



## NASA SBIR 2020 Phase I Solicitation

### Z5.05 Lunar Rover Technologies for In-situ Resource Utilization and Exploration

Lead Center: JSC

Participating Center(s): ARC, GRC, KSC

Technology Area: TA4 Robotics, Telerobotics and Autonomous Systems

#### Scope Title

Enabling Rover Technologies for Lunar Missions

#### Scope Description

The objective of this subtopic is to innovate lunar rover technologies that will enable In-Situ Resource Utilization (ISRU) and exploration missions. In particular, this subtopic will develop ideas, subsystems components, software tools, and prototypes that contribute to more capable and/or lower-cost lunar robots.

A potential lunar ISRU application is the prospecting, characterization, and collection of volatiles that could be processed to produce oxygen, fuel, etc. Recent remote sensing measurements, modeling, and data from LCROSS (Lunar Crater Observation and Sensing Satellite) indicates that there may be an abundance of volatiles (e.g., hydrogen) near the lunar poles. However, the distribution of the volatiles at and under the surface is unknown. The Lunar Rover Technologies for In-situ Resource Utilization and Exploration subtopic seeks new robotic technology that will enable rover technologies for lunar missions to support ISRU activities. This does not include new ISRU technology (which is solicited by subtopics T2.05 - Advanced Concepts for Lunar and Martian Propellant Production, Storage, Transfer, and Usage for the STTR solicitation and S4.02 - Robotic Mobility, Manipulation and Sampling for the SBIR solicitation).

The expected environment at the lunar poles involves all the challenges observed during the Apollo mission (thermal extremes, vacuum, radiation, abrasive dust, electrostatic dust) plus the addition of low sun angles, potentially less consolidated regolith, and permanently shadowed regions with temperatures as low as 40K. This subtopic seeks new technology to address these challenges.

Phase I success involves technical feasibility demonstration through analysis, prototyping, proof-of-concept, or testing. Phase II success will advance TRL to a level of 4-5. Of specific interest are:

- Mobility architectures, including novel mobility mechanisms and lunar dust tolerant mechanisms.
- Cryo-capable actuators capable of operating at extremely cold temperatures (in environments as cold as -230C). Preferably solutions will not include heaters as they significantly increase the power draw for normal operations during the lunar day. Novel materials capable of maintaining metallurgical properties at cryogenic temperatures will be considered. Also desired are cryo actuators featuring dust tolerances and the ability to operate at high temperatures as well (approaching 150C).

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- Magnetic gearing applications for space. NASA and others are developing relatively low ratio (less than 25:1 per stage) concentric magnetic gearing for aeronautics applications. Space applications demand high speed-reduction ratio (often more than 1000:1) and high specific torque (>50 Nm/kg), operation in environmental temperatures down to -230C (40K), operation in low-atmosphere or hard vacuum, with high reliability and energy efficiency. Phase I work would include identifying the most suitable magnetic gear topologies to meet these space application needs, defining the technology development challenges including thermal and structural issues, advancing the most critical aspects of the technology, and producing a low-fidelity prototype to prove the feasibility of the concept(s).
  - Perception systems and algorithms with a path toward flight for the lunar surface capable of operating in the harsh lighting conditions that might include high dynamic range, shadowed regions, low angle illumination, and opposition effects
  - Lunar regolith terramechanical modeling tools and simulations, especially tools that integration with existing commercial and open source robotic analysis and simulation tools.
  - Rover embedding and entrapment detection and escape approaches including slip monitoring, regolith sensing/modeling, low ground pressure wheels and soft soil tolerant mobility architectures.

For all the above, it is desired to have been demonstrated in, or have a clear path to operating in, the lunar environment. NASA has plans to purchase services for delivery of payloads to the Moon through the Commercial Lunar Payload Services (CLPS) contract. Under this subtopic, proposals may include efforts to develop payloads for flight demonstration of relevant technologies in the lunar environment. The CLPS payload accommodations will vary depending on the particular service provider and mission characteristics. Additional information on the CLPS program and providers can be found at this link: <https://www.nasa.gov/content/commercial-lunar-payload-services>. CLPS missions will typically carry multiple payloads for multiple customers. Smaller, simpler, and more self-sufficient payloads are more easily accommodated and would be more likely to be considered for a NASA-sponsored flight opportunity. Commercial payload delivery services may begin as early as 2020 and flight opportunities are expected to continue well into the future. In future years it is expected that larger and more complex payloads will be accommodated. Selection for award under this solicitation will not guarantee selection for a lunar flight opportunity.

## References

NASA is still formulating its approach to future lunar science and exploration. The current plan is to start with small commercial landers (<100kg) beginning as early as 2019, with relatively high launch cadence (2+ launches/year). In the future, NASA seeks to build mid-to-large landers, with an eye on human-rated landers with a first mid-sized lander planned for 2022.

