Towards An Understanding Of Rover Technology Needs For Future Lunar Applications

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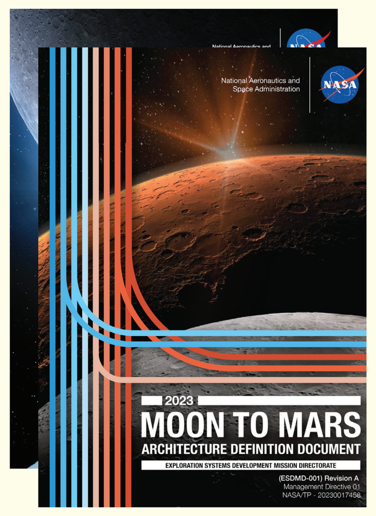
Lunar Surface Innovation CONSORTIUM

Envisioning a Sustained Lunar Presence



NASA's Moon to Mars (M2M) strategy and objectives document [1] and STMD's Envisioned Future Priorities [3] establish long-term goals and objectives for the agency's return to the lunar surface and eventual human exploration of Mars. These strategy documents outline the desired state and suggested path forward for lunar technology development within specific capability areas.

The 2023 Architecture Definition Document (ADD) [2] provides information about processes, framework, and decomposition of objectives to allow success in achieving human exploration of the cosmos and includes descriptions of lunar surface elements including: a Human-class Delivery Lander, and the need for a Lunar Terrain Vehicle (LTV) and Pressurized Rover (PR) to enable greater exploration access across the lunar South Pole.

A variety of mobility capabilities, Autonomous Excavation & Construction (AE&C) and ISRU capabilities are specifically featured in the documents. For example, the Autonomous Systems and Robotics goals [4] explicity state the desire for:

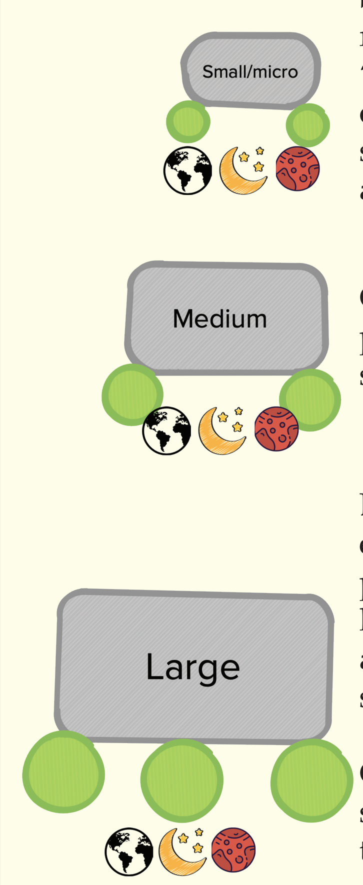
- an autonomous fast-moving science rover;
- the ability for autonomous, persistent lunar surface operations for long-range and worksite operations (traveling up to 750 km/yr);
- remotely-operated intra-vehicular robotics for maintenance and utilization;
- robust robot mobility for extreme access;
- durable, maintainable robotics for heavy-duty surface work, including bulk excavation (up to 400 metric tons);
- high-volume materials transport (up to 600 km/yr) and surface construction (up to 15,000 kg carrying capacity).

Notably, ISRU functions have shared interest with AE&C, including robust and rugged mobility capabilities, and the need for maintenance and repair.

What can we do now?

Operated on Earth | Operated on the Moon | Operated on Mars

Scale



Size of a suitcase or backpack - smaller size rovers are effective as "scouts" sent ahead of other more valuable resources to test terrain and accessibility

Can carry payloads or perform tasks, but too small to transport crew

Large, uncrewed rovers allow for maximum payload transport, or large-scale tasks such as excavation and construction.

Crewed rovers are essential for transportation over large distances.

