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 low-Earth orbit (LEO), robotic precursor, and human exploration missions, providing systems that interact with humans, handle surface equipment and move people and their payloads across planetary surfaces. The objective is to produce new technology that will reduce crew extra-vehicular activity (EVA) and intra-vehicular activity (IVA) workloads and risk in LEO, and Lunar operations and reduce the total mass and volume of equipment and materials required to support missions. The proposals should focus on technology to improve the operations of exploration equipment, allowing for less expensive, more productive and less risky missions. This research will provide technology 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 science performed between crews.

Subtopics

**X7.01 Supportability Technologies for Long-Duration Space Missions**

*Lead Center: JSC*

*Participating Center(s): LaRC*

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:

- Compact, portable systems to generate reverse engineering data to support manufacturing of replacement items during a mission. This will allow generation of a duplicate part based on an existing part if CAD models are not available.

- 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.

- Laundry system. This will provide the capability for extended reuse of crew clothing. Any laundry system must utilize a minimal amount of water or no water at all. Any water used should be easily recycled - either being reintroduced into the spacecraft water system or recycled internal to the laundry system. Additional emphasis should be placed on the mass and volume of the equipment and minimization of power requirements.

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**X7.02 Human-System Interaction**

**Lead Center:** JSC

**Participating Center(s):** ARC, JPL, LaRC

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 automation 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 operational tasks (assembly, maintenance, inspection, payload transport, etc.), real-time advisory
systems that will support the space and lunar based crew, and mission operation concepts and systems that link ground supervisors across time delays to remote spacecraft and robots. 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) somewhat remote, and far remote. Particular interest is given to systems that flexibly support human-robot operations in the presence of time-delays of up to 10 seconds.

- **Software frameworks and interaction infrastructures** that facilitate the creation and operation of joint human-agent teams. Conventional control architectures do not adequately address human-system interaction needs, particularly in terms of coordination, teaming, direct and indirect commanding, and information sharing between humans, robots, and distributed software agents. Of particular interest are extensions to existing NASA human-robot architectures and software frameworks including: automatic event and situation summarization, notification and dialogue based on user state (role, availability, location, interface), centralized task coordination/dispatch, user activity monitoring, and automated detection of domain events.

- **Adaptive user interfaces** including perception (visual gesturing), speech recognition, context awareness, computational cognitive models and/or 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.

- **Embedded real-time advisory and action planning systems** for fully autonomous integrated systems that support remote and onboard vehicle operations for the Crew Exploration Vehicle (CEV).

- **Engineering systems** that support flight demonstrations of dexterous robots working with EVA crew using CEV and ISS to prove capabilities for space and lunar operations. This will provide human, robotic and human-robot team options for dexterous EVA tasks, robotic EVA capabilities for excursions into high radiation fields beyond Low Earth Orbit (LEO), and the ability to respond to onboard situations with prompt EVA action.

- **Accurate and affordable methods** for prototyping and evaluating human-system interaction. This includes model-based simulation and trade studies for analyzing multiple interaction “dimensions” (spatial distribution, autonomy level, team makeup, task dependencies, etc.) and missions (pre-cursor robotic, short-stay sorties, and long-duration outpost).

- **Vehicle control systems 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.
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 systems for site clearing, pad construction, and regolith manipulation; 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:

- Highly reliable and durable surface systems for site preparation, pad construction, site sampling and prospecting are needed for planetary exploration. Sample collection may require excavating, picking, and physical manipulation of materials, as well as tagging and transport to an analysis site. Emphasis will be placed on proposals that address both manned and unmanned vehicle control operating capabilities of the surface system.

- Flexible and adaptive systems to deploy and emplace site infrastructure, such as beacons for communication, survey, navigation, etc. Emphasis should be placed on developing 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.

- Access/handling and transportation equipment (including cargo carriers) for delivery and deployment of materials, components, and infrastructure. Vehicle systems that can self-deploy, that can function in rough and steep terrain, and that can controlled at various levels of autonomy are of particular interest.

- Commodities distribution systems (including umbilicals) for routing to equipment and infrastructure. Commodities distribution systems are necessary to interconnect distributed surface assets (e.g., access/handling and transportation equipment, launch and landing systems, communication relays, power plants) to support long-duration sorties and sequential mission architectures.

- Vehicle control architectures that support on-board driving, teleoperation, and autonomous operations. Particular emphasis is placed on architectures that can flexibly support and adapt to multiple control modes, that include activity monitoring and operator intent prediction, and that can tolerate up to 10 seconds of time-delay.

- Highly reliable, durable, and long-life systems (mechanical, electrical, software, power train, lubricants, etc). This includes design and implementation of integrated actuator, suspension and control avionics for surface vehicles and evaluation of test articles in field experiments (preferably in lunar analog environments).