TRIDENT OPERATIONS ON THE LUNAR SURFACE AS PART OF THE PRIME-1 MISSION ONBOARD THE INTUITIVE MACHINES ATHENA LANDER.

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Introduction: The Regolith and Ice Drill for Exploring New Terrain (TRIDENT) is a one-meter class rotary percussive drill that was recently demonstrated on the Lunar surface as part of the Polar Resources Ice Mining Experiment-1 (PRIME-1) mission. PRIME-1 flew aboard the second flight of the Intuitive Machines Nova-C lander (nicknamed Athena). The launch took place on February 26, 2025 and the landing took place on March 6, 2025 on the Mons Mouton plateau on the Lunar south pole. The vehicle had an off-nominal landing, resulting in the lander coming to rest on its side with the PRIME-1 payload facing up (Figure 1). From this configuration, TRIDENT was not able to drill into the lunar surface. However, power and an appropriate range of motion were available; as such, the team was able to perform successful functional checkouts and demonstrate all functions in the lunar environment. In this abstract, we describe the operations performed on the lunar surface.

TRIDENT Mechanism: To better understand the functionality demonstrated, we first describe the TRIDENT mechanism. TRIDENT is a rotary percussive drill that uses a system of two linear stages to deploy the drill onto the lunar surface and advance the auger into the subsurface. The left half of Figure 1 illustrates key subsystems that enable this. In summary, the drill head contains the actuators enabling auger rotation and percussion. The drill head and auger travel along the feed stage to advance the auger into the ground for drilling. This feed stage is mounted on the deploy stage, which presses the footpad down onto the ground before drilling begins.

TRIDENT is also outfitted with temperature sensors (RTDs) and heaters, largely to monitor mechanism and actuator survival and operational temperature limits. Of particular interest are two temperature sensors in the auger: one in the bit, and another ten centimeters above the bit co-located with a heater. These nominally enable

