Achieving sustained human presence in space and on lunar and Martian sites requires innovative life support and habitation technologies. Proposals are sought that improve life support and habitation systems in the areas of: Advanced Life Support including closed loop, and to a lesser extent, open loop technologies for air revitalization (including lunar dust abatement technologies), water reclamation, solid waste management (including small disposal units for human waste), food management systems (including galley), and biomass production; Extra Vehicular (EVA) technologies including suit assembly, life support systems, power communications and information handling; Contingency Response technologies including fire prevention, detection and suppression, \textit{in situ} fabrication and repair, and \textit{in situ} resource utilization; Advanced Environmental Monitoring and Control including air, water and surface monitoring, external environment monitoring, and life support integrated control.

Subtopics

**X12.01 Advanced Life Support: Air and Thermal**

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

Advanced life support systems will be essential to enable human planetary missions as outlined in the Vision for Space Exploration. Innovative, efficient, and practical concepts are needed for regenerative air revitalization, ventilation, temperature, and humidity control. Requirements include safe operability in micro- and partial-gravity, ambient and reduced-pressure environments, high reliability, regeneration and minimal use of expendables, ease of maintenance, and low-system volume, mass, and power. Proposals should explicitly describe how their work is expected to improve power, volume, mass, logistics, crew time, safety and reliability, with comparisons to existing state-of-the-art technologies. Information and documentation on advanced life support systems can be found at http://advlifesupport.jsc.nasa.gov.

**Air Revitalization**

The management of cabin atmosphere in spacecraft and habitats includes concentration, separation, and control techniques for oxygen, carbon dioxide, water vapor, particulates and trace chemical components. This includes processing and recovering resources derived from waste streams and from \textit{in situ} planetary resources. Technologies focused at closing the air loop will have higher priority. Areas of emphasis include:
• Atmosphere revitalization process integration to achieve energy and logistics mass reductions;

• Separation of carbon dioxide from a mixture primarily of nitrogen, oxygen, and water vapor to maintain carbon dioxide concentrations below 0.3% by volume;

• Recovery of oxygen from carbon dioxide including approaches to deal with by-products of the process;

• Regenerable processes for removing trace chemical components from cabin air and/or gas product streams from other systems (e.g., water reclamation, waste management, etc.);

• Regenerable, re-usable, particulate filters for air;

• Novel approaches to suspended particulate matter removal from cabin and habitat atmospheres, including approaches to isolating cabin and habitat living areas from external dust sources such as Martian or lunar soil; and

• Methods of storage and delivery of atmospheric gases to reduce mass and volume and improve safety.

**Advanced Thermal Control Systems**

Thermal control is an essential part of any space vehicle, as it provides the necessary thermal environment for the crew and equipment to operate efficiently during the mission. A primary goal is to provide advanced technologies for temperature and humidity control; however, advanced active thermal control also includes technologies in the areas of heat acquisition, transport, and rejection. Areas of emphasis include:

• Liquid-to-liquid heat exchangers that provide two physical barriers preventing inter-path leakage;

• Advanced technologies to control cabin temperature and humidity in microgravity. Condensate that is collected must be able to be recovered and transported to the water recovery system;

• Alternate methods of atmospheric humidity control that do not use liquid-to-air heat exchanger (dependent on the spacecraft active thermal control system) or mechanical refrigeration technology;

• Technologies to inhibit microbial growth on wetted surfaces. Applications include condensate collection surfaces for humidity control and heat exchangers resident in water loops;

• Lightweight, versatile, and efficient heat acquisition devices including flexible cold plates, to provide cooling to electronics, motors, and other types of heat producing equipment that is internal to the cabin;

• Lightweight, controllable, evaporative heat rejection devices that can operate in environments ranging from space, Mars’ atmosphere, and Earth’s atmosphere;

• Alternative heat transfer fluids that are non-toxic, non-flammable, and have a low freezing temperature;

• Energy storage devices that maintain the integrity of food or science samples. For maintenance of temperatures of -20°C, -40°C, -80°C or -180°C;

