



## NASA SBIR 2009 Phase I Solicitation

### X6 Lunar Operations

This call for technology development is in direct support of the Exploration Systems Mission Directorate's (ESMD) Exploration Technology Development Program (ETDP). The purpose of this research is to develop component and subsystem level technologies to support the Constellation Program's (CxP) human lunar return missions. The initial missions will be heavily engaged in construction methods, regolith excavation, establishing self-sustaining power generation, and producing life support consumables in-situ in order to establish continuous operational capability via earth based and lunar based human and robotic assets.

The objective is to produce new technology that will reduce lunar operations workloads associated with crew extra-vehicular activities (EVA) and intra-vehicular activities (IVA), and reduce the total mass-volume-power of equipment and materials required to support both short and long duration Lunar stays as well as maximizing crew and outpost safety during landing, launch and lunar operations. The proposals must focus on component and subsystem level technologies in order to maximize the return from current SBIR funding levels. Doing so increases the likelihood of successfully producing a technology that can be readily infused into the Constellation Program.

Lunar operations are a stepping-stone toward achieving long-term space exploration goals. This research focuses on technology development for the critical functions that will secure an extended human presence on the lunar surface and ultimately enable surface exploration for the advancement of scientific research. Surface exploration begins with short duration missions to establish a foundation which leads to extensible functional capabilities. Successive buildup missions establish a continuous operational platform from which to conduct scientific research while on the lunar surface. Reducing risk and ensuring mission success depends on the coordinated interaction of many functional surface systems including life support, power, communications infrastructure, and transportation. This topic addresses technology needs associated with lunar surface systems infrastructure, interaction of humans and machines, mobility systems, payload and resource handling, regolith excavation and mitigation of environmental contaminations. For more information, see the following websites:

<http://www.nasa.gov/exploration/home/LER.html>

[http://www.nasa.gov/multimedia/podcasting/Haughton\\_Mars\\_project.html](http://www.nasa.gov/multimedia/podcasting/Haughton_Mars_project.html)

<http://robonaut.jsc.nasa.gov/index.asp>

[http://www.nasa.gov/centers/ames/multimedia/images/2008/K\\_10\\_38.html](http://www.nasa.gov/centers/ames/multimedia/images/2008/K_10_38.html)

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<http://www.lpi.usra.edu/meetings/leagilewg2008/pdf/4001.pdf>

[http://www.nasa.gov/home/hqnews/2008/jun/HQ\\_08149\\_Moses\\_Lake.html](http://www.nasa.gov/home/hqnews/2008/jun/HQ_08149_Moses_Lake.html)

## Subtopics

### X6.01 Robotic Systems for Human Exploration

Lead Center: JSC

Participating Center(s): ARC, KSC

The objective of this subtopic is to provide advanced capabilities for lunar surface system assets that deliver, handle, transfer, construct, and prepare site infrastructure for lunar operations. This includes robust dexterous manipulation capabilities; large and small cargo transporters for delivery and deployment of construction materials, power generation systems, and habitable enclosures.

This subtopic seeks to develop technologies that reduce the risk of Extra-Vehicular Activity (EVA), facilitates remote robotic operations by both flight crew and ground control, and enables autonomous robotic operations. Automation and robotics capabilities include the ability to use robots for site setup and 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: systematic site survey (engineering and/or science), inspection, emergency response, site preparation (clearing, leveling, excavation, etc.), instrument deployment, payload offloading, dexterous manipulation, and regolith handling for In-situ Resource Utilization.

Maximizing the useful life of surface assets is essential to a successful lunar program. Material components must be robust and tolerate extreme temperature swings and endure harsh environmental effects due to solar events, micrometeorite bombardment, and abrasive lunar dust.

Proposals are sought for the following technology needs:

- Low-mass, high-strength, long-life, non-pneumatic wheel assembly capable of spreading the supported load over a large 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. Low psi contact patch. Minimal deformation of wheel under varying terrain makeup. Minimal rolling resistance. High performance in 4-sigma soil. 10,000 km expected life. 40K to 400K operating temperature range. Supports 100x its own mass.
- Active and passive damping materials for suspension components that provide extended range of motion (45 degrees in pitch), extreme temperature tolerance (40K to 400K), reactive rates of 1-3 msec, and withstand torsional forces of 3000 N-m.
- Active suspension components that reclaim and store energy absorbed through the suspension system.
- Fluid and electrical connectors that can be repeatedly mated and de-mated (5000+ cycles) without failure

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in a contaminating environment consisting of regolith (abrasive dust) grains ranging in size from 100um down to 10um. Capable of carrying up to 10kw of power transmission or withstanding up to 3000psi pressures.