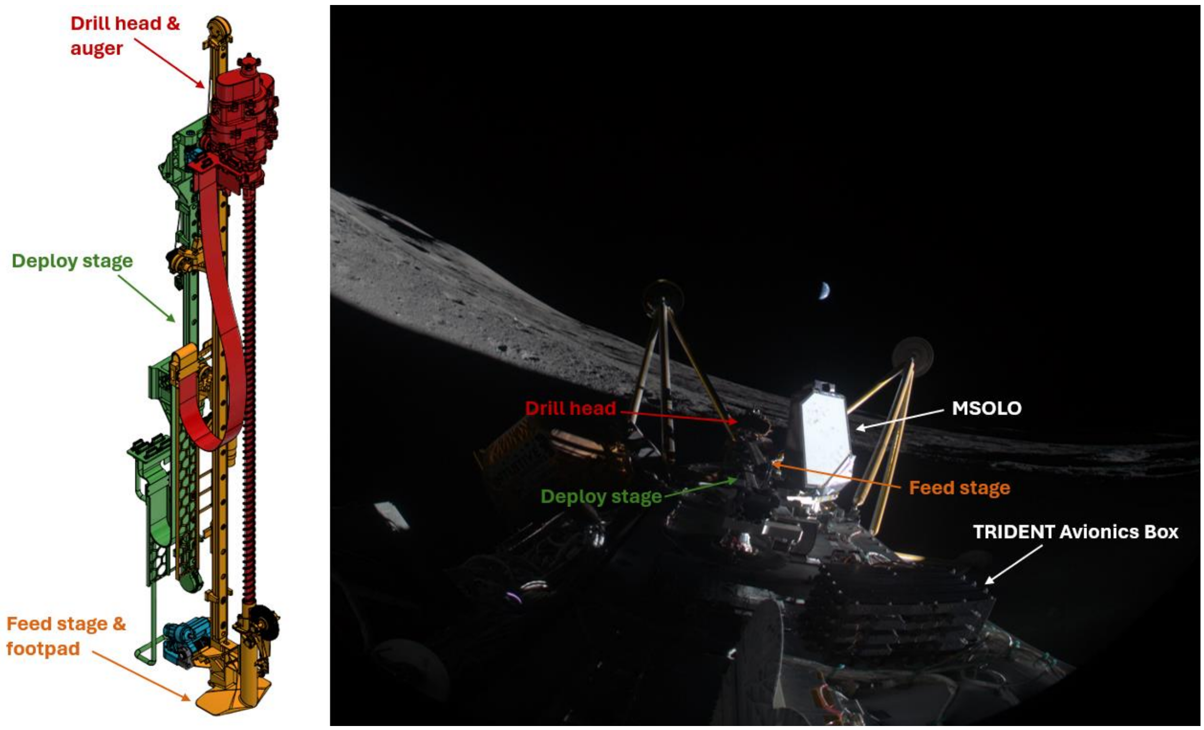

Figure 1: *TRIDENT mechanism with primary subsystems labeled (left) and photo taken by lander on the lunar surface showing TRIDENT and MSOLO on top-facing panel – note that image was taken at the end of operations when TRIDENT was in its fully deployed state, with the drill head at the bottom of the feed stage (right). Photo Credit: Intuitive Machines.*

TRIDENT to make downhole temperature and thermal conductivity measurements. Lastly, TRIDENT has a dedicated avionics box that enable these motions and measurements.

In-Transit Check Out: The first time TRIDENT was operated in space was during an in-transit check out. This procedure includes health checks of the mechanisms and avionics box, and spinning of the auger. This operation proceeded nominally.

Surface Operations: After confirmation of the off-nominal landing, the TRIDENT team formulated a new concept of operations to demonstrate as much functionality as possible from a horizontal lander attitude. All aspects of the TRIDENT mechanism, temperature sensors, and avionics were successfully demonstrated during the operational window of the Athena lander on the lunar surface. The TRIDENT operations team sent commands to demonstrate the following functions, in this order:

(1) Auger rotation
(2) Percussion
(3) Launch lock release (lower, then upper)
(4) Deployment of footpad to the ‘surface’ (extension to lower hardstop, travel distance 35 cm)
(5) Deployment of auger to 1 m ‘depth’ (extension to lower hardstop, travel distance 1 m)
(6) Cycled on auger heater, observed auger RTDs register increase, then decrease in temperature

This sequence resulted in the drill being positioned approximately as it would have been at the conclusion of drilling to a full depth of one meter, as shown in the right half of Figure 1. Temperature sensors distributed throughout the system read nominally and self-consistently throughout these operations.

Results: All operations were executed nominally as commanded. This means that the full TRIDENT system successfully survived the harsh environments of launch, an off-nominal landing, and of the lunar surface. This also included a period in which the avionics box experienced a temperature drop below its rated survival limit, and an especially dusty operating environment.

The regolith dust coating present on Athena and its payloads after landing can be observed by comparing the image taken on the lunar surface (ex., Figure 1), with images taken in transit (ex., Figure 2). This dust is especially evident on the avionics box (due to it’s flat faces and uniform color) but is also observable on the TRIDENT mechanism, and of particular interest, on the feed and deploy rails.

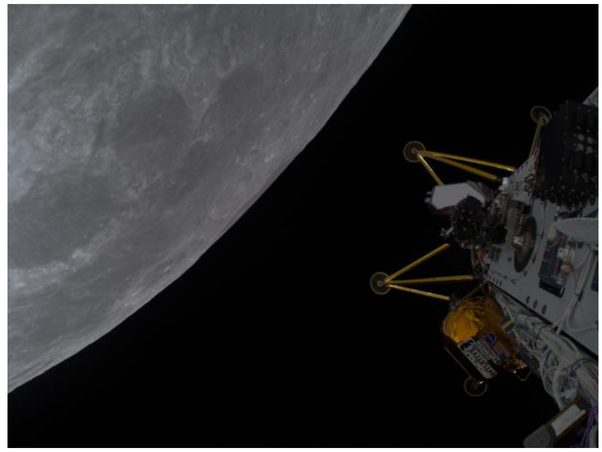

Figure 2*: Photo taken by lander (same camera as Figure 1) in low lunar orbit featuring the PRIME-1 payload. Note that all mechanisms and faces are clean. Photo Credit: Intuitive Machines*

While these operations did not include drilling a hole in the lunar surface, the hard vacuum, harsh temperature, and dusty environment of the lunar surface demonstrated the robustness of the TRIDENT design. Potential future missions, such as the Volatiles Investigation Polar Exploration Rover (VIPER), may take advantage of this reduction in risk.

References: [1] Official Intuitive Machines (2025). *IM-2_Athena_Mons_Mouton Landing* https://flic.kr/p/2qQywoe [2] Official Intuitive Machines (2025). *IM-2 Mission in Low Lunar Orbit 2.* https://flic.kr/p/2qPWKAK