• Highly accurate, remotely monitored, in situ, non-intrusive thermal instrumentation; and

• Low-energy, low-noise, high-capacity fans or similar devices for moving air.
Component Technologies

Energy efficient, low mass, low noise, low vibration, or vibration isolating, fail-safe, and reliable components for handling gases, fluids, particulates, and solids applicable to spacecraft environmental control and air revitalization, including actuators, fans, pumps, compressors, coolers, tubing, ducts, fittings, heat exchangers, couplings, quick disconnects, and valves that operate under varied levels of gravity, pressure, and vacuum. Mass flow monitoring and control devices that have similar attributes and that are easily calibrated and serviced.

X12.02 EVA Technologies

Lead Center: JSC
Participating Center(s): ARC, GRC

Advanced Extravehicular Activity (EVA) systems are necessary for the successful support of future human exploration space missions. Advanced EVA systems include the space suit pressure garment, the portable life support system, tools and equipment, and mobility aids such as rovers. Exploration EVA missions require innovative approaches for maximizing human productivity and for providing the capability to perform useful work tasks. Top-level requirements include reduction of system weight and volume, increased hardware reliability, maintainability, durability, and operating lifetime, increased human comfort, and less-restrictive work performance capability in the space environment, in hazardous ground-level contaminated atmospheres, or in extreme ambient thermal environments. Areas in which innovations are solicited include the following:

Environmental Protection

- Radiation protection technologies that protect the suited crewmember from radiation;
- Puncture protection technologies that provide self-sealing capabilities when a puncture occurs and minimizes punctures and cuts from sharp objects;
- Dust and abrasion protection materials or technologies to exclude or remove dust and withstand abrasion; and prevent dust adhesion; and
- Flexible space suit thermal insulation suitable for use in vacuum and low ambient pressure.

EVA Mobility

- Space suit low profile bearings that maximize rotation necessary for partial gravity mobility requirements and are lightweight.

Life Support System
• Long-life and high-capacity chemical oxygen storage systems for an emergency supply of oxygen for breathing;

• Low-venting or non-venting regenerable individual life support subsystem(s) concepts for crewmember cooling, heat rejection, and removal of expired water vapor and CO₂;

• Fuel cell technology that can provide power to a space suit and other EVA support systems;

• Lightweight convection and freezable radiators for thermal control;

• Innovative garments that provide direct thermal control to crewmember;

• High reliability pumps and fans that provide flow for a space suit but can be stacked to give greater flow for a vehicle;

• CO₂ and humidity control devices that, while minimizing expendables function in a CO₂ environment; and

• Variable conductivity flexible suit garment that can function as a radiator for high metabolic loads and as an insulator during period of low physical activity and low metabolic rates.

Sensors, Communications, Cameras, and Informatics Systems

• Space suit mounted displays for use both inside and outside the space suit-outside mounted displays will be compatible with the space environment;

• CO₂, bio-med (heart rate and blood oxygen level), radiation monitoring, and core temperature sensors with reduced size, lightweight, increased reliability, decreased wiring, and packaging flexibility;

• Visible spectrum camera that provides environment awareness for crewmembers and the public and are integratable into a spacesuit that is lightweight and low power;

• Lightweight sensor systems that detects N₂, CO₂, NH₄, O₂, ammonia, hydrazine partial pressures, including self-powered sensors;

• Lightweight, low power, radio and laser communications with the capability to integrate audio, video, and data on the same data stream to provide reliable communications between the crew and a lander or habitat; and

• Low power, lightweight, radiation hardened, or radiation tolerant informatics computer systems with standard graphics outputs and standard audio inputs and outputs, capable of running commercial operating systems and applications.