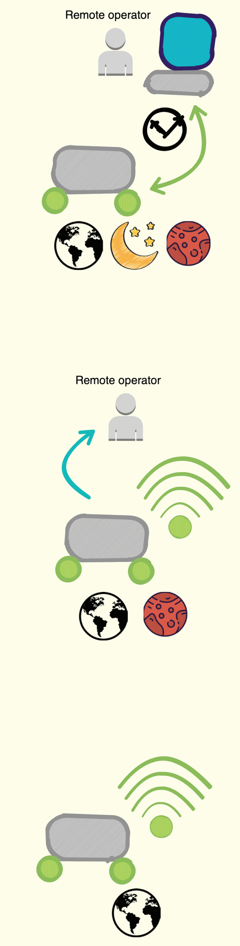
Power Source

Solar – Photo-volatic cells are power limited during Lunar night or if cells are obscured by lunar dust

Battery – Rovers have been used on the moon with limited life batteries (Apollo) as well as re-chargeable batteries (Lunokhod-1)

RTG – unlimited power but the usual hazards of radioisotopes thermoelectric generators

Autonomy

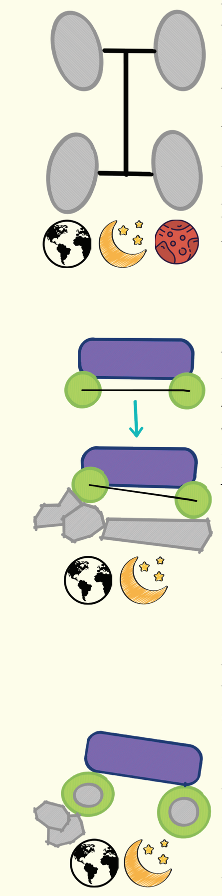


Remotely operated, human-in-the-loop – These rovers require human interaction and have time delays between commanding and executing desired operations.

Semi-autonomous or "smart" rover – These rovers are outfitted with hazard avoidance and active suspension systems to reduce failures in an unpredictable environment.

Fully autonomous – can work non-stop performing individual tasks or cooperatively with a network of similar rovers

Drivetrain



Multiple wheel drive with individually steerable wheels – allows for tight-turning and maximum maneuverability.

Active Chassis System (adjustable height) – allows rover to clear small boulder and other obstacles.

Flexible wheels – designed to work at temperature extremes, warp to absorb ground irregularities and flex when necessary

Understanding Mobility Needs

Supporting NASA's goals of sustained human presence on the Moon and the agency's desire to demonstrate ISRU and E&C capabilities on the lunar surface in the near future, a variety of mobility cases and scales will likely be necessary to meet all the necessary demands of an expansive ISRU or E&C mission [5,6] and the objectives and use cases outlined in the ADD [2]. Establishing a long-term presence most likely will require a "fleet" of rovers, some for science and exploration, others for autonomous uninterrupted construction and still more for for crew transport.

Use Cases

Assumes Single Vehicle

Rover Classes	*ISRU Prospecting*	*ISRU Material Transportation*	*ISRU Regolith Excavator & Loader*	*Long-Rage Traversability*	*Site Survey*	*Infrastructure Deployment*
Desired capabilities as defined in [2,4,5,6]	• Operate in PSR • Recon: 25 to 100 km² area • Carry neutron spectrometer and/or camera • Operate for months over 100s of km	• Operate from PSR to processing site • Carry metric tons of icy regolith • Operate for weeks with daily round trips of 10s of km	• Operate in PSR • Dig 100m x 100m area down to about 1m • Multiple trips per day • Assume to be equipped for icy regolith excavation	• Operate in extreme terrain • Multiple trips over 1000s of km over months or years • Carry small science or infrastructure payloads for deployment	• Operate in areas of interest for exploration or site preparation, including PSR and extreme terrains • Carry survey instruments for mapping • Map areas up to 100s of km² over mission lifetime	• Haul metric tons of regolith between points repeatedly • Construction, such as tamping • May be equipped with special construction tools • Deploy infrastructure elements (e.g.VSAT) in potentially extreme terrain
Sub-R (ex. SLIM microrover)	X	X	X	X	O	X
1R (ex. Mini RE-RASSOR)	X	X	X	X	O	X
2R (ex. RASSOR)	X	O	O	X	O	X
3R (ex. Yutu-2)	O	O	O	X	O	X
4R (ex. Opportunity)	O	O	O	O	O	X
5R Half the size of the Apollo Lunar Roving Vehicle	O	O	O	O	O	O
6R (ex. VIPER)	O	O	O	O	O	O
6R+ (ex. LTV)	O	O	O	O	O	O

