



NASA SBIR 2017 Phase I Solicitation

Human Exploration and Operations

H1.01 Mars Atmosphere Acquisition, Separation, and Conditioning for ISRU

Lead Center: KSC

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

Technology Area: TA15 Aeronautics

Innovative technologies and approaches are sought related to ISRU processes associated with collecting, separating, pressurizing, and processing gases collected from the Mars atmosphere. State of the art (SOA) technologies for these ISRU processes either do not exist, are too small of scale, or are too complex, heavy, inefficient, or consume too much power. Proposals must consider and address operating life issues for Mars surface applications that can last for up to 480 days of continuous (day/night) operation. All proposals need to identify the State of the Art of applicable technologies and processes. Hardware to be delivered at the conclusion of Phase II will be required to operate under Mars surface pressure, atmosphere constituent, and temperature conditions. Therefore, thermal management during operation of the proposed technology will also need to be specified in the Phase I proposal. Requirements and specifications for Mars surface conditions and soil properties can be found in the ISRU Topic Description. Phase I proposals for innovative technologies and processes must include the design and test of critical attributes or high risk areas associated with the proposed technology or process. Proposals will be evaluated on mass, power, complexity, and the ability to achieve hardware specifications below.

Technologies are sought for collection and compression of Mars atmosphere gases for subsequent processing into oxygen and possibly fuel. Based on redundancy and production margin assumptions (40% of total production rate), carbon dioxide in the Mars atmosphere must be acquired and compressed to a minimum of 103.4 KPa (15 psi) pressure and up to a desired 517.1 KPa (75 psi) at a rate of 0.6 kg/hr for oxygen and fuel production and 2.7 kg/hr for oxygen production alone. Multiple units are allowed, but should be justified based on overall mass, power, thermal, and/or operation duration requirements. Understanding the change in mass, power, volume, and complexity as a function of outlet pressure is also an important factor in selection. Since carbon dioxide is the main gas of interest, techniques and technologies that separate the carbon dioxide from the other gases in the Mars atmosphere before, during, or after compression are considered beneficial in the selection process. Proposers should consider but not be limited to past work on Mars atmosphere collection, separation, and compression technologies such as carbon dioxide freezing, rapid cycle adsorption pumps, and mechanical compressors. For concepts that separate carbon dioxide from other Mars gases at Mars atmosphere pressures, proposers must include an active flow device to ensure the remaining gases do not prevent further separation and collection of the carbon dioxide. Proposals should consider the impact on atmosphere flow to overcome flow resistance due to filtration devices that will need to be placed at the inlet. Power needed for the proposed technology operation should be differentiated between electrical and thermal, and consideration should be given on how the thermal management system and the Mars environment could minimize the need for electrical-to-thermal energy conversion. Since downstream carbon dioxide processing technologies are performed at a minimum of 400°C, cooling of the compressed gas to below this temperature is not required for downstream operations.

Technologies are sought for separation of nitrogen and argon from the Mars atmosphere during or after Mars carbon dioxide separation and compression. Mars atmosphere gas flow rates, pressures, and temperatures are as specified above for Mars atmosphere/carbon dioxide compression. Power needed for the proposed technology

operation should be differentiated between electrical and thermal, and consideration should be given on how the thermal management system and the Mars environment could minimize the need for electrical-to-thermal energy conversion. All proposals need to identify the State of the Art of applicable technologies and processes. At this time, it is not known whether the nitrogen and argon will be stored as a pressurized gas or a cryogenic liquid, so it should be noted which storage option is more beneficial for the proposed technology.

H1.02 Mars Soil Acquisition and Processing for In Situ Water

Lead Center: KSC

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

Technology Area: TA15 Aeronautics

Innovative technologies and approaches are sought related to ISRU processes associated with excavating and processing soils on Mars to remove, collect, and clean in-situ water for subsequent use in oxygen and fuel production or delivery to the habitat for life support and radiation shielding usage. Proposals must consider and address operating life issues for Mars surface applications that can last for up to 480 days of continuous (day/night) operation. All proposals need to identify the State of the Art of applicable technologies and processes. Hardware to be delivered at the conclusion of Phase II will be required to operate under Mars surface pressure, atmosphere constituent, and temperature conditions. Therefore, thermal management during operation of the proposed technology will also need to be specified in the Phase I proposal. Requirements and specifications for Mars surface conditions and soil properties can be found in the ISRU Topic Description. Phase I proposals for innovative technologies and processes must include the design and test of critical attributes or high risk areas associated with the proposed technology or process. Proposals will be evaluated on mass, power, complexity, and the ability to achieve hardware specifications below.

Technologies are sought for excavation and transfer of hydrated and icy Mars soils. For hydrated soils, the excavated soil can be delivered to a centralized soil processing plant or processed on the excavation rover itself.

The amount of water content in the hydrated Mars soil can vary from as low as between 1.5 and 2% on the surface at almost all locations on Mars to above 10% depending on the location and mineral. The concentration of water may also increase below a desiccated layer of soil at the surface, so technologies for excavation and transfer need to consider soil properties and water content as a function of depth and minerals and should be applicable to a range of landing sites where icy soils do not exist. The need to excavate down to at least 0.5 meters should be considered. The amount of water content in icy Mars soil can vary greatly as a function of depth and latitude.

Based on analysis of Mars orbital data, proposers should assume a minimum of 10% by weight of water/ice up to 90%. Due to human landing and ascent considerations, Mars water based resources should be constrained between +/- 50 deg. latitude. Based on the potential high water content by mass in icy soils, it is expected that icy soil excavated will be either processed in-situ or on the excavation rover itself. Proposers should also assume that up to 0.5 m of soil may exist above icy soils and that excavation down to at least 1 meter is required. Proposers should note the impact on concept mass, power, and complexity for excavation down to 3 meters. Proposals should consider water loss due to hardware temperature, material agitation, and duration of soil exposure to the environment before transfer to soil processing systems. Note requirements for the mobility platform associated with hydrated soil excavation and transfer will be included in the H8 Robotic Systems Topic.