Integration

• Robot control by EVA crewmember via voice control or other methods;

• Minimum gas loss airlocks providing quick exit and entry and can accommodate an incapacitated crewmember; and

• Work tools that assist the EVA crewmember during operations in zero gravity and at worksites; specifically, devices that provide temporary attachments, which rigidly restrain equipment to other equipment and the EVA crewmember, and that contain provisions for tethering and storage of loose articles such as tool sockets.
EVA Navigation and Location

- Systems and technologies for providing an EVA crewmember real-time navigation and position information while traversing on foot or a rover; and

- Systems and technologies for managing and locating tools during planetary surface science and maintenance EVA sorties.

X12.03 Contingency Response Technologies

Lead Center: GRC

Participating Center(s): JSC, MSFC

Decades of experience in manned space flight have demonstrated that during any mission, unexpected events will occur. If the crew is adequately equipped to address such contingencies during exploration missions, the chances of successfully completing that mission can be greatly increased. The objective of this subtopic is to develop technologies in the areas of fire prevention, detection, and suppression (FPDS) and in situ fabrication and repair (ISFAR) that will support the crew in the event of a fire or if a critical component breaks during a mission, respectively. These technologies may be in the form of devices, models, and/or instruments for use in microgravity and/or for commercial applications on Earth. The top-level requirements for a viable technology include the reduction of system hardware weight and volume and increased hardware reliability, durability, and operating lifetime. Research conducted during the Phase 1 contract should focus on demonstrating the technical feasibility of the FPDS or ISFAR protocol/system and show a path toward a Phase 2-specific deliverable. The contractor will, when appropriate, deliver a demonstration unit of the instrumentation for NASA testing before the completion of the Phase 2 contract.

Fire Prevention, Detection, and Suppression

The objective of the Fire Prevention, Detection, and Suppression (FPDS) subtopic is to develop technologies that, when incorporated into the design philosophy and functional design of exploration vehicles and habitats, will quantitatively reduce the likelihood of a fire and reduce the impact to the mission should a fire occur. The element is composed of four major theme areas including: fire prevention and material flammability, fire signatures and detection, fire suppression and response, and analysis of fire scenarios. Innovations are sought in the following theme areas:

- Quantifying the effects of microgravity, 1/6-g (lunar) and 1/3-g (Martian) on the ignitability of materials and the subsequent flame spread, particularly related to determining relevant low-gravity behavior from normal gravity tests;

- Improving the performance of spacecraft fire safety systems through the development of advanced fire detection and suppression systems and strategies as well as predicting the effects of smoke and precursor generation and transport; and
- Developing techniques for creating and analyzing the effectiveness of fire resistant materials and coatings, including fire prevention techniques, for spacecraft structures, radiation shielding materials, paneling, fabrics (cotton, paper, synthetics), foams, etc.

**In Situ Fabrication and Repair**

*In Situ* Fabrication and Repair develops technologies for life support system maintenance and integrated habitat radiation shielding fabrication with a focus on contingency response and maximization of *in situ* resource utilization to reduce launch mass and volume. The manufacture or repair of components during a mission is essential to human exploration and development of space. Fabrication and repair beyond low Earth orbit is required to reduce resource requirements, spare parts inventory, and to enhance mission security. Proposals are sought in the technical themes listed below:

- Application of Free Form Fabrication (FFF) methods to low gravity (3/8 and 1/6 g level) manufacturing of near net shape products and spare parts from *in situ* derived resources or provisional feedstock;
- Processes for extracting *in situ* resources into raw materials and feedstock for use with rapid prototyping technology;
- Extension of fused deposition methods to the use of binderless metal wire feed stock;
- Adaptation of ultrasonic consolidation methods to use narrow ribbon metal feedstock to reduce subsequent machining operations and waste;
- Novel and innovative *in situ* repair methods such as but not limited to: welding, composite repair, and self healing materials;
- Development of highly automated habitat construction methods that incorporates *in situ* materials on surface or primary structure may use *in situ* construction;
- Development of dust mitigation techniques applicable to planetary habitat construction;
- Integration of radiation shielding materials into habitat construction methods; and
- Innovative approaches for recycling of materials for secondary uses.