- Low power sensors for inspection and surface navigation and obstacle avoidance that are not adversely affected by the accumulation of lunar dust on the sensor. Developing robust sensor technologies will enable mobility assets to execute automated path planning, automated driving, and obstacle avoidance.
- Robot user interfaces enabling more efficient interaction with robots, facilitating situational awareness and telepresence, and reducing the amount of interaction effort required to operate robots. Appropriate user interfaces will support humans and robots operating in a shared space, close but separated, line-of-sight remote, and ground control remote. Particular interest is given to systems that robustly support robot operations with up to 10 seconds of communications delay.
- Modular implements for digging, collecting, transporting and dumping lunar soil. The excavation rates are in the order of 50 kg/hr for regolith mining for O<sub>2</sub> production and 300 kg/hr for Site preparation tasks. Total amounts of regolith required are 100 tons for O<sub>2</sub> production and over 2,000 tons for a full outpost deployment. Excavation capabilities involve excavation and collection of both unconsolidated and consolidated surface regolith. Regolith Excavation includes tasks such as clearing and leveling landing areas and pathways, buildup of berms (2.5 m high) and burying of reactors or habitats for radiation protection (2 m deep), and regolith transportation for oxygen production (500 m distance) . Robotic excavation hardware must be able to operate over broad temperature ranges (40 K to 400 K) and in the presence of abrasive lunar regolith and partial-gravity environments. Expectations for maintenance by crew must be minimal and affordable (annual cycle). Therefore, general attributes desired for all proposed hardware include the following: lightweight, abrasion resistant, vacuum and large temperature variation compatible materials, low power, robust/low maintenance, and minimize dust generation/saltation during operation.
- Large surface area, i.e., 100 m X 100 m, soil stabilization/solidification techniques to prevent dust and regolith disturbances/ejecta from vehicular or suited EVA traffic (7 - 70 kilopascal bearing pressure).

## **X6.02 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.

Lunar lander and surface systems will likely employ common hatch and airlock systems for docking, mating, and integration of spacecraft, habitat, EVA, and mobility elements. The large number of EVAs will require hatches that are safe if non-pressure assisted, and do not have to be serviced or replaced regularly. Lunar lander and surface systems will require materials and mechanisms that do not collect dust and do not abrade when in contact with lunar regolith. Technologies are also needed to remove lunar regolith, including dust, from materials and

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mechanisms. Lunar Surface systems will require EVA compatible connectors for fluid, power, and other umbilicals for transfer of consumables, power, data, etc. between architecture elements that will maintain functionality in the presence of lunar regolith, including dust. Lunar surface systems (power, mobility, communications, etc.) will require gimbals, drives, actuators, motors, and other mechanisms with required operational life when exposed to lunar regolith, including dust. Radiators and other thermal control surfaces for lander and surface systems must maintain performance and/or mitigate the effects of contamination from lunar regolith, including dust.

Also included in the technical scope is the development of lunar regolith simulants. Simulants that are properly designed, analyzed, and produced are critical to understanding the effects of dust on humans and mission critical subsystems and how to handle and utilize regolith on the lunar surface. Proposals are requested in technology areas that improve simulant fidelities, reduce simulant manufacturing costs and schedules, and improve on simulant development processes and characterization techniques and methods.

### **Lunar Regolith Simulants**

- Should cost
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- Be producible in quantities up to 30 tons/year;
  
- Have reproducible production processes;
  
- Have particle size distributions representative of lunar regolith from 0.5 to 1000µm in size.

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 out gassing 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.

### **Mechanical Systems**

- Should achieve
- Should achieve dynamic seal wear life of 20 million cycles;
  
- Should achieve 300% improvement in bearing life (frictional torque vs. time) relative to lubricated SOA bearings contaminated with lunar fines.

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.

### **Materials and Coatings**

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- Should demonstrate reduced initial contamination (>90%) compared to conventional materials;
  - Should demonstrate improved efficiency of cleaning processes (>99% removal of initial contamination) without damage.

Another area of interest encompassed by this subtopic is alternative technologies for lunar dust removal that may be used in a variety of lunar surface applications. Both manual and automated cleaning systems are sought and may be derived from any or a combination of particle removal forces appropriate for use on the lunar surface.

### **Cleaning Systems**

- Should demonstrate >99% removal of dust contamination. Tolerable contamination levels will be application specific.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path to hardware or production demonstration in Phase 2. When possible, a demonstration unit or material quantity should be delivered for functional and environmental testing and characterization and evaluation at the end of Phase 2.