Technologies are sought for processing of hydrated and icy Mars soils to extract water. Soil processing for water extraction needs to consider the range of water content in Mars soils and water extraction rates defined below.

Proposals for soil processing also need to define potential water loss due to valve/enclosure sealing for closed soil reactors or losses due to exposure to the surrounding environment or soil for open soil reactors. Proposals need to consider what other volatiles and contaminants are released due to soil processing/heating. Proposed solutions that perform in a non-continuous fashion are acceptable, as long as they achieve the same total production quantities on a daily or weekly basis. Understanding the change in mass, power, volume, complexity, and contaminant release as a function of water content in the soil, heating temperature, and heating method are important factors in selection. Power needed for the proposed technology operation should be differentiated between electrical and thermal, and consideration should be given on how the thermal management system and the Mars environment could minimize the need for electrical-to-thermal energy conversion.

Based on past and recent human Mars exploration mission studies, to meet ascent propellant production rates with margin, approximately 1.6 kg/hr of water must be collected and cleaned for subsequent processing. At this time, 3 soil processing units for extraction of water from Mars soils is baselined for human Mars missions. Multiple excavation and processing units are allowed, but should be justified based on overall mass, power, thermal, and/or operation duration requirements. Proposers can submit combined excavation and soil processing technologies.

Technologies are sought for the separation, collection, and cleaning of water released from soil processing of hydrated and icy Mars soils. Separation of contaminants from water can be performed in the vapor phase during release or after collection, but technologies need to be regenerative. Separate and multiple technologies for collection, separation, and cleanup can be proposed for any one or all of the functions (separation, collection, and cleaning) All must operate in conjunction with the soil processing reactors for the soil/water production rates, contaminants, and mission durations specified above. It is encouraged that proposers for soil processing of Mars soils also consider including technologies requested below for water separation, collection, and cleanup since the two technology needs can be highly interconnected. Multiple units are allowed, but should be justified based on overall mass, power, thermal, and/or operation duration requirements. Water will need to be clean enough to be fed to a proton exchange membrane (PEM) water electrolysis unit.

Proposals for ISRU hardware for Mars material excavation, transfer, and processing for the extraction of water need to consider physical, mineral, and volatile characteristics and variations for hydrated and icy soils, as well as the types of volatiles and contaminants released during heating. Information on potential Mars water-based resources and mineral properties can be found in the recent Mars Water In-Situ resources Utilizations (ISRU) Planning (M-WIP) Study posted at https://mepag.jpl.nasa.gov/reports/Mars_Water_ISRU_Study.pdf [1], and information on what volatiles and contaminants are released due to soil processing/heating can be found in "Volatile, Isotope, and Organic Analysis of Martian Fines with the Mars Curiosity Rover" by Leshin et al., For example, besides water, varying amounts of CH₃Cl, HCN, SO₂, HCl, and H₂S were released as a function of temperature. Further research and evaluation of mineral properties, constituents, and potential contaminants based on different hydrated and icy soil minerals is highly recommended and should be addressed in proposals.

H2.01 Lunar Resources

Lead Center: KSC

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

Technology Area: TA15 Aeronautics

Whereas the Moon was once thought to be dry, more recent discoveries indicate that there are a variety of resources that exist on the Moon in an embedded or frozen state in the regolith. When acquired and exposed to higher temperatures and vacuum, these resources will change state into the vapor phase and are known as volatiles. Examples of this are polar water ice or hydrogen and helium 3 embedded in the regolith grains by the sun.

Lunar volatiles are a meaningful first focus area for a space exploration strategy because:

- Use of local space resources, including lunar volatiles, for propellant, life support, etc. will improve the sustainability of human space exploration.
- Technologies and methods for accessing lunar volatiles are relevant to potential future Mars resource utilization.

An ancillary benefit is that the volatiles are of great interest to the science community and provide clues to help understand the solar wind, comets, and the history of the inner solar system.

Recent data from NASA's Lunar CRater Observation and Sensing Satellite (LCROSS), and Lunar Reconnaissance Orbiter (LRO) missions indicate that as much as 20% of the material kicked up by the LCROSS impact was volatiles, including water, methane, ammonia, hydrogen gas, carbon dioxide and carbon monoxide. The instruments also discovered relatively large amounts of light metals such as sodium, mercury and possibly even

silver.

Small payloads up to 2 kg in mass are needed to characterize and map the lunar volatiles resources so that they can be included in a future lunar ISRU strategy. This payload may be delivered to the Moon on a small commercial lunar lander and could be stationary on the lander, mobile on a mobility device, or it may itself be mobile and/or deployable. Impactors and other devices that are used or released in lunar orbit are not within the scope of this solicitation.

The entire surface of the Moon is covered with fragmental and unconsolidated crushed rock material known as regolith, which was formed over billions of years of high-energy impacts by meteorites, comets and other solar system debris. Estimates are that this regolith covers the top 8-10 meters of the Moon's surface. Regolith represents a significant resource due to the bound oxygen that is present in some minerals; metals such as aluminum, iron and magnesium that can be extracted to make parts; and its use as a bulk construction aggregate material for civil engineering structures or radiation shielding. In addition other engineering parameters such as trafficability must be known before effective exploration can take place.

Silicate minerals, composed dominantly of silicon and oxygen, are the most abundant constituents, making up over 90% by volume of most lunar rocks. The most common silicate minerals are pyroxene, $(Ca,Fe,Mg)_2Si_2O_6$; plagioclase feldspar, $(Ca,Na)(Al,Si)_4O_8$; and olivine, $(Mg,Fe)_2SiO_4$. Oxide minerals, composed chiefly of metals and oxygen, are next in abundance after silicate minerals. They are particularly concentrated in the mare basalts, and they may make up as much as 20% by volume of these rocks. The most abundant oxide mineral is ilmenite, $(Fe,Mg)TiO_3$, a black, opaque mineral that reflects the high TiO_2 contents of many mare basalts. The second most abundant oxide mineral, spinel, has a widely varying composition and actually consists of a complex series of solid solutions. Members of this series include: chromite, $FeCr_2O_4$; ulvöspinel, Fe_2TiO_4 ; hercynite, $FeAl_2O_4$; and spinel (sensu stricto), $MgAl_2O_4$. Another oxide phase, which is only abundant in titanium-rich lunar basalts, is armalcolite, $(Fe,Mg)Ti_2O_5$.