**X12.04 Advanced Environment Monitoring and Control**

*Lead Center:* JPL  
*Participating Center(s):* GRC, JSC

This subtopic addresses monitoring and control technologies, which support the operation of an Advanced Life Support (ALS) system for future long duration space missions. There are two application areas: Acoustics Monitoring and Environmental Controls.

**Acoustics Monitoring Section**
The objective is a proof-of-concept acoustic sensor system consisting of fixed and crew-worn transducers. At least ten fixed transducers shall be distributed in a habitable volume of at least 2x2x6m. The goal for the fixed microphones is to provide sound pressure level measurements with Type I measurement accuracy over the Octave Band frequency range from 63 Hz through 20 kHz. The system shall be capable of measuring 1/3 Octave Band, Octave Band, and Narrow Band sound pressure levels averaged over a specified interval with user defined data acquisition parameters. The fixed microphones shall also operate as an acoustic dosimeter with Type III accuracy and shall measure and log the maximum, A-weighted, Overall Sound Pressure Level every 30 seconds for at least 24 hours. The system shall also detect Hazard Levels of 85+ dBA and generate an alarm. The crew-worn transducer, clipped to a shirt collar, shall operate as a Type III acoustic dosimeter and shall measure and log the maximum, A-weighted, Overall Sound Pressure Level every 30 seconds for at least 24 hours. The size and mass of the device shall be comparable to COTS dosimeters. All system measurements shall be carried out remotely and the data managed by software. The system shall be demonstrated in a mock-up, and calibrations and comparisons made with appropriate instruments and methods.

Environmental Controls

Advanced Environmental Controls - the development of advanced control system technologies is necessary for the integrated operation of environmental systems for future long-duration human space missions. The interdependence of advanced environmental processing systems requires a non-avionics requirements process that allows design for controllability. This year particular emphasis is placed on the following:

- Control strategies for closed-loop systems - closed loop and biological systems have different constraints and control paradigms than conventional processes. There is a need for new control algorithms, analyses, design methodologies, strategies, and techniques to provide this capability;

- Ontologies for integrated operations - human exploration missions involve hundreds of systems developed by dozens of organizations. To develop software that can integrate across these systems and integrate with operations requires the use of common terminology across multiple disciplines. A common ontology must be developed to enable the integration of control of advanced life support systems; and

- Development and integration of autonomous system and inter-system control with crew and ground operations - there is a need for tools, architectures, and technologies that can support the integration of operations between crew, ground operators, ground applications, and on-board applications.

X12.05 Advanced Life Support: Food Provisioning and Biomass

Lead Center: JSC

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

Exploration missions beyond low Earth orbit greatly limit allowable consumables and require development of innovative low maintenance, reconfigurable, reusable, or self-sufficient food production. Advancements are necessary to develop a combination of extended duration shelf life stored foods augmented with fresh foods grown within the spacecraft. Crop systems, in addition to producing fresh vegetables, storage roots, grains and legumes may contribute to air revitalization and utilize wastes from water recovery and waste management systems.
Crop Systems

The production of biomass (in the form of edible food crops) in closed or nearly closed environments is essential for the future of long-term planetary exploration and human settlement in lunar and Mars base applications. These technologies will lead not only to food production but also to the reclamation of water, purification of air, and recovery of inedible plant resources in the comprehensive exploration of interplanetary regions. Areas in which innovations are solicited include:

- Crop lighting, such as LED, solar collectors and innovative technologies. Lighting transmission and distribution systems, luminaries, fiber optics, water jackets, and other heat removal technologies are also areas of interest;

- Water and nutrient management systems such as hydroponics and/or solid substrates for food production and separation of nutrients from waste streams are solicited. In this area, regenerable media for seed germination plant support are also of interest as is separation and recovery of usable minerals from wastewater and solid waste products for use as a source of mineral nutrients. Consideration should be given for systems operation in microgravity and hypogravity (1/6 g on Moon, 3/8 g on Mars) environments; and

- Other areas of interest: crop mechanization and automation, facility or system sanitation, crop health measurement, flight equipment support, structures and environmental monitoring and control technologies that are specific to crop systems (e.g., ethylene detection and removal, sensors for root zone oxygen and water content, etc.).

