COMMERCIAL LUNAR SURVEYING AND PAYLOAD MOBLITY SERVICES: THE LUNAR OUTPOST MOBILE AUTONOMOUS PROSPECTING PLATFORM (MAPP) A.J. Gemer[1], J.A. Cyrus[1], and J.B. Cyrus[1], [1]Lunar Outpost, Inc. (2830 E. College Ave, Unit 106, Boulder CO 80303, AJ@lunaroutpost.com).

Introduction: Mobile robotic systems for lunar surface operations are essential to provide ground-truthing of orbital sensor data sets, create depth profiles of ISRU materials, and advance modeling efforts while augmenting remote sensing data and advancing the Science Mission Directorate's Strategic Goals and Objectives of enabling sustainable long-term exploration and utilization of space resources [1]. NASA's Lunar Strategic Knowledge Gaps specify a requirement for robotic in-situ measurements of volatiles on the lunar surface, enabling sustainable commercial opportunities in cis-lunar space and increasing the resolution of surface and subsurface science data at lunar areas of interest [2]. Lunar Outpost is addressing these needs through technology maturation and risk retirement of the Mobile Autonomous Prospecting Platform (MAPP), a robust, adaptable robotics platform for providing commercial lunar prospecting and surface mobility services.

Lunar Outpost, Inc.: Lunar Outpost is a HUB-Zone-certified small business with expertise in the defense, aerospace, robotics, and air quality industries. As a company, Lunar Outpost is focused on creating dual-use technologies that enable a sustained human presence on the lunar surface, while also having a near-term positive impact here on Earth. To this end, Lunar Outpost has leveraged this expertise to provide innovative solutions in the terrestrial air quality monitoring industry, while concurrently developing enabling technologies to accelerate the commercial space economy.

The Mobile Autonomous Prospecting Platform (MAPP): The Lunar Outpost MAPP is a cost-effective 10kg-class lunar rover platform, designed to fulfill multiple needs in the next stage of lunar exploration. It was the first commercial prospector to be publicly demonstrated in the USA, when it was unveiled and began testing at the Colorado School of Mines Lunar Testbed Facility, demonstrating it's suitability for NASA's Commercial Lunar Payload System program, which seeks to establish a catalog of high-TRL lunar lander payloads. Key features differentiating MAPP from other commercial rovers are its small size and mass (allowing one or more MAPPs to function as secondary payloads aboard larger landers), large payload mass fraction (allowing it to carry a wide range of instruments and commercial payloads), focus on lunar resource prospecting and ISRU, and the advanced TRL level of its critical subsystems.

Commercial Payload Accomodations. The Lunar Outpost MAPP reserves significant interior volume and approximately half of its total mass for commercial payloads. These payloads may be mounted internally or externally to the body, depending on science and survival requirements. Initial payloads are high-TRL science instrumentation from NASA or other institutions that require or benefit from surface mobility, and in the future, swarms of MAPPs will carry commercial surveying and prospecting sensors for ISRU materials.

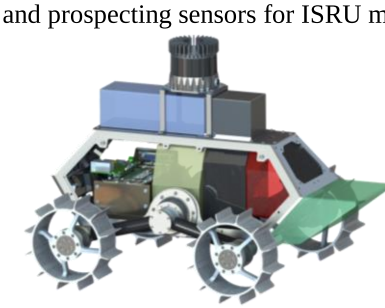

Figure 1: MAPP Payload Volumes

Figure 1 illustrates the four available payload spaces available aboard the rover; internal volumes are shown in yellow (1133 cm^3) and red (675 cm^3), and external accommodations are shown in green (945 cm^3) and blue (675 cm^3). The drill, shown in gray, is removable if desired, adding 1212 cm^3 for additional internal/external payload space. A composite enclosure may be added to the top of the rover, allowing the blue payload volume to be adapted for both internal and external payloads, as desired.

Mission 1 (M1) Overview. Launched aboard the SLS or commercial rockets and deployed by upcoming landers built through NASA's Lunar Surface Transportation Capability and CLPS [3] [4], the LO MAPP will utilize an architecture of space systems currently existing or in development to achieve its mapping and prospecting objectives. Upon landing, MAPP will perform health checkout tests before initiating deployment from the lander; interface compatibility checks with several proposed CLPS landers are underway to ensure that MAPP can be deployed by a range of future spacecraft. MAPP will proceed to survey the landing site, characterize communications signal strength between rover and lander, and utilize a 360° LIDAR sensor to generate a high-fidelity model of the landing site topography. MAPP will then autonomously navigate to its first waypoint, while operating its forward-facing surface imaging instrumentation. At the first waypoint, MAPP will deploy its regolith drill and record spectra of the drill cuttings. This process will continue along further waypoints; autonomous operation and hazard avoidance is accomplished via a combination of vision-based navigation (VBN) and LIDAR mapping. Current power budgets allow for a total drive distance of several kilometers; mission duration is extended by solar PV augmentation using proprietary optimization algorithms to continuously calculate the power-optimal CONOPS. M1 will span one lunar day (~14 Earth days) and will consist of mostly sunlit traverses with the ability to survive brief shadow occlusions (such as driving behind a large rock or "peeking" into a crater). The M1 MAPP is not expected to survive the conditions of the lunar night; future MAPPs will be capable of extreme low-temperature survival and operation.