Small payloads up to 2 kg in mass are needed to characterize and map the mineral resources so that they can be included in a future lunar ISRU strategy. This payload may be delivered to the Moon on a small commercial lunar lander and could be stationary on the lander, mobile on a mobility device, or it may itself be mobile and/or deployable. Impactors and other devices that are used or released in lunar orbit are not within the scope of this solicitation.

The relevant lunar Strategic Knowledge Gaps (SKG's) for this subtopic are listed below:

I-C. Regolith 2: Quality/ quantity/distribution/form of H species and other volatiles in mare and highlands regolith (requires robotic precursor missions).

Robotic in-situ measurements of volatiles and organics on the lunar surface and eventual sample return of "pristine" samples. Enables prospecting for lunar resources and ISRU. Feeds forward to NEA-Mars. Relevant to Planetary Science Decadal survey.

I-D-1. Composition/quantity/distribution/form of water/H species and other volatiles associated with lunar cold traps.

Required "ground truth" in-situ measurement within permanently shadowed lunar craters or other sites identified using LRO data. Technology development required for operating in extreme environments. Enables prospecting of lunar resources and ISRU. Relevant to Planetary Science Decadal survey.

I-D-3 Subsection c: Geotechnical characteristics of cold traps

Landed missions to understand regolith densities with depth, cohesiveness, grain sizes, slopes, blockiness, association and effects of entrained volatiles.

I-D-7 Subsection g: Concentration of water and other volatiles species with depth 1-2 m scales

Polar cold traps are likely less than ~2 Ga, so only the upper 2-3 m of regolith are likely to be volatile-rich.

I-D-9 Subsection I: mineralogical, elemental, molecular, isotopic make up of volatiles

Water and other exotic volatile species are present; must know species and concentrations.

I-D-10 Subsection j: Physical nature of volatile species (e.g., pure concentrations, inter-granular, globular)

Range of occurrences of volatiles; pure deposits (radar), mixtures of ice/dirt (LCROSS), H₂-rich soils (neutron).

I-E. Composition/volume/distribution/form of pyroclastic/dark mantle deposits and characteristics of associated volatiles.

Required robotic exploration of deposits and sample return. Enables prospecting for lunar resources and ISRU. Relevant to Planetary Science Decadal survey.

I-G. Lunar ISRU production efficiency

Measure the actual efficiency of ISRU processes in the lunar environment. Highly dependent on location & nature of the input material. Process at high temperature to test techniques for extracting metals (e.g., Fe, Al) from regolith. This is enhancing long duration activity on the Moon and potentially beyond LEO.

III-C-2 Lunar surface trafficability – in-situ measurements

Characterization of geotechnical properties and hardware performance during regolith interactions on lunar surface.

III-D-1 Lunar dust remediation

Test conceptual mitigation strategies for hardware interactions with lunar fines, such as hardware encapsulation and microwave sintering of lunar regolith to reduce dust prevalence.

III-D-2 Regolith adhesion to human systems and associated mechanical degradation

In-situ grain charging and attractive forces, and cohesive forces under appropriate plasma conditions to account for electrical dissipation. Analysis of wear on joints and bearings, especially on space suits.

III-D-4 Descent / ascent engine blast ejecta velocity, departure angle and entrainment mechanism

Measurement of actual landing conditions on the lunar surface and in-situ measurements of witness plates and other instrumentation.

III-G Test radiation shielding technologies

Protecting human crews beyond the magnetic fields of the Earth from space radiation is a critical. In addition to Earth-based testing, could be further accomplished during lunar robotic missions.

All proposals need to identify the state-of-the-art of applicable technologies and processes. Hardware to be delivered at the conclusion of Phase II will be required to operate under lunar equivalent vacuum and temperature conditions, so thermal management during operation of the proposed technology will need to be specified in the Phase I proposal. Phase I proposals for innovative technologies and processes must include the design and test of critical attributes or high risk areas associated with the proposed payload technology or process to achieve the objectives of the Phase II delivered payload hardware. Proposals will be evaluated on mass, power, volume, and complexity. At the end of Phase II, the payload hardware should be capable of being ready to be flown in space within one year, with additional testing taking place during that year.

H3.01 Habitat Outfitting

Lead Center: LaRC

Participating Center(s): LaRC, MSFC

Technology Area: TA15 Aeronautics

Early definition of habitat outfitting for a vehicle is important because it will influence the overall vehicle architecture and layout. Vehicle outfitting provides the equipment necessary for the crew to perform mission tasks as well as provide them a comfortable, safe and livable habitable volume. Effective and efficient human-system interfaces and interactions are critical and should be considered as an integral part of this effort and demonstrated. Integrated outfitting is often a distributed hardware set that operates in unison or independently to perform a habitation function. Outfitting includes secondary structure (e.g., floors and walls), crew structures (e.g., crew quarters, radiation storm shelters) as well as the distribution of outfitting items (e.g., crew personal items) and utilities (e.g., avionics, ventilation, lighting) to sustain the crew during a mission. Habitat features and capabilities that allow autonomous monitoring or robotic interaction of items to enable habitat outfitting (e.g., high accuracy localization systems or mounting approaches) prior to crew arrival or after crew departure are also of interest. Concepts that can reuse launch support structure for outfitting are advantageous if it can be done without significant or with no crew interaction. Concepts should be capable of outfitting habitats with diameters of 3-8 meters and lengths of 4-10 meters. Habitat atmospheric pressure may vary from 0-1 atm for launch and 0.5-1 atm during crew usage. The following habitat outfitting specific habitat outfitting areas are requested.

