LISTER Pneumatic Regolith Excavation at Mare Crisium: Preliminary Drilling Report from Blue Ghost Mission 1.

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Introduction: In March 2025, Firefly Aerospace's Blue Ghost robotic lander touched down softly on Mare Crisium and delivered a pneumatic drill heat flow probe to the lunar surface. This payload, Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity (LISTER), was developed by Honeybee Robotics and Texas Tech University to achieve the first robotic measurements of lunar heat flow and the first such measurements since Apollo 17.

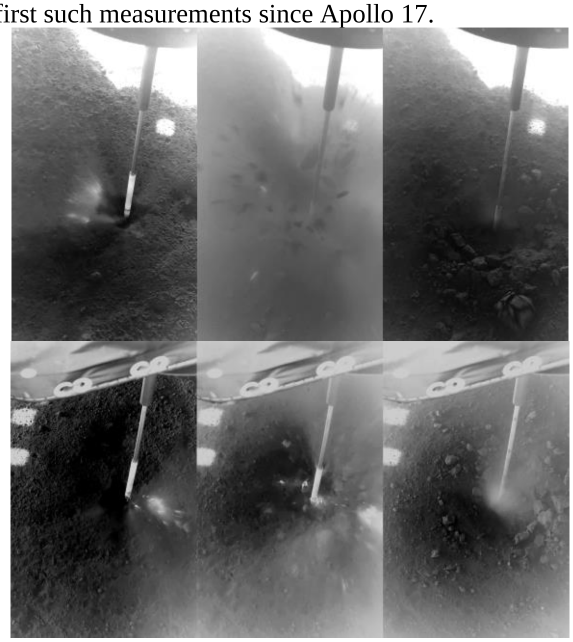

Figure 1. LISTER starts pneumatic drilling on the Moon (see video [1]). Surprisingly well-consolidated regolith produced explosive eruptions of friable clods in the first centimeters of penetration.

After drilling to a final depth of 1 meter, LISTER became the deepest-reaching robotic planetary subsurface thermal probe and the first U.S. robotic drill to operate on the Moon. LISTER successfully demonstrated first-of-its kind pneumatic regolith excavation as well as the use of a coiled metal tube straightener for linear boom deployment (Fig. 1). This paper presents a preliminary assessment of drilling performance on the Moon. Separate publications will address the thermal measurements and scientific results.

LISTER Pneumatic Drill Design and Operations Concept: LISTER's drilling and sensor mechanism weighs less than 9 kg and fits within a 32 x 33 x 43 cm volume. The mechanism is a lander-agnostic system, designed to attach to a downward-facing surface, such as a lander underbelly (Fig. 2).

LISTER uses a unique pneumatic excavation system to rapidly excavate lunar regolith [2,3]. It deploys a stainless steel coiled tubing boom (Fig. 2), straightening it to act as a stiff drilling boom. The probe tip at the endof the boom advances while emitting a nitrogen gas jet, fed through the boom and exiting from the probe tip nozzle, blowing away regolith particles.

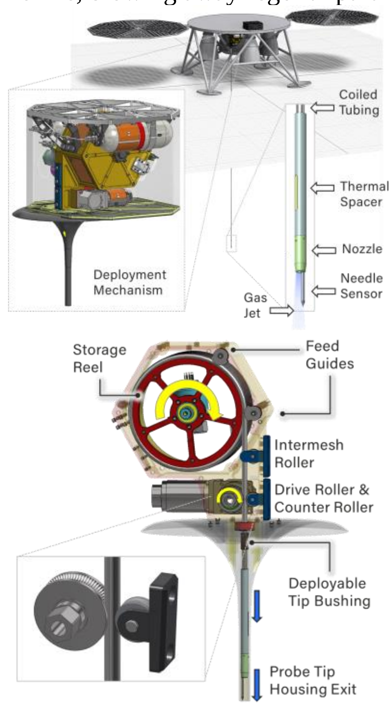

Figure 2. (Top) LISTER mechanism on generic lander. (Bottom) Deployment system diagram.

A short, thin needle sensor is mounted at the end of the probe tip (Fig. 2). The drill makes stops at pretargeted depths. At each stop, the gas jet shuts off and the needle sensor is pushed into the bottom-hole regolith to make temperature and thermal conductivity measurements. For the mission, measurements were planned with ~0.5-m intervals down to 3-m depth.

Drilling Performance on the Moon: To address potentially challenging subsurface conditions, LISTER employs a reciprocating motion known as "dithering". The motion is automatically triggered when high probe tip force is detected (via motor current) and potentially allows the gas jet to loosen rock hazards and eject or divert them from the drill path. In development tests, this method was effective in penetrating 1.5 meters in simulant with 3-5 mm rocks at 33%vol, but given sufficient rock size, concentration, and depth, excavation tends to stall in a "gravel bottom" condition where gas jet erosion has removed fine particles but retained and concentrated coarse particles [3].