Food Provisioning

- Safe, nutritious, acceptable, and varied shelf-stable foods with a shelf life of 3 to 5 years will be required to support the crew during future exploration missions to the Moon or Mars. Shelf-life extension may be attained through food preservation methods and/or packaging. Packaging materials must provide sufficient oxygen and water barrier properties to maintain shelf life. Food packaging technologies are needed that minimize a potentially significant trash management problem by using packaging with less mass and volume and/or by using packaging that is biodegradable, recyclable, or reusable;

- Processing crops or bulk ingredients into edible food ingredients or table-ready products will be necessary to provide a self-sustaining food system for an exploration mission. Equipment that is highly reliable, safe, automated, and minimizes crew time, power, water, mass, and volume will be required. Equipment for processing raw materials must be suitable for use in hypogravity (e.g., 1/6g on Moon, 3/8g on Mars) and in hermetically sealed habitats;

- Food preparation systems will be required to heat and rehydrate the shelf stable food items and to prepare meals from the processed and re-supplied items. Technologies to support on-orbit crew meal storage, preparation, dining activities, and trash dispensing are being sought; and

- Food quality and safety are essential components in the maintenance of crew health and well being. Efforts should be focused on control of food spoilage and food quality throughout the entire shelf life of the food. Effects of radiation on crop functionality and the stored food system quality are also needed.
X12.06 Habitation Systems

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

Habitation Systems

Habitation systems for future crewed micro-gravity transits, reduced gravity planetary lunar or Martian surfaces, and long duration, deep-space environments are requested. Products can include basic research, system analysis, mockup evaluation, functionality demonstrations/tests, and actual prototype hardware. Exploration missions away from low Earth orbit greatly limit allowable consumables and require development of innovative low maintenance, re-configurable, and reusable systems. Minimal volume configurations (or dual use) during non-use mission phases are highly desirable.

Habitation systems should consider the following broad themes: re-configurable crew volumes for multi-gravity environments (micro and reduced gravity), multi-use work stations, multi-gravity translation strategies, crew radiation exposure mitigation, physically and psychologically ergonomic personal volumes, automated deployment, quiescent operations between missions, multi-purpose stowage systems for food/trash, advanced hygiene systems, and automated housekeeping/self-repairing habitat surfaces, durability, commonality of hardware/systems, and low total life-cycle costs. Specific areas in which advanced habitability system innovations are solicited include:

**Wardroom Systems:** Erectable or inflatable systems that support crew dinning, conference, external viewing (windows), illumination, and relaxation activities. Includes off-nominal uses (emergency medical or repair) while maintaining hygienic conditions.

**Galley Systems:** Systems requiring minimal crew preparation (heating, cooling, and rehydration) for food heating and accurate water dispensing. Specific areas include systems that allow individual crew meal flexibility and high-energy efficiency.

**Crew Hygiene Systems:** Low maintenance/self-cleaning fecal, urine, menstrual, emesis, hand/body wash, and grooming systems. Specific areas include non-foaming separators and no-rinse/non-alcohol hygiene products. Toilet systems should consider air, liquid, vacuum, and low-gravity transport methods. Collected waste should be prepared for recovery or long-term stabilization. Integrated hygiene systems should provide, acoustic and odor isolated private crew volumes compatible with multi-gravity interfaces.

**Crew Accommodation Systems:** Reconfigurable, deployable, or inflatable integrated crew accommodations that provide visual and acoustical isolated crew volumes for sleeping, audiovisual communication/entertainment, personal stowage, quiet ventilation/thermal control, and radiation exposure reduction/safe-haven.

**Clothing Systems:** Low mass reusable or long usage clothing options that meet flammability, out gassing, and crew comfort requirements. Used clothing cleaning/drying systems with low-water usage and non-toxic detergents/enzymes compatible with biological water reclamation systems or non-water cleaning methods.
Stowage Systems: Interior/exterior stowage systems for partial gravity environments that maximize usable volume and include contents identification and inventory control systems. Long-term external stowage for biological or other wastes on a planetary surface that safe and consistent with planetary protection policies.