Interior Structures

Deployable, inflatable, 3D printable from processed launch packaging, reusable secondary structure, and crew structures for outfitting the vehicle habitable volume. Concepts should not be constrained to the ISS rack geometry or attachments. Concepts must be volumetrically and mass efficient, and have a metric less than 25 kg/m³ for an enclosed volume. Proposed technologies that provide a surface area (e.g., floor) or utility (e.g., plumbing) should define a normalized metric (e.g., kg/ m² or kg/m/plumbing run). The selection of non-metallic materials is very important in a spacecraft and will need to meet off-gassing and flammability requirements. Concepts should also have surfaces that either resist the accumulation of dust and dander or are readily cleanable. Structures should include appropriate factors of safety and assumptions should be included in the proposal. Concepts should be capable of sustaining launch loads (which can be in a stowed configuration) of 6g axial and 2g lateral. Crew structures must be capable of withstanding crew kick loads of 125 lbs when fully deployed. Concepts that are also applicable to habitat and life support equipment mounting are desirable.

Autonomous Outfitting Capabilities

Development of features and systems are required that can enable habitat structures, crew equipment, logistics, and trash to be interacted with autonomously with no direct crew involvement. Requested capabilities are rapid identification, localization in 3D space (including pose or orientation), and interaction with items. The intent is to allow robotic interaction with items prior to crew arrival and after crew departure. This may include deployment of interior structures, maintenance of the habitat, or monitoring of the habitat including health and status of items. Systems may also enable or facilitate human-machine interactions by providing greater situational awareness. Development of the robotic elements themselves are excluded from this subtopic. Mechanisms, electro-mechanical, and software applications and algorithms that enable autonomous outfitting and maintenance capability are requested. Dependencies on batteries are highly undesirable. Concepts that provide significant automated vehicle health monitoring should consider submission to the 'Autonomous Systems' topic.

Additional information on NASA needs can be found in 2015 NASA Technology Roadmaps including but not limited to sections TA06 6.1.4.2 and TA07 7.2.1.3, 7.2.1.7, 7.2.1.9, 7.4.1.1, and 7.4.1.3. These roadmaps are available at the following link: (<http://www.nasa.gov/offices/oct/home/roadmaps/index.html> [2]). An example of an inflatable habitat can be found at (<http://www.nasa.gov/content/bigelow-expandable-activity-module> [3]). Examples of conference papers on habitat outfitting and crew structures (TransHab, ISS Crew Quarters, Waste and Hygiene Compartments, Multipurpose Cargo Bags) can be found at the Internal Conference on Environmental Systems and the AIAA Space Conference websites. Human Research Program (HRP)-related research on Habitable Volume and Habitat Design can be found at the following link: <https://humanresearchroadmap.nasa.gov/risks/risk.aspx?i=162> [4]. Other related risks can be found at the following link: <https://humanresearchroadmap.nasa.gov/explore/> [5].

Phase I Deliverables - Detailed analysis, proof of concept test data, and predicted performance (mass, volume, positioning accuracy). Deliverables should clearly describe and predict how performance of targeted habitat vehicles are enhanced, improved, or integrated. Evaluation of concepts for human-system performance should be predicted.

Phase II Deliverables - Delivery of technologically mature components/subsystems that demonstrate deployments and/or automated features are required. Prototypes must be full scale unless physical verification in 1-g is not possible. Consideration of recovery from deployment failures should be included. Ability to sustain launch loads and on-orbit crew loads needs to be demonstrated. Evaluation of concepts for human-system performance should be validated with modeling as a minimum and demonstrated where possible.

H3.02 Environmental Monitoring for Spacecraft Cabins

Lead Center: LaRC

Participating Center(s): ARC, JSC, MSFC

Technology Area: TA15 Aeronautics

Environmental Monitoring is comprised of the following four monitoring disciplines: air, water, microbial and acoustics. ISS has employed a wide variety of analytical instruments to deal with critical items. These functional needs are required to address identified risks to crew health during Exploration-class missions. The current approach onboard ISS, if any, will serve as the logical starting point to meeting the functional needs. However, the following limitations were found common to all the current approaches on-board ISS for any missions beyond low-Earth orbit (LEO): reliance on return sample and ground analysis, require too much crew time, constraints on size, mass, and power, lack of portability, and insufficient calibration life. Hence a concerted effort is underway to address these gaps and mature those solutions to ground and flight technology demonstrations. Technologies that show improvements in miniaturization, reliability, life-time, self-calibration, and reduction of expendables are of interest.

In-Line Silver Monitoring Technologies

NASA is interested in sensing technologies for the in-line measurement of ionic silver in spacecraft potable water systems. Overall, the sensing technology should offer small, robust, lightweight, low-power, compatible design solutions capable of stable, continuous, and autonomous measurements of silver for extended periods of time. Sensors of particular interest would provide: Continuous in-line measurement of ionic silver at concentrations between 0 and, at least, 1000 parts per billion (ppb); A minimum detection limit of 10 ppb or less; Measurement accuracies of at least 2.5% full scale (1000 ppb); Stable measurements in flows up to 0.5 L/min and pipe diameters up to $\frac{3}{4}$ inch; High sampling frequency, e.g., up to 1 measurement per minute; Stable calibration, greater than 3 years preferred; Minimal and/or no maintenance requirements; Operation at ambient temperature, system pressures up to 30 PSIG, and a solution pH between 4.5 - 9.0; A volumetric footprint less than 2000 cubic centimeters; Input/output signal(s) capable of interfacing with small embedded controllers, e.g., 4-20 mA or 0 – 5 V. In addition, the sensing technology should have a little to no impact on the overall volume, portability and concentration of silver being maintained within the spacecraft water system.

Sample Processing Module for the ISS Microbial Monitors

NASA continues to invest in the near- and mid-term development of highly-desirable systems and technologies that provide innovative ways to monitor microbial burden and enable to meet required cleanliness level of the closed habitat. To date, developing sample collection module and sample detection PCR systems such as RAZOR, Wet-lab 2 systems are planned for surface, water, and air. The sample collection and sample concentration modules are being developed but biomolecule (DNA, protein, etc.) processing and subsequent sample transfer modules that could deliver biological materials to the sample detection systems (PCR, microarray, sequencers, etc.) are not matured. More importantly, the future sample processing/transfer module should be compatible with existing NASA sample detection PCR systems. NASA is interested in an integrated sample collection/concentration/extraction system that could feed samples to conventional or molecular microbial monitoring techniques.