This dithering motion was put to use early in the LISTER mission, as around 0.32 m depth, the drill encountered difficult subsurface conditions, with video evidence showing ~2-5 mm rock particles ejected from the borehole. The team hypothesized that a gravel bottom failure was developing and developed a new drilling command sequence that favored rapid, repetitive dithering. This adaptation allowed LISTER to make further progress until, we believe, concentrations of obstructing coarse particles became too great and LISTER was no longer able to eject or displace enough obstructions to continue past 1 meter (Fig. 4).

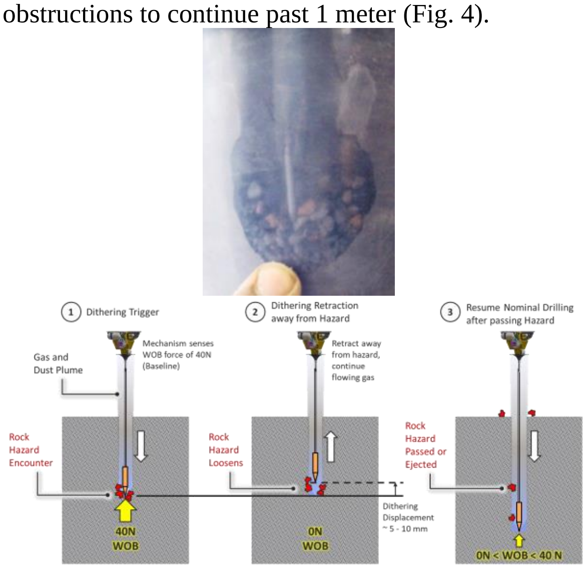

Figure 3. The "gravel bottom" hazard (top) and the dithering mitigation developed against it (bottom). Large concentrations of coarse particles at depth can severely impact drilling performance.

Surprising Consolidated Regolith Surface: Lander-captured video of early drilling operations shows LISTER starting to penetrate consolidated regolith that remained exposed after lander thruster scour. Ejected material is friable and readily breaks upon collision and impacts. A preliminary "rapid ablation cascade" theory is proposed to explain eruptions of consolidated regolith seen on video (Fig. 5). The high degree of consolidation observed in this mission may motivate further investigation and ongoing updates to lunar regolith simulant compositions for Earth-based testing [4].

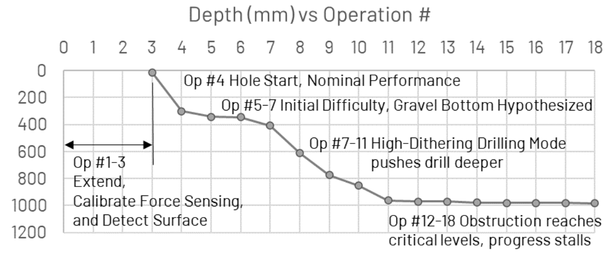

Figure 4. LISTER drill operation summary.

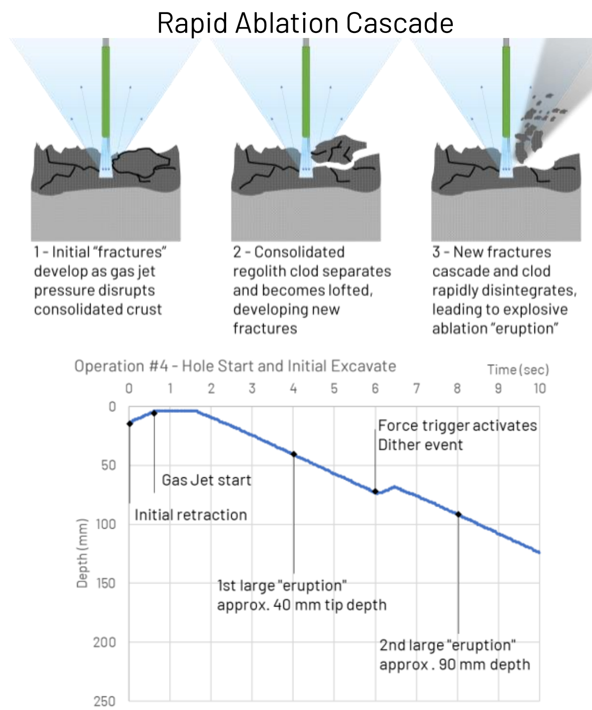

Figure 5. (Top) Proposed rapid ablation cascade mechanism for eruptions in the first 10 cm of drilling in consolidated regolith. (Bottom) Depth plot shows eruptions are not aligned with tip force loading events, but occur with some standoff between the jet and the excavation front. No later eruptions are recorded.

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