This call for technology development is in direct support of the Exploration Systems Mission Directorate (ESMD) Technology Development Program. The purpose of this research is to develop new technologies to support lunar exploration missions, providing systems that interact with humans, handle surface equipment and move people and their payloads at, and away from, a lunar outpost. The objective is to produce new technology that will reduce crew extra-vehicular activity (EVA) and intra-vehicular activity (IVA) workloads, lunar operations and reduce the total mass and volume of equipment and materials required to support missions. The proposals should focus on component technologies to improve the operations of exploration equipment, allowing for less expensive, more productive and less risky missions. This research will focus on technology development for the critical functions that fall into three phases of surface exploration. The first phase of surface exploration will be functions that are needed prior to crew arriving at a site. These precursors may be hours, days, weeks or years ahead of the crew landing on the surface. The second phase of surface exploration will be during a crew's stay at the site. This work will include supporting the crew in IVA and in EVA tasks. The third phase of surface exploration will include long-term maintenance of the facility, as well as supporting activities performed between crews.

Subtopics

X7.01 Supportability

Lead Center: JSC

Participating Center(s): GRC, KSC, LaRC, MSFC

The objective of this subtopic is to develop technologies that can support the goal of significantly reducing the mass and volume of material required to support long-duration human spaceflight missions. Eventually, as the distance of mission destinations increases, resupply will become impossible. Therefore, unless support materials are prepositioned, it will be necessary for all required materials to be transported with the crew. The difficulty presented by this situation is compounded by the need for more material as mission duration increases. Capabilities to address these issues should be developed and demonstrated in conjunction with long duration lunar missions and, as they reach sufficient maturity, will be valuable enhancements to these missions.

This subtopic seeks proposals addressing maintenance and repair technologies that enable repair of failed hardware at all levels, technology that supports the production of replacement components during a mission, and technologies that reduce the quantity of material directly supporting the crew. Proposals are sought which address the following technology needs:
- Real-time, non-destructive evaluation during layer-additive processing for on-the-fly quality control. This will provide capabilities for in-process quality control and may serve as an input for closed-loop process control. Equipment should be portable, compact, and capable of integration with layer-additive manufacturing systems.

- Non-destructive material property determination. This will provide an in-process quality control capability to ensure that material deposited during layer-additive processing meets required material property criteria. Equipment should be portable, compact, and capable of integration with layer-additive manufacturing systems.

- Recycling/generation of feedstock materials for deposition processes. This will provide the capability to recycle failed parts and material removed from near-net-shape parts during machining operations to serve as feedstock material for subsequent layer-additive manufacturing. Initial focus should be placed on metallic materials. Additionally, emphasis should be placed on total system mass and volume.

- Compact, portable multi-axis machining systems. This will provide subtractive manufacturing capabilities to achieve final design dimensions and surface finishes following layer-additive processes that produce near-net-shape parts. Equipment to accomplish this should be of the minimum mass and volume possible while still providing required capabilities.

- Compact, portable, vacuum-compatible multi-axis manipulator. This will provide the capability for complex manipulation of the item itself, the processing equipment, or both during layer-additive manufacturing and machining. To be compatible with the widest variety of candidate processes, manipulation equipment should be vacuum compatible. Additionally, equipment to accomplish this should be of the minimum mass and volume possible while still providing required capabilities.

Rapid manufacturing processes have advanced rapidly in recent decades. The technology has gone from a means of quickly producing models to a means of quickly producing usable hardware. NASA seeks technology improvements which extend the efficiency of rapid manufacturing and improve the properties of resulting components. NASA also seeks to identify different applications that will highlight the capabilities of rapid manufacturing in support of the Vision of Space Exploration and potential commercial applications. NASA also seeks technology focused on integration of rapid manufacturing, computer numerical control, coordinate measuring machines, Robotics and Digital Manufacturing and Simulations technologies. This technology should be focused on an autonomous system where the parts fabricated in rapid manufacturing can be positioned for machining on critical surfaces, then positioned for measurements and inspections and ultimate delivery (independently and remotely). The results should be an autonomous system where these technologies are integrated as modules to produce the end result.

**X7.02 Human Systems Interaction**

Lead Center: JSC

Participating Center(s): ARC, GRC, GSFC, JPL, KSC, LaRC, MSFC

The objective of this subtopic is to create an effective and efficient operational interface between a human and a robotic system that is supporting the human. This subtopic seeks to develop technology that reduces the risk of
Extra-Vehicular Activity (EVA), improves the productivity of Intra-Vehicular Activity (IVA) and facilitates remote operations by both flight crew and ground control. Automation and robotics capabilities include the ability to use robots for site operations, both at an outpost and at remote lunar surface locations. Site operations support focuses on two types of activities: (1) tedious, highly repetitive, long-duration tasks that cannot be performed by EVA crew and (2) rapid response for addressing emergency, time-critical situations. Candidate tasks include: mobile camera platform control, systematic site survey (engineering and/or science), inspection, emergency response, site preparation (clearing, leveling, etc.), and instrument deployment. Proposals are sought which address the following technology needs:

- Telepresence and variable autonomy teleoperation systems that support human and robot teams operating: (1) in a shared space, (2) close but separated, (3) line-of-sight remote, and lunar. Particular interest is given to systems that flexibly support human-robot operations in the presence of time-delays of up to 10 seconds.