The scope of this solicitation is the sample processing and sample transfer systems. Furthermore, integration of sample collection, concentration steps and a sample delivery to the molecular instruments (such as PCR) as a single module is solicited.

Required technology characteristics include: 2-year shelf-life and functionality in microgravity and low pressure environment (~8 psi). Technologies that show improvements in miniaturization, reliability, life-time, self-calibration, and reduction of expendables are also of interest. The proposed integrated sample collection/concentration/extraction delivery system for molecular microbial monitoring detection should be capable of collecting all kinds of microorganisms as well as identifying “problematic” microbial species on-board ISS (ISS MORD: SSP 50260; <http://emits.sso.esa.int/emits-doc/ESTEC/AO6216-SoW-RD9.pdf> [6]). Existing PCR systems are: Biofire’s Razor (<http://biofiredefense.com/razorex/> [7]) and Cepheid’s Smart Cycler (<http://www.cepheid.com/us/cepheid-solutions/systems/smartycycler> [8]).

Hydrazine Measurement Technology

NASA currently has hydrazine measurement technology that is sensitive, selective, and reliable – but the time to make the measurement is relatively slow. It takes 15 minutes to collect and analyze a sample. This is operationally acceptable for the current operational environment, but future missions will likely need a hydrazine measurement capability that responds more quickly. The primary use of the Hydrazine Monitor is for measurements of spacecraft cabin atmosphere. NASA is especially interested in systems with the following performance parameters:

- Hydrazine lower detection limit of 1 ppm when measured in STP conditions.
- Ammonia / hydrazine selectivity ratio of 25:1 or better (e.g., background concentrations of 50ppm ammonia will measure as no more than 2 ppm hydrazine).
- Response time (T90) or 30 seconds or faster.
- Measurement range of 1 ppm to 1000 ppm.
- Instrument size smaller than 2500 cubic centimeters.

H3.03 Environmental Control and Life Support

Lead Center: LaRC

Participating Center(s): ARC, GRC, MSFC

Technology Area: TA15 Aeronautics

Spacecraft Cabin Carbon Dioxide Removal

NASA currently has CO₂ removal and capture systems that are compact and effective, but future missions may require CO₂ capture technology that control to lower levels, and operate with greater power efficiency. NASA is especially interested in systems with the following performance parameters:

- Removal rate of 4 kg/day.
- Operate in an environment with 1.5 mmHg ppCO₂.
- System size 0.3 cubic meters.
- System power use 500 watts of power.
- Effectively separate out water vapor (less than 100 ppm water vapor in the CO₂ product is desired).

Oxygen Separation from Air

NASA mission planners envision future mission scenarios that require oxygen separation from spacecraft cabin air. New technology developments show promise for reliable, low power performance. System safety, and the ability to easily verify oxygen product purity are especially important. Reliable operation without service or repair is key, but many R&D designs cannot report Mean Time Between Failure. If MTBF data is not available, an assessment of reliability should be provided. Although pressurization of product oxygen is not the intent of this call, future requirements for oxygen delivery pressure are variable, depending on mission scenario: some scenarios use ambient pressure (<5psig) oxygen, while other scenarios intend to store oxygen at pressures as high as 3600 psig.

NASA is interested in systems with the following performance parameters:

- Production rate: 15 slpm.
- Power use: ?450 W (30 Watts/liter).
- Sound level: <45 dB.
- System size: 0.03 cubic meters (200 cc/liter).

Carbon Repurposing

Several oxygen recovery technologies currently under consideration for future long-duration missions involve production of solid carbon. For technologies whose goal is to maximize oxygen recovery by producing this carbon, approximately 1 kg of solid carbon must be disposed of or repurposed daily for a crew of four. Repurposing this carbon will reduce logistical challenges associated with disposal and will ultimately result in materials or processes advantageous to long-duration missions.

The carbon product includes nanofibers, microfibers, and amorphous carbon. It may contain quantities of metals including, but not limited to iron, nickel, and cobalt. Venting or disposal of this carbon to space will present considerable logistical challenges and will result in large volumes of space debris. Disposal of this carbon on a planetary surface may result in concerns for Planetary Protection or science. NASA is seeking technology and/or processes that repurpose solid carbon and its contaminants and that result in useful products for transit, deep space, or planetary surface missions.

Filtration of Particulate Carbon and Hydrocarbons from Process Gas Streams

Oxygen recovery technology options almost universally result in particulates in the form of solid carbon or solid hydrocarbons. Mitigation for these particulates will be essential to the success and maintainability of these systems during long duration missions.

Techniques and methods leading to compact, regenerable methods for removing residual particulate matter generated from Environmental Control and Life Support (ECLS) system process equipment such as carbon formation reactors and methane plasma pyrolysis reactors is desirable for long-duration manned life support. Filtration performance approaching HEPA rating is desired for ultrafine particulate matter with minimal pressure drop. The gas filter should be capable of operating for hours at high particle loading rates and then employ techniques and methods to restore its capacity back to nearly 100% of its original clean state through in-place and autonomous regeneration or self-cleaning operation. The device must minimize crew exposure to accumulated particulate matter and enable easy particulate matter disposal or chemical repurposing.

Solid State Microwave Generator for Environmental Control and Life Support

Many possible future technologies for human spaceflight may utilize microwave energy, including plasma pyrolysis of methane, incineration and solid waste drying, and ovens for food heating. Traditional microwave generating systems have significant inefficiencies resulting in a high mass, high volume power system. Solid state microwave generators have the potential to limit the total mass and volume of a microwave power system. However, limited advancement has been achieved at power levels of 1kW and higher.

NASA is seeking solid state microwave generators with the following capabilities:

- Microwaves generated and controlled at 2.38-2.54GHz (nominally 2.45GHz).
- Maximum output power level capability of 1-5kW.
- Variable power output over entire range (0-max kW).
- Input power of 120VDC.
- Efficiency greater than or equal to 50%.
- Method of measuring/monitoring output power.
- Method of measuring/monitoring reflected power.