Key

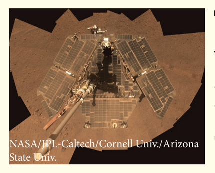
X : This size rover class likely would not be able to perform the function within the use case

O: This size rover class will likely be able to perform the functions within the use case

Establishing a sustained lunar presence will require contributions from NASA and its international partners, as well as typical aerospace contractors, newer aerospace companies, non-typical aerospace contractors (e.g., terrestrial excavation and construction companies), and input from academic institutions. These rovers will need to be durable, be able to be repaired *in situ* and thus maintained for long-term use, and be able to traverse long distances with some level of autonomy. Further work will map capabilities of mobility platforms to specific needs and size classes to provide traceability to current technology and inights into new technology developments that may be needed for sustained exploration.

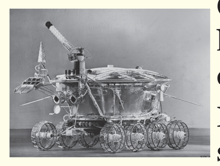
Learning from the past

We can learn lessons from design and operation of rovers flown in previous planetary missions to enable more robust design and exploration on the lunar surface



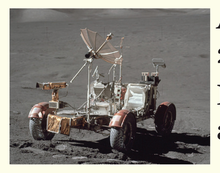
The MER-Opportunity rover operated for 14 years on the Mars surface before a major dust storm reduced the power from the solar arrays to where comm was not possible.

Lesson Learned: some environmental conditions are too much to overcome but an active dust mitigation strategy is important when relying on solar arrays for power.



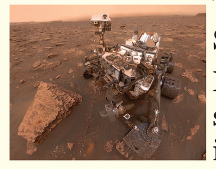
On April 20, 1973, Lunokhod-2 drove into a relatively small crater and the radiator got covered in dust while leaving. On May 10, the temperature inside the spacecraft became critical and operation was stopped; radio contact with the rover was lost the next day. The mission was officially terminated 3 June 1973.

Lesson Learned: Active dust mitigation is needed when relying on radiators to provide cooling to rover systems and electronics.



Apollo 17 conducted 3 lunar surface excursions, totaling 22 hours, driving this 3rd lunar vehicle a total of 22.2 miles, deployed instruments and collected 254 pounds of rock and soil samples.

Lessons learned: All of the Apollo-era Lunar rovers were successful but were designed for a limited life and the Artemis program needs rovers that can sustain unlimited lifetime missions.



The Curiosity rover has been active on Mars for 4187 sols (over 11 years) exploring Gale crater and Mount Sharp on Mars as part of NASA's MSL mission.

Lessons learned: Each wheel is independently steered, actuated and geared to allow for climbing in soft sand as well as scrambling over rocks. Patterned tracks in the sand indicate distance travelled. Sensors limit the rover from exceeding excessive tilt angles.

What are we missing?

Please add any other needs, requirements, comments about SOA, etc, to ensure we have a complete picture of the field!

Please take our survey to help us understand your needs more fully!

References: [1] NASA (2023) Moon to Mars Strategy and Objectives Document, NP-2023-03-3115-HQ; [2] NASA (2024) Exploration Systems Development Mission Directorate Moon to Mars Architecture Definition Document (ESDMD-001) – Rev. A; [3] https://techport.nasa.gov/framework; [4] https://techport.nasa.gov/file/144879; [5] htt[s://techport.nasa.gov/143280; [6] https://techport.nasa.gov/143281