- Adaptive user interfaces including perception, speech recognition, context awareness, computational cognitive models, and collaborative 3D graphics, and EVA display devices (i.e., pressure-suit compatible devices and displays). Specific design objectives include enabling more natural interaction with autonomous systems, facilitating situational awareness, increasing overall productivity by reducing the amount of interaction effort the human has with the robot, and flexibly displaying multi-modal and mission-specific data.

- Geospatial tools for situational awareness including content generation tools for geospatial information, particularly for supporting planetary surface missions; software libraries for generating, parsing, and importing heterogeneous mission data (orbital imagery, navigation information, sensor and instrument readings, etc.); and terrain modeling (Digital Elevation Map).

- Vehicle control components and navigation sensors that support on-board driving, teleoperation, and autonomous operations. Control systems should support multiple control modes, include activity monitoring and operator intent prediction, and tolerate up to 10 seconds of time-delay. Navigation sensors that utilize passive computer vision (real-time dense stereo, optical flow, etc.) and/or active illumination (for recognizing/tracking non-textured objects and operation in permanently shadowed regions) are of particular interest.

**X7.03 Surface Mobility and Transportation**

*Lead Center: JSC*

*Participating Center(s): ARC, GRC, GSFC, JPL, KSC, LaRC, MSFC*

The objective of this subtopic is to provide new capabilities for delivery, handling, transfer, construction and repackaging of Extra Vehicular Activity (EVA) equipment and preparation of site infrastructure for lunar operations. This includes access/handling and transportation equipment/carriers for delivery and deployment of materials, components, and infrastructure; surface mobility systems to provide the power train for site clearing, pad construction, and regolith manipulation (note that the power train attachments for this activity will be provided by the in situ resource utilization (ISRU) area); and commodities distribution systems (including umbilicals) for routing to equipment and infrastructure. These new capabilities are required to make planetary surface missions more reliable, safer, and affordable.
Several vehicle features will be critical to surface operations: expanded mobility, range and duration, life support recharge, crew following, automated path planning, automated driving, and obstacle avoidance. Vehicles with life support recharge capabilities will extend useful EVA time. The ability of a vehicle to follow a crewmember will enable science and exploration support equipment to be carried for the astronaut as well as extend the traverse distances. While the utility of autonomy is easily recognized when the crew is not on the surface, these functions could also be advantageous to long traverses and rescue or emergency operations when crewmembers are present.

Proposals are sought which address the following technology needs:

- Lightweight, power-efficient manipulation devices (dexterous and non-dexterous) that can be deployed on small rovers and that are appropriate for multiple tasks. Much of this activity can be performed with teleoperated and semi-autonomous robots controlled from ground. Some of this activity, however, will also require human presence at the site. In both cases, the effectiveness of Human-Robot interaction (HRI) will have a major impact on the efficiency and productivity of mission operations.

- Low-mass, high-strength, long-life wheels capable of spreading supported load over an extended contact patch area and moving over surface terrain similar to loose beach sand. Range, Life, Mass, Mean-time-to-repair, and Mean-time-between-failure are key performance parameters being sought.

- Reliable navigation sensors to support surface mobility by a range of vehicles (ranging from MER-class to LRV-class). For example, a range finder with dynamically-operated foveal aperture could support wide field-of-view scanning and three-dimensional object tracking.

- Navigation and communication infrastructure technologies for use on the Lunar surface to support surface mobility and communication between lunar base, EVA astronaut and mobile rover/robotic assistant.

X7.04 Surface System Dust Mitigation

Lead Center: GRC
Participating Center(s): ARC, GSFC, JPL, JSC, KSC, LaRC, MSFC

The general objective of the subtopic is to provide knowledge and technologies (to Technology Readiness Level (TRL) 6 development level) required to address adverse dust effects to exploration surface systems and equipment, which will reduce life cycle cost and risk, and will increase the probability of sustainable and successful lunar missions. The subtopic will help to develop a balance of near- and long-term knowledge and technology development, driven by Exploration Systems Mission Directorate needs and schedule requirements, aligned with existing technology investments where possible. The technical scope of the subtopic includes the evaluation of lunar dust effects and development of mitigation strategies and technologies related to Exploration Surface Systems, such as: Rovers and Robotic Systems, In Situ Resource Utilization (ISRU) Systems, Power Systems, Communication Systems, Airlock Systems and Seals, Habitats, and Science Experiments.

The subtopic specifically requests technologies addressing dynamic mechanical systems used for lunar surface
missions with potential to mitigate effects of lunar dust. For lubricated mechanisms, such as drives and pointing mechanisms, the sealing element must be durable enough to maintain a hermetic seal to prevent lubricant outgassing and dust contamination for at least 5 years. Also, the bearings, gears, etc. of the mechanism must be robust enough to survive and provide nominal operation with lunar dust contamination and possible lubrication starvation.

The subtopic also requests proposals for advanced materials, coatings, and related technologies with the proper combination of physical, mechanical, and electrical properties, and lunar environmental durability, suitable for use in dust mitigation applications on the lunar surface.