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- Method of dispersing/absorbing reflected power up to maximum output power.
 - Utilizes non-air cooling method (e.g., liquid cooling).

H3.04 Logistics Reduction

Lead Center: LaRC

Participating Center(s): ARC, LaRC

Technology Area: TA15 Aeronautics

All human space missions, regardless of destination, require significant logistical mass and volume that is directly proportional to mission duration. As our exploration missions increase in distance and duration, logistics reduction becomes even more important since they may need to be pre-deployed 2-5 years before a crew arrives. Reducing the initial mass and volume of supplies, or reusing items that have been launched, will be very valuable. Logistics unique to a spacecraft system (i.e., life support and propulsion) are not addressed by this subtopic and are not requested. Three of the largest logistics consumables are the logistical packaging (e.g., cargo bags, foam, retention straps, and cargo support pallets), clothing, and food. Approximately 1,000 cargo bags (0.053 m³ each) may be required for a Mars mission's logistics. Cargo is typically packed in foam, placed in a bag, and strapped to the vehicle or a cargo pallet/structure in the vehicle. Clothing is currently disposed of on the Space Station when it becomes too dirty to wear because there is no way to clean it. Food nutritional content and quality decreases over time and depends on the specific nutrients, food matrix, food packaging, and storage environment. Food may need to be stored up to five years before consumption, and maintaining stable nutrition is a significant challenge. Reductions in food mass, nutrient studies, and nutrient generation are not requested as part of this subtopic. All proposals should consider maintainability as well as dormancy periods without crew.

Vehicle Level Cold/Alternate Atmosphere Food Storage

Innovative use of materials, insulation, and heat removal systems are requested. Standalone systems as well as innovative approaches integrated into portions of the vehicle structure and thermal loops are acceptable. One method of increasing food nutrient shelf-life is with cold stowage and/or alternate atmospheres (i.e., low oxygen composition). Stored food volumes of 2-8 m³, with average packaged food density of 250-500 kg/m³, may be required at temperature ranges of -80° to +20°C. Oxygen levels <21% and food compartment pressures less than one atmosphere are being studied for their effects. Ability to control the atmosphere and pressure in the cold stowage volume is beneficial but is not required of a submitted technology, nor is the full temperature range listed above required. Systems must be capable of surviving launch loads (6g axial and 2g lateral) when fully loaded and be capable of autonomous operation for up to five years in microgravity. Concepts must be volumetrically efficient, mass efficient, and highly reliable since loss of food quality can result in loss of crew performance. The advantages of proposed concepts compared to the ISS Refrigerator/Freezer Rack (RFR) and terrestrial high efficiency freezers must be described. The ISS RFR, which never flew but achieved temperatures of -22°C and +4°C in freezer and refrigerator modes, had a secondary mass penalty of 1.36 kg for every 1 kg of food due to cabinet, drawers, insulation, cooling system and rack masses. (NASA/TP-2015–218570) The goal is to lower this secondary mass penalty for cold stowage below 0.2 kg per 1 kg of food. For long term storage of food, drawers are not required. At the same time, the refrigeration and insulation systems should be efficient enough to run (at steady state) on less than 0.15 Watts per kg of food frozen at -22°C in a 23°C ambient.

Alternative Launch Packaging of Logistics and Cargo

Alternatives to the existing ISS use of Cargo Transfer Bags (CTBs), foam, straps, and cargo pallets is required. Cargo densities of 510 kg/m³ (single CTB capability) must be supported during launch acceleration of 6g axial and 2g lateral. Total packaging mass efficiencies of all required materials between the cargo and the vehicle pressure shell structure should be less than 0.3 kg packaging/kg of cargo. Concepts should be capable of scaling between logistics vehicles with diameters of 3-8 meters and lengths of 4-10 meters. Logistics vehicle atmospheric pressure may vary from 0-1 atm for launch and 0.5-1 atm during crew use.

Innovative Crew Clothing Systems to Extend Duration of Wear

Innovative systems that refresh crew clothing to extend the duration of wear are requested. Crew exercise clothing, for example, is currently discarded into the trash after 2-3 uses because there are no space laundry systems. The goal is to extend the duration of wear by 2-3 times or more for several types of garments. Systems must be capable of sanitizing/refreshing a small set of crew clothing that includes exercise t-shirts, exercise socks, exercise shorts, male and female undergarments, and male and female daily wear, such as crew polo shirts. The system should provide odor control while preserving the appearance, color and brightness, and the physical and mechanical properties of the fabrics, which include cotton, wool and modacrylic. Odor control can be through absorption, adsorption, denaturation, or neutralization of pH and odorous compounds, etc. Innovative use of technologies, such as ultraviolet light, microwaves, vacuum, ozone, steam, CO₂, charcoal filtration, minimal water, or other technologies will be considered. The crew clothing sanitizing/refreshing system must be capable of operating for a minimum of 3 years in microgravity with minimal consumables, crew time requirement and electrical power. Cleaning/washing agent should be limited to less than 10 grams of consumables per kg of crew clothing for each refresh. No water or extremely low water usage systems are preferred, but if water is used, water usage should be less than 200 grams per kg of clothing washed. No hazardous gases or particles can be released into the crew atmosphere during or after operation. Concepts must be volumetrically efficient, mass efficient, not adversely impact the closed loop life support systems, and be highly reliable. Cleaning/washing systems may be used during outbound transit to Mars, then be dormant for up to 18 months prior to the return trip to Earth. Controlling microbial activity and odor during this dormancy is important to habitat and crew health.

