REVOLUTIONIZING LUNAR SUBSURFACE EXPLORATION THROUGH ADVANCED DRILLING TECHNOLOGIES. J. C. Palmowski1, K. A. Zacny1, K. F. Bywaters1, R. E. May1, E. Eshelman1, J. T. Schultz1
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Introduction: The REBELS (Rapidly Excavated Borehole for Exploring Lunar Subsurface) system presents an advanced end-to-end technology for accessing, studying, and harvesting deep regolith deposits on the moon. REBELS leverages a suite of existing, high-TRL (4-7) technologies to accomplish this, including coiled-tube deployment with pneumatic excavation (both concepts inspired by LISTER, a TRL-6 CLPS payload), and rotary-percussive drilling (inspired by the TRL-7 TRIDENT drill, a PRIME-1 and VIPER payload). At the surface, the system can harvest the excavated regolith with a pneumatic collection head situated at the top of the borehole (inspired by PlanetVac, a TRL-6 CLPS payload). If applicable, the system is also capable of melting and extracting water, as demonstrated by the Mars-based In Situ Resource Utilization (ISRU) technology RedWater in a recently successful end-to-end test of the TRL6 design. In addition to ISRU capabilities, The REBELS Bottom-Hole Assembly (BHA) also embeds multiple downhole instruments for nondestructive, in situ measurements of the subsurface regolith formation. One such instrument is a high-performance VIS camera and optics assembly for imaging of borehole texture, granularity, stratigraphy, and mineralogical composition. REBELS will also include downhole Dielectric Spectroscopy capabilities with integrated conductive probes contacting the borehole for measuring regolith electrical properties, particularly capacitance and conductivity. By enabling exploration beyond the current depth limitations, REBELS will provide invaluable insights into the Moon's geological history, while also providing a promising means of lunar resource utilization, laying the groundwork for future human exploration and habitation of the moon.

Figure 1. REBELS system overview (left) and notional lander architecture at full deployment length (right).

Figure 2. REBELS subsystems (left) inspired by Honeybee heritage technology (right): 1. Coiled-Tubing, Storage Drum and Pneumatic Excavation, 2. Coiled-Tubing Injector, 3. Downhole Science Instruments, 4. Rotary-Percussive Drill, 5. Pneumatic Collection Head.

Background: REBELS is inspired by heritage from various existing technologies developed by Honeybee Robotics: RedWater, LISTER, TRIDENT, PlanetVac, and SMART. Each of these technologies contributes unique capabilities to the REBELS system, enhancing its potential for deep subsurface exploration and resource utilization.

RedWater is an R&D project that recently closed out NASA funding with a successful end-to-end demonstration of a TRL-6 system. Although RedWater is designed for Mars, it proved that the LISTER coiled tubing and pneumatic excavation concepts can be scaled up to a size more suitable for an instrumented drill, such as REBELS. RedWater also further proved rotary-percussive drilling capabilities.

LISTER (Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity) is a heat flow probe payload that will be flying on an upcoming NASA CLPS mission, and is the first Honeybee project that incorporated coiled tubing for downward penetration.

TRIDENT is a TRL-7 rotary-percussive drill that captures cuttings from a depth of up to 1 meter and transfers them to the surface for further processing and utilization. It is slated to fly to the moon in the near future on both PRIME-1 and VIPER missions.

SMART (Sensing, Measurement, Analysis, and Reconnaissance Tool) is another R&D project funded by NASA to build an instrumented drill for downhole science investigation, including NIR spectroscopy,
neutron spectroscopy, dielectric spectroscopy, and context imaging camera. REBELS design draws inspiration from both the dielectric spectroscopy and the context camera design of SMART, and in the future, may incorporate NIR as well.

PlanetVac is a technology for acquiring and transferring regolith from the lunar surface to instruments (for in situ analysis) or sample returned container (for sample return missions). It is slated to fly as a payload on a CLPS mission in the near future.

Collectively, these heritage of these technologies streamlines the development efforts of the REBELS system, providing a comprehensive solution for robust lunar exploration and resource utilization.

Methodology: The primary innovation of REBELS lies in its ability to conduct in situ science investigations and ISRU (In-Situ Resource Utilization) applications at unprecedented depths. The Bottom-Hole Assembly (BHA) of REBELS is equipped with instruments that can be activated in real time during the drilling process, allowing for immediate subsurface data collection. Moreover, the system's capability to pneumatically clear and analyze borehole cuttings in real time at the surface level represents a significant advancement in lunar exploration technology. The technology can also crossover as a resource harvesting device in support of ISRU, with the ability to capture large quantities of lunar regolith as it penetrates into the ground.

Development Status: The various subsystems of REBELS are currently being developed, with Technology Readiness Levels (TRL) ranging from 4 to 9, through various NASA projects. This development status indicates a promising trajectory towards the operational deployment of REBELS in the near future.

Figure 3. Mission concepts for REBELS include a 10-m depth lunar drill as payload on a lander (left), a version of REBELS for extreme depths, potentially as deep as 100-m (top-right), and a REBELS spin-off designed for 10-m depth ISRU and subsurface science investigations on Mars (bottom-right).

References:


