A GEOLOGIST'S PERSPECTIVE OF LUNAR SURFACE OPERATIONS WITH SMALL PRESSURIZED ROVERS.

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Introduction: Drawing from landing site and crew traverse studies in the south polar region (e.g., [1-5]) and from fully-staffed simulations of lunar missions (e.g., [6-8]), including a 28-day-long simulation of a mission to the lunar south polar region, the potential contributions of a small pressurized rover to lunar surface science are summarized here.

Mission Concept and Science Opportunity: The basic trade to be made is between walking extravehicular activity (EVA) and traverses augmented by an unpressurized rover (UPR) or small pressurized rover (SPR). Rover mobility is favored because it dramatically expands the capabilities of crew on the surface. A field-based trade study demonstrated that a SPR (**Fig. 1**) provides a far more productive and safe mobile platform than a UPR (see [6] for details or [9] for a brief summary). Mission concepts utilizing dual SPR have been developed.

Lunar surface science capabilities using the vehicle were initially evaluated for missions to the Schrödinger basin [2,3] and Kepler crater [10]. The Schrödinger basin is a high-priority target, because a global landing site study [11] found that it is the location where the largest number of lunar science and exploration objectives [12] can be addressed. A study of human missions to the lunar surface by the International Space Exploration Coordination Group (ISECG) [13] outlined a sequential series of five landing sites: Malapert massif, Shackleton crater, Schrödinger basin, Antoniadi crater, and the center of the South Pole-Aitken basin. At each of those sites, four crew use dual SPR to explore regions up to 100 km radius with two 14-day-long loops during 28- or 42-day-long missions. The size of the exploration zone is driven, in part, by the desire to develop a Mars-forward capability. An initial assessment of those five landing sites and the traverses between them [5] demonstrates a large fraction of the science objectives for the Moon [12] can be addressed using SPRs. While the focus here is on surface science, the vehicle can support engineering tasks, such as excavation of regolith [14] for radiation shielding of a habitat.

Vehicle as a geological tool. The SPR provides mobility, visibility, accessibility, surface documentation, and surface sampling, making it a valuable geological tool during intravehicular activity (IVA) and EVA [9]. For recovery of samples, SPRs should have geological tool racks consisting of hammers, tongs, scoops, rakes, extension handles, drill, and/or drive tubes. A rover needs sufficient volume to store and transport >100 kg of samples [15]. Field-based mission simulations showed that a waist-high platform for working with samples and/or tools is useful (comparable to the waist-level work station on Apollo's lunar module). Because the vehicle may encounter scientific and *in situ* resource utilization (ISRU) targets during tele-robotic traverses between crew landings [16,17], a robotic arm for sampling during those tele-operational phases may be useful, too.

Rapid egress/ingress. To reduce timeline, mass, and volumetric overhead, a rapid egress and ingress system has been envisioned [7]. That type of system greatly enhances lunar surface exploration [9,18]. If an SPR does not have a rapid egress/ingress system, then the efficiency of the SPR is compromised. A study of an Apollo 17 traverse [18] indicated it would take crew in an SPR, without rapid egress/ingress, double the time it took the Apollo 17 crew. A rapid egress/ingress system may be facilitated by reduced cabin pressures and a new exploration atmosphere [19].

Crew productivity. A Generation I vehicle was tested in a series of 3-day, 14-day, and 28-day mission simulations. Tests include >1152 hrs of astronaut time in the vehicle and 2832 hours of total crew time in high-fidelity simulations in analogue terrains. Three-day mission simulations using UPR and SPR showed traverses within the SPR were easier on crew because they did not spend an entire day in spacesuits, thus enhancing EVA productivity at each traverse station. A human factors assessment indicated 57% greater performance and 61% less EVA time using the SPR configuration relative to the UPR configuration [6].

Figure 1. A proto-type small pressurized rover that has been tested in 3-, 14-, and 28-day long simulations of lunar missions with (inset) a concept flight vehicle.

Range. A dual SPR operational mode may extend the ~6 mile (~10 km) Apollo-era walk-back limit on distance from a lander to 150 mi (~240 km) [20], which would exceed that needed to traverse the 100 km-radius exploration zones being examined [5] for the ISECG five-mission scenario. It potentially extends the distance travelled from a lander by a factor of 25 compared with the limit of the Apollo Lunar Roving Vehicle (LRV) and, thus, an area 625 times larger. A rover also allows crew to deploy instrument packages (e.g., seismometers) far from a landing site.

Potential Mass of the Investigation: Based on a Generation I vehicle, a mass of 3000 kg with a 1000 kg payload capacity has been estimated [20], which will need to be updated based on a Generation II (Space Exploration Vehicle) cabin and flight design. Due to their masses and volumes, SPRs will likely be deployed to the lunar surface in advance of crew. Tele-operation of the vehicle, either from Houston or an orbiting platform would allow trafficability conditions to be explored prior to crew landing and to verify the reliability of the vehicle prior to crew landing.

Data Rate: Mission simulations of lunar missions revealed that (i) continuous communication between a crew and a science operations center produces higher quality science than does twice-a-day communication, and (ii) that high data bandwidth (>1 Mbits/s) is needed that includes the ability to transmit, in real time during an EVA, high definition video. The current Artemis surface operation plan [21] provides a 10 Mbits/s Ka-Band link from the surface to an orbiting platform and a 100 Mbits/s Ka-Band link from that platform to Earth with a latency of only 3 s. Any critical activities must be designed to accommodate loss of signal ~14% of the time due to the orbit of the orbiting platform [22], unless other communication assets become available.

Estimates of the Cost to Develop and Operate the Investigation: Costs include terrestrial versions of the SPR for training purposes, flight versions of SPRs, and flight-ready spares for contingency launch. Costs also include training of crew for human missions to the surface; and training for science operations staff for both crew and tele-robotic traverses.

Amount of Crew Interaction Needed: The vehicle is a home and refuge for crew during surface missions, protecting them from solar particle events (SPE), acute suit malfunctions, and medical emergencies [7]. An SPR can be tele-operated by crew from orbit, too.

Requirements for Landing Site(s): Topography in the south polar region is severe and may limit walking EVA and rover access to local targets. Topography can also form barriers to longer-distance traverses and require circuitous paths between regions of interest. A post-Apollo analysis recommended the ability to traverse 25° slopes [23]. While the UPR chassis was designed to accommodate up to 15° slopes in terrestrial analogue terrains [24], the SPR climbed 18 to 20° slopes on cinder-covered volcanic vents, which suggests a 25° slope may be possible on the Moon.

Conclusions: A SPR, originally designed for mobility, is also a productive geological tool [9]. A crew working from within an SPR, with the capability for rapid egress and ingress, is far more productive [18]. A rover can be used to conduct subsurface surveys during crew traverses and (tele-robotically) between crew landings [16,17].

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References: [1] Kring D. A. et al. (2010) *Shackleton and Malapert Traverse Science Objectives*. [2] O'Sullivan K. M. et al. (2011) in *GSA Special Paper*, *477*, 117–127. [3] Bunte M. K. et al. (2011) *GSA Special Paper*, *483*, 533–546. [4] Lemelin M. et al. (2014) *Planet. Space Sci.*, *101*, 140–161. [5] Allender E. J. et al. (2019) *Adv. Space Res.*, *63*, 692–727. [6] Abercromby A. F. J. et al. (2010) *NASA-TP-2010-216136*, 131p. [7] Abercromby A. F. J. et al. (2012) *NASA-TP-2012-217360*, 144p. [8] Gruener J. E. et al. (2013) *Acta Astronautica*, *90*, 406–415. [9] Kring D. A. (2017) *European Lunar Symposium*. [10] Öhman T. and Kring D. A. (2012) *J. Geophys. Res.*, *117*, E00H08, doi:10.1029/2011JE003918. [11] Kring D. A. and Durda D. D., eds. (2012) *A Global Lunar Landing Site Study to Provide the Scientific Context for Exploration of the Moon*, LPI Contrib. 1694, 688p. [12] NRC (2007) *The Scientific Context for Exploration of the Moon*. [13] Hufenbach B. (2015) IAC, 66th, Paper#IAC-15,A5,1,1,X30756, 11p. [14] Mueller R. P. (2009) AIAA 2009-646. [15] Kring D. A. (2020) *this conference*, Abstract #5037. [16] Kring D. A. (2017) *Ann. Mtg. LEAG*, Abstract #5014. [17] Kring D. A. and Heggy E. (2020) This conference, Abstract #5038. [18] Kring D. A. et al. (2017) *SSERVI Exploration Science Forum*. [19] Abercromby A. F. J. et al. (2015) *Acta Astronautica*, *109*, 76–87. [20] NASA (2008) *NF-2008-10-464-HQ*. [21] NASA (2019) *NexSTEP-1 BAA*, v. Sept. 30. [22] Whitley R. and Martinez R. (2016) *IEEE Aerospace Conf.*, doi: 10.1109/AERO.2016.7500635. [23] LExSWG (1995) *Lunar Surface Exploration Strategy, Final Report*, 50p., LPI. [24] Harrison D. A. et al. (2008) *IEEEAC*, Paper #1196, 13p.