Additional information on NASA needs can be found in NASA Technology Roadmaps including but not limited to sections TA06 6.1.4.11 and TA07 7.2.1.9. These roadmaps are available at the following link: (<http://www.nasa.gov/offices/oct/home/roadmaps/index.html> [2]). Examples of conference papers on refrigeration technologies such as Merlin, and the ISS Refrigerator Freezer Rack can be found at the Internal Conference on Environmental Systems, and food storage issues are described in the Human Research Program Investigators Workshop. Specific references include: Winter, J., Zell, M., Hummelsberger, B., Hess, M. et al., "The Crew Refrigerator/Freezer Rack for the International Space Station," SAE Technical Paper 2001-01-2223 and http://www.nasa.gov/mission_pages/station/research/experiments/MERLIN.html [9]

Phase I Deliverables - Detailed analysis, proof of concept test data, and predicted performance (mass, volume, thermal performance). Deliverables should clearly describe and predict performance over the state of the art.

Phase II Deliverables - Delivery of technologically mature components/subsystems that demonstrate deployments and/or automated features are required. Prototypes should be full scale unless physical verification in 1-g is not possible. Ability to sustain launch loads and on-orbit crew loads needs to be demonstrated. A minimum of 2 months of cold stowage/alternate atmosphere performance should be demonstrated if relevant.

H4.01 Damage Tolerant Lightweight Pressure Structures

Lead Center: LaRC

Technology Area: TA15 Aeronautics

Damage to and the resultant leakage of the suit structure is a criticality 1 failure that could result in loss of mission or life. NASA is striving to build a robust suit structure that can withstand the wear and tear related to exploration of a planetary surface. A highly mobile exploration spacesuit must have lightweight and robust hard upper torso. Hard upper torsos are used on the current Extravehicular Mobility Unit systems and desirable for the future because they are robust structures that require little maintenance, they provide simple and robust interfaces with the portable life support system, and they create a consistent and well sized structure for the mobility joints.

On recent development of the Z-2 space suit, NASA evaluated the use of carbon fibers, fiberglass, and kevlar composite structures to push the state of the art for a complex geometry, lightweight, and damage tolerant hard upper torso structure. Development included evaluation of various lay-ups, material combinations, and polymer systems. The end product was a hybrid composite structure of carbon and fiber glass composite. The hybrid structure was able to withstand impact energies around 100J.

NASA is interested in developing an innovative, new structure that is even more robust to impact and can maintain a low leakage level or re-seal the pressure structure after impact or damage. Hybrid laminates, materials, and construction methods should be considered to optimize toughness and damage tolerance (strength and durability). Special consideration should be given to select materials and configurations which lend themselves to manufacturability to complex shapes and repair-ability. NASA has also investigated the use of thin films on pressure vessels to make a composite structure more robust to damage and leakage. Mechanical strength of the selected materials should be characterized in both the "pristine" and "damaged" (after impact) condition, including Tension, Compression, and Interlaminar shear.

Performance targets:

- No leakage after Low Velocity Impact (LVI) of 300J of energy using ASTM D-7136 impact test with 2" diameter steel impactor and impact velocities of less than 15 ft/s.
- Structure density of less than 1.7 g/cm³.
- Primary structure and sample thickness of 0.125" or less.

Reference:

Ross, A., Rhodes, R., Graziosi, D., Jones, B., Lee, R., Haque, B., and Gillespie Jr., J., "Z-2 Prototype Space Suit Development", ICES-2014-091, 44th International Conference on Environmental Systems, Tucson, AZ, July 2014.

H4.02 Small, Accurate Oxygen Compatible Gas Flow Meter for Suit Operations

Lead Center: LaRC

Technology Area: TA15 Aeronautics

The current state of the art for flow measurement on the current ISS Extravehicular Mobility Unit (EMU) space suit is a flapper valve tied to a microswitch. The current EMU flapper valve technology only supports microgravity EVAs (single flow rate requirement) with a sufficient versus non-sufficient flow measurement capability. With the multi-mission goals of the advanced space suit, variable flow rates are required. Therefore, the goals for the required flow meter include accurate measurement of 2-8 acfm \pm 1% with a pressure drop requirement of less than 0.68 in-H₂O in a pure oxygen (O₂) environment. This flow meter needs to also fit within a volume/shape factor of approximately 2.5 in x 1.5in x 3in or less. An innovation is required since currently available flow meters do not meet these specifications.

The Portable Life Support System (PLSS) capable of supporting planned exploration missions is capable of adapting between varied Space Suit Assembly (SSA) architectures that are optimized for micro-gravity Extra-Vehicular Activities (EVAs) from vehicles such as the International Space Station (ISS) to rear-entry walking suits suitable for operation on the lunar and Martian surfaces. The varied suit designs and associated crewmember exertion within the suits under micro-gravity to partial gravity require the ability to vary the suit ventilation flow rate and also to vary the monitoring/alarming for the selected ventilation flow rates. This limits the application of existing flapper-microswitch style low pressure drop flow switches and requires application of technologies such as flow/pressure drop measurements or thermal mass flow measurements. One of the most constraining requirements is the low permissible pressure drop as the flow measurement has been integrated as a measured pressure drop across the ventilation loop heat exchanger 0.68 +/- 0.07 in-H₂O with ventilation gas flow at 6 acfm (170 lpm) and suit pressure of 4.3 psia and 60°F and 100% O₂ (traces of NH₃, H₂O, CO₂); the allocation of differential pressure (DP) will be ~0.5 in-H₂O should the measurement not be acquired across an existing pressure drop in the system. Evaluation of commercial off-the-shelf (COTS) DP sensors has yielded units that are either too large or orientation/vibration sensitive as this hardware needs to operate and tolerate up to 2 grms Grms vibration during operation and >9 grms Grms while stowed.

Volume/shape factor is approximately 2.5 in x 1.5 in x 3 in or less including fluid ports and electrical connectors; if added as an in-line flow, 1 in inlet/outlet porting will be necessary. The absolute pressure range with 100% oxygen is up to 25 psia; the optimal choices would include materials not considered flammable in this environment to reduce compatibility issues with things such as kindling chain ignitions of human generated debris. A thermal mass

flow measurement would also seek to minimize the energy input and operating temperature above the core stream temperature to further improve oxygen compatibility. The measurement range for the sensor is 2-8 acfm +/- 1% with 100% O₂, suit pressure from 3.5-25 psia, temperature from 50-90°F, RH 0-50%, and CO₂ from 0-15mmHg. The sensor must also tolerate low dose rate to 30 krad as well as high energy particles to 75 MeV-cm²/mg without destructive Single Event Effects (SEE) such as latchup, gate rupture, burnout, etc. The ambient operating environment will range from sea level conditions to vacuum with ambient thermal sink ~50°F. Operating life will need to be 8 years without calibration and 5000 hrs of powered operation.

