Scope Title
Bulk Regolith Infrastructure

Scope Description
It is envisioned that some of the first possible lunar infrastructure will be structures composed of bulk regolith and rocks. The intent of this subtopic is to develop lunar civil engineering technologies (designs, processes, etc.) that produce such structures, and to develop concepts of operations (ConOps) for their construction in the south polar region of the Moon. This is the lunar equivalent of terrestrial “Earth Works.” Earth-based civil engineering processes and related technologies are not directly applicable to the lunar environment, therefore new lunar civil engineering technologies must be developed.

The desired outcome of this effort is “Regolith Works,” which are engineered surface features and structures that function as Artemis Program risks mitigation infrastructure. Regolith Works are sought for scaled lunar construction demonstrations and to guide the development of robotic equipment that will build the infrastructure. The following lunar civil engineered structures are of interest to NASA. Proposers are welcome to suggest other regolith-based infrastructure concepts. Construction materials and processes that go beyond manipulation of bulk regolith and rocks are not in scope for this subtopic.

- Bulk regolith-based launch/landing zones designed to minimize risks associated with landing/launching on unprepared surfaces for (Commercial Lunar Payload Services) CLPS and (Human Landing System) HLS vehicles.
- Rocket Plume Surface Interaction (PSI) ejecta and blast protection structures.
- Regolith base and subgrade for supporting hardened launch/landing pads, towers, habitats and other in situ constructed structures.
- Pathways for improved trafficability.
- Solar Particle Event (SPE) and Galactic Cosmic Ray (GCR) shielding structures.
- Structures for access to subgrade (e.g., trenches, pits).
- Emplaced regolith overburden on structures and equipment.
- Meteoroid impact protection structures.
- Topographical features for terrain relative guidance for flight and surface vehicles.
- Flat and level operational surfaces for equipment positioning, regularly accessed locations, and dust mitigation applications.
- Sloped regolith ramps for access to challenging locations.
- Utility corridors (e.g., electrical, comm, fluids).
• Shade structures.
• Elevated operational surfaces.

Exact requirements for the full-scale bulk regolith structures are not yet known. Assumptions should be made with supporting rationale to enable initial designs. Specification of lunar civil engineering design criteria should be provided including geotechnical properties.

Tests and validated models/simulations should be developed to characterize the regolith infrastructure performance in its intended applications in lunar environments. For example, effects of ejecta impingement upon proposed PSI ejecta protection structures should be characterized including phenomenon such as erosion or secondary ejecta trajectories.

Development of PSI modeling capabilities is not in scope for this subtopic, but collaboration with ongoing PSI modeling efforts is welcome. Information on PSI characteristics can be obtained in the peer-reviewed literature and public NASA reports in the reference section.

ConOps should be developed to define the sequence of steps to complete construction tasks. The ConOps should begin with the natural lunar surface including hills, valleys, and surface and subsurface rocks, and end with the completed bulk regolith infrastructure verified to meet design criteria. A sequence of all required functions of robotic systems and implements should be defined to achieve the task. References to recommended existing spaceflight or prototype hardware should be provided for each function. In cases where hardware does not exist, conceptual implement designs should be proposed, and critical functions demonstrated in laboratory environments. Concepts should be appropriate for a CLPS scale demonstration mission on the lunar surface (e.g., 25 kg overall mass, 8 kg budget for implements). Assume that the implements would attach to an existing modular mobility platform with interfaces at the forward and aft position. A depiction of the integrated construction system concept should be provided.

Proposers may select one or more structures of interest to develop. Infrastructure designs that maximize risk reduction for the Artemis Program will be prioritized. ConOps that show promise for implementation by a single, compact, robotic construction system will rank high. Additionally, concepts that employ the high TRL implements will be prioritized. NASA is seeking bulk regolith infrastructure that can be demonstrated in the near term.

Research institute partnering is anticipated to provide analytical, research, and engineering support to the proposers. Examples may include applying civil engineering principles and planning methods, identification and development of needed standards or specifications for lunar structures and operations, regolith interaction modeling, development of analytical models and simulations for verification of system performance, and methods for the design and prototyping of hardware and associated software.

**Expected TRL or TRL Range at completion of the Project**

2 to 5

**Primary Technology Taxonomy**

**Level 1**

TX 07 Exploration Destination Systems

**Level 2**

TX 07.2 Mission Infrastructure, Sustainability, and Supportability

**Desired Deliverables of Phase I and Phase II**

• Research
• Analysis
• Prototype
• Hardware
Software

Desired Deliverables Description

Phase I must include the civil engineered design of bulk regolith infrastructure including associated testing, modeling, and simulations. Phase I must also include a concept of operations for constructing the infrastructure and verifying the as-built characteristics meet design criteria. An overall construction system concept must be provided. Phase I proposals should target a TRL of 3 for structures and implements.

Phase II deliverables must include prototype demonstration of construction and characterization of bulk regolith infrastructure. This infrastructure construction must be achievable using civil engineering technologies adaptable to robotic systems and implements. Proof of critical functions of the infrastructure and systems must be demonstrated. Structures and systems must be developed to a minimum of TRL 5. Phase II must also include updates to the bulk regolith infrastructure designs, tests, modeling, and simulation based on Artemis Program needs refinement and new information that will be provided by NASA to the selected awardees.

State of the Art and Critical Gaps

While civil engineering and construction are well established practices on Earth, lunar applications remain at low TRLs. The design requirements and functional capabilities of bulk regolith-based lunar infrastructure are not well defined. To date, very few studies have performed civil engineering designs of bulk regolith infrastructure for lunar surface applications. Tests have been performed on Earth but only for short periods of time and with limited environmental and operational fidelity.

Relevance / Science Traceability

Construction of bulk regolith infrastructure directly addresses the STMD Strategic Thrust “Land: Increase Access to Planetary Surfaces.” It also addresses the strategic thrust of “Explore: Expand Capabilities Through Robotic Exploration and Discovery.”

References

Plume Surface Interaction (PSI)

https://www.nasa.gov/directorates/spacetech/game_changing_development/projects/PSI

Rocket Plume Interactions for NASA Landing Systems


Gas-Particle Flow Simulations for Martian and Lunar Lander Plume-Surface Interaction Prediction

https://doi.org/10.1061/9780784483374.009

Understanding and Mitigating Plume Effects During Powered Descents on the Moon and Mars

https://baas.aas.org/pub/2021n4i089?readingCollection=7272e5bb