at 0.005 W/mK [6].



Probe Stem Fully Extended

References Cited: [1] National Research Council (2011) pub# 13117. [2] Cohen et al. (2009) ILN Final Report. [3] Wieczorek and Huang (2006), LPSC XXXVII, 1682. [4] Saito et al. (2006), Bull. Japanese Soc. Planet. Sc. 16, 158-164. [5] Zacny et al. (2011) LEAG 2028. [6] Nagihara et al., in press, Planetary & Space Sci.

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