Two candidate landing sites are recommended: an area on Lacus Mortis near 44°N, 25°E in the northeastern quadrant of the near-side, and a crater near 88°S, 125°E at the South Pole. Site 1 is on a flat basaltic mare plain and may be near an area of high titanium content ejecta. Site 2 is of low slope angle, and though it has surface ice, is not a permanently shadowed region [5]. Additionally, there is a high level of geological diversity in the area, proving valuable to planetary geologists, scientists, and engineers alike [6].

Science Instrumentation. For M1, the proposed instrument payload includes a forward-facing multispectral imager along with the 10cm regolith drill and drill-facing NIR spectrometer.

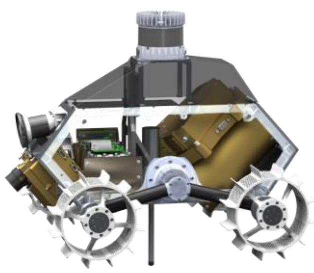

Figure 2: MAPP M1 Instrument Configuration

The regolith drill has been developed in-house at Lunar Outpost, and uses a flight-qualified Maxon motor, gearbox, and motor controller. The linear actuators used to deploy the drill are designed using COTS extreme-environment robotics components, and the drill bit is an adaptation of previously demonstrated spaceflight drills. The forward-facing imager is the third generation Near Infrared Volatiles Spectrometer System (NIRVSS) [7]. NIRVSS measures the surface morphology, minerology, and temperature, and detects volatiles including H_2O, CO_2, and CH_4. Water ice can be detected in concentrations of <0.25%. For M1, the instrumentation payload is configured with the NIRVSS Bracket Assembly mounted to the front of MAPP and scanning the lunar surface ahead of the path of travel. The drill-facing spectrometer is the NIRSpec instrument, an adaptation of the LADEE Ultraviolet Spectrometer (UVS), and analyzes subsurface volatile concentrations by focusing on drill cuttings raised to the surface by the drill bit. NIRSpec has a FOV of 0.1-1.0 degrees, a spectral range of 800-2500nm, and a spectral resolution of 8nm.

System of proven, high-TRL components. MAPP is largely designed using high-TRL, COTS components to reduce development cycle time and buy down mission risk; the battery (TRL 9), drive motors (TRL 8), VBN camera (TRL 8), science instruments (TRL 6), and CPU/control electronics (TRL 6) have already been spaceflight-qualified and/or flight-proven on prior orbital missions

Testing at CSM's Center for Space Resources (CSR). A prototype MAPP has been tested at Colorado School of Mines' Lunar Testbed Facility (LTF), demonstrating its ability to operate in a simulated lunar terrain and providing a high degree of testing fidelity. Mobility and lifetime testing at the LTF will be augmented by performing reduced-gravity traction testing, using a specially-designed weight-offloading frame. The regolith drill has also been prototyped and demonstrated, and development will continue as science instrument integration progresses. Flight-qualification vibration and thermal-vacuum testing will satisfy the TRL advancement goals of the LO MAPP program.

Conclusion: The LO-MAPP provides cost-effective commercial lunar prospecting and payload mobility services on the lunar surface. The MAPP's low mass and compact size allow it to be landed aboard a wide range of commercial lunar landers, making it a flexible primary or secondary payload. With a robust drivetrain and extensive science capabilities, swarms of MAPPs will deliver commercial ISRU-focused payloads to sites of interest around the lunar surface, enhancing scientific understanding and generating valuable data to augment future ISRU mission planning.

References:

[1] NASA (2018) *2018 Strategic Plan*. [2] NASA (2016) *Strategic Knowledge Gaps.* [3] NASA (2019) *Lunar Surface Transportation Capability RFI.* [4] NASA (2018) *Commercial Lunar Payload Services (CLPS).* [5] P. D. Spudis, B. Bussey, J. Plescia, J.-L. Josset and S. Beauvivre (2008) *Geophysical Research Letters, vol. 35, no. 14.* [6] S. Li, P. G. Lucey, R. E. Milliken, P. O. Hayne, E. Fisher, J.-P. Williams, D. M. Hurley and R. C. Elphic, (2018) *Proceedings of the National Academy of Sciences, vol. 115, no. 36, pp. 8907-8912.* [7] T. L. Roush, A. Colaprete, R. Elphic, K. Ennico-Smith, J. Heldmann, C. Stoker, M. Marinova, R. McMurray, E. Fritzler and S. Morse (2015) *Advances in Space Research, vol. 55, no. 10, pp. 2451-2456.*