Further information can be found at the following:

- How to survive a Lunar night: <https://www.sciencedirect.com/science/article/pii/S0032063310003065>
- Apollo Experience Report - Thermal Design of Apollo Lunar Surface Experiments Package: <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19720013192.pdf>
- The Lunar Environment: [https://www.lpi.usra.edu/publications/books/lunar\\_sourcebook/pdf/Chapter03.pdf](https://www.lpi.usra.edu/publications/books/lunar_sourcebook/pdf/Chapter03.pdf)
- Commercial Lunar Payload Services - CLPS: <https://www.fbo.gov/index?s=opportunity&mode=form&id=46b23a8f2c06da6ac08e1d1d2ae97d35&tab=core&cvview=0>
- Survive and Operate Through the Lunar Night Workshop: <https://www.hou.usra.edu/meetings/survivethenight2018/>
- NASA's Exploration Campaign: Back to the Moon and on to Mars: <https://www.nasa.gov/feature/nasas-exploration-campaign-back-to-the-moon-and-on-to-mars>
- NASA Exploration Campaign: <https://www.nasa.gov/sites/default/files/thumbnails/image/nasa-exploration-campaign.jpg>

Additional information on NASA's interest in landers that might host the rovers can be found at the following:

- NASA Seeks Ideas to Advance toward Human-Class Lunar Landers (<https://www.nasa.gov/feature/nasa-seeks-ideas-to-advance-toward-human-class-lunar-landers>)
- Lunar Surface Transportation Capability Request for Information (RFI)

Magnetic gearing references:

- Tlali, P. M., Wang, R-J., and Gerber, S., "Magnetic gear technologies: A review," 2014 Intl. Conference on Electrical Machines, p. 544-550, Berlin, Germany, Sept. 2 – 5, 2014.
- Justin J. Scheidler, Vivake M. Asnani, and Thomas F. Talerico, "Overview of NASA's Magnetic Gears Research," presented at the AIAA / IEEE Electric Aircraft Technology Symposium, Cincinnati, Ohio, July 12 – 13, 2018.
- Vivake M. Asnani, Justin J. Scheidler, and Thomas F. Talerico, "Magnetic Gearing Research at NASA," presented at the 74th Annual Forum of the American Helicopter Society, Phoenix, AZ, May 14 – 17 2018.
- Aaron D. Anderson and Vivake M. Asnani, "Concentric Magnetic Gearing - State of the Art and Empirical Trends", NASA TM, in-press.

**Expected TRL or TRL range at completion of the project:** 3 to 5

### **Desired Deliverables of Phase II**

Prototype, Analysis, Hardware, Software

### **Desired Deliverables Description**

Example deliverables coming from a successful phase II within this subtopic, might including some of the following:

- Designs of cryo-capable or dust tolerant mechanisms motor controllers with test data and prototypes
- Prototype rovers or scale versions of prototype rovers showing novel mobility architecture for escaping entrapment in regolith
- Software algorithms including demonstrating slip detection or image processing in harsh lunar lighting conditions
- Software packages either standalone or integrated with commercially available or open-source robotic simulation packages (preferred).

NASA is also interested in technologies demonstrations that could serve as payloads on commercial landers at the end of phase II.

### **State of the Art and Critical Gaps**

Current state of the art in robotic surface mobility is the MER/MSL (Mars Exploration Rover/Mars Science Laboratory) rovers for Mars and the Chinese Chang'e on the moon. Since the end of the NASA Constellation program in 2011, there has been only small pockets of technology development for the lunar surface within NASA and other space agencies, plus the small business/academic communities.

The specific areas noted above for targeted development (mechanisms, cryoactuators, magnetic gearing, perception systems, terramechanics simulations and novel mobility architectures) are all of specific interest as they are specific challenges unique to the lunar surface and lunar poles specifically.

Magnetic gearing has become practical in recent years due to the availability of high energy density magnets and design topologies that conserve volume. As a result, there has been an exponential growth in R&D for Earth applications like wind/wave energy generators and hybrid vehicle power-trains.

### **Relevance / Science Traceability**

This SBIR resides within STMD as a vehicle for development of technology objectives. It is expected that successful projects would infuse technology into either the STMD Game Changing Development (GCD) or Technology Demonstration Missions (TDM) programs. Technology could also be infused into joint efforts involving STMD's partners (other mission directorates, other government agencies, and the commercial sector). Flights for these technology missions could be supported on small commercial lunar landers (SMD) or possibly mid-size

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NASA lunar landers (HEOMD).

Potential customers:

- Autonomy and robotics
- Robotic ISRU missions
- Payloads for Commercial Lunar Payload Services landers
- Commercial vendors

Future prospecting/mining operations