X12.07 Advanced Life Support: Water and Waste Processing

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

Regenerative closed-loop life support systems will be essential to enable human planetary exploration as outlined in the Vision for Space Exploration. These future systems must provide additional mass balance closure to further reduce logistics requirements and to promote self-sufficiency. Recovery of useful resources from liquid and solid wastes will be essential. Requirements include safe operability in micro- and partial-gravity, ambient and reduced-pressure environments, high reliability, regeneration and minimal use of expendables, ease of maintenance, and low-system volume, mass and power. Proposals should explicitly describe how the work is expected to improve power, volume, mass, logistics, crew time, safety and/or reliability, giving comparisons to existing state-of-the art technologies. Additional documentation and information can be found at http://advlifesupport.jsc.nasa.gov, including the expected composition of solid wastes and wastewater, which can be found within the "Baseline Values and Assumptions Document".

Water Reclamation

Efficient, direct treatment of wastewater and product water consisting of urine, brines, wash water, humidity condensate, and or product water derived from in situ planetary resources, to produce potable and hygiene water supplies. Technologies that contribute to closing the water loop will be given higher priority. Areas of emphasis include:

- Novel methods of process design and integration to minimize trace contaminant carryover from the cabin atmosphere leading to reduced logistics needs;
- Physicochemical methods for primary wastewater treatment to reduce total organic carbon from 1000 mg/L to less than 50 mg/L and/or total dissolved solids from 1000 mg/L to less than 100 mg/L;
- Post-treatment methods to reduce total organic carbon from 100 mg/L to less than 0.25 mg/L in the presence of 50 mg/L bicarbonate ions, 25 mg/L ammonium ions and 25 ppm other inorganic ions;
- Methods for the phase separation of solids, gases, and liquids in a microgravity environment that are insensitive to fouling mechanisms;
- Methods for the recovery of water from brine solutions;
- Methods to eliminate or manage solids precipitation in wastewater lines;
- Disinfection technologies for potable water storage and point-of-use. Residual disinfectants for potable water that is compatible with processing systems including biological treatment; and
• Techniques to minimize or eliminate biofilm and microbial contamination from potable water and water treatment systems, including components such as pipes, tanks, flow meters, check valves, regulators, etc.

Solid Waste Management

Wastes (trash, food packaging, feces, biomass, paper, tape, filters, water brines, clothing, hygiene wipes, etc.) must be managed to protect crew health, safety, and quality of life, to avoid harmful contamination of planetary surfaces (Moon, Earth, and Mars), and to recover useful resources. Treatment methods can include both oxidative and non-oxidative approaches. Areas of emphasis include:

• Volume reduction of wet and dry solid wastes;
• Small and compact fecal collection and/or treatment systems;
• Water recovery from wet wastes (including human fecal wastes, food packaging, brines, etc.);
• Stabilization, sterilization, and/or microbial control technologies to minimize or eliminate biological hazards (to the crew, to Mars, to Earth) associated with waste;
• Mineralization of wastes (especially fecal) to ash and simple gaseous compounds (e.g. CO$_2$, CH$_4$);
• Containment of solid wastes onboard the spacecraft that incorporates odor abatement technology;
• Containment devices or systems, with low volume and mass, that can maintain isolation of disposed waste on planetary surfaces (such as Mars); and
• Microgravity-compatible technologies for the containment and jettison of solid wastes in space.

Component Technologies

Energy-efficient, low-mass, low-noise, low-vibration or vibration isolating, fail-safe, and reliable components for handling fluids, slurries, biomass, particulates, and solids applicable to spacecraft wastewater treatment and solid waste management, including particle size reduction technologies (0.2 cm to 100 microns), actuators, pumps, conveyors, tubing, ducts, bins, fittings, tanks, couplings, quick disconnects, and valves that operate under varied levels of gravity, pressure, and vacuum.