H4.03 Sensors to Measure Space Suit Interactions with the Human Body

Lead Center: LaRC

Participating Center(s): JSC

Technology Area: TA15 Aeronautics

Space suits can be tested unmanned for range of motion and joint torque in an attempt to quantify and compare space suit joint designs and overall suit architecture. However, this data is irrelevant if humans using the suits aren't effective. Characterizing human suited performance has continued to be a challenge, partly due to limitations in sensor technology. One concept is to use sensors placed at/on the human body, underneath the pressure garment to obtain knowledge of the human bodies movements. This data could then be compared against the suit motion. Various sensors, sensor technologies, and sensor implementations have been attempted over two decades of efforts, but each has had issues. Previous efforts have used Force Sensitive Resistors (FSR), TouchSense shear sensors, pressure-sensing arrays (Tek scan etc.), piezo-electric sensors, among others but have not met all requirements. Most issues have centered around accuracy when placed on the pliant surface of the skin, and accuracy when placed over curved surfaces of the skin. Accuracy has been sufficient to delineate low, medium or high levels of force but not a reliable quantitative value. This, combined with aberrant readings when the sensor is bent has led to these sensors only providing a rough idea of the interaction between the suit and the skin: while in a controlled environment the sensors are accurate to within 10% or so, the accuracy falls significantly when measuring the skin and being bent or pressed in inconsistent ways; on the order of 50% accuracy or worse. The sensors also are prone to drift (falling out of calibration) quickly during use. Lastly, the sensors, while pliant, are still relatively thick and as such translates to discomfort and loss of tactility. This is typical during all previous testing but most notable when sensors are bent along an axis (or worse, along two axis such as required to follow a complex anatomical contour). As such, the effect on the suit/skin interface that is being measured is changed, which adds an additional complication to interpreting data output from these sensors. Much of the work within JSC has improved the integration, comfort, and calibration of these sensors, but the accuracy performance characteristics when in use have not been sufficient to meet requirements. A new sensor technology is warranted for use in our application.

Current critical needs that this technology would enable include the ability to optimize suit design for ergonomics, comfort and fit without the sole reliance on subjective feedback. While subjective feedback is important, developing a method to quantify the amount of force or pressure on a particular anatomical or suit landmark will aid in providing a richer definition of the suit/human interface that can be leveraged to make space suits more comfortable while reducing risk of injury. Taken together, these improvements will enhance EVA performance, reduce overhead and reduce personnel and programmatic risk. This technology implementation would require relatively accurate pressure or force readings in the medium to high range.

In the future, alternative space suit architectures such as mechanical counter pressure may be feasible, and a critical ancillary to such an architecture is to verify that necessary physiological pressure requirements are being met to ensure the health and safety of the crew. To this end, the technology should be able to accurately measure mechanical pressure on the human skin in the low pressure (< 10 psi) range.

Performance targets vary upon application, but the sensing technology should have the following characteristics:

- Measures force and/or mechanical pressure.
- Accurate to within 10%.

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- Resistant to aberrant readings when under moderate bending, shear or torsion.
 - Either sufficiently pliant, or high enough spatial resolution, to follow anatomical curves on the human skin without discomfort or lack of mobility.
 - Thin profile (~mm).
 - Packaged at high spatial resolution (~cm) or sufficiently small to facilitate a custom packaging/substrate solution with a high spatial resolution.
 - Free of rigid or sharp points that would cause discomfort.
 - Low power (~5V, ~mA).
 - Capable of integration to the inside of the pressurized suit surface as well as the human skin (or integrated to conformal garment).
 - At this early stage, a simple digital readout capability to evaluate sensor performance.

For this SBIR opportunity specifically, we are looking for a single sensor technology that targets the above requirements including readout capability. They should either be packaged into a component level prototype (shoulder or arm segment with multiple sensors) or a flexible packaging option (multiple sensors that could be integrated ad-hoc into a component level prototype through placement of said sensors on the skin or comfort garment).

The most attention should be paid to maximizing spatial resolution, accuracy and thinness for this prototype. Lastly, as previous work has demonstrated a relatively high failure rate of these sensor types over time, the individual sensor elements should be replaceable and/or spares should be provided.

H5.01 Mars Surface Solar Array Structures

Lead Center: LaRC

Participating Center(s): GRC

Technology Area: TA15 Aeronautics

Initial manned missions to the Mars surface may use large photovoltaic (PV) solar arrays to generate power for habitats, ISRU, science investigations, and battery charging. Nominal overall size of the solar array "farm" is 2500 m². Because of the critical nature of electrical power, this equipment may be prepositioned and validated prior to human landings. Modular solar array designs could be based on individual deployable structures with 50-150 m² of area each. Another approach could be a single monolithic structure. Regardless of the configuration, autonomous deployment/assembly is assumed to be required.

This subtopic seeks innovations in lightweight structures, robust deployment/retraction mechanisms, and autonomous assembly focusing on the process of post-landing deployment and erection of a large solar power system on the surface of Mars. Each lander might have its own modular power system that could be relocated closer to the loads to reduce cabling lengths and grow available power as the human Mars base grows.

Design guidelines for these autonomously deployed Mars solar array structures are:

- 2500 m² total solar cell area; < 5000 kg total mass including all mechanical and electrical components; and < 20 m³ total launch volume.
- Loads: 5 g axial, 2 g lateral, 145 dB OASPL for launch and 50 m/s Mars surface winds. Ideally > 1 g deployed strength to allow unconstrained Earth deployment qualification.
- Capable of being optionally deployed on lander, offloaded and transported to another site, and then optionally interfaced with other power units.
- Deployable/retractable at -50° C on terrain with up to 0.5 m obstacles and 15 deg slopes. Operating height > 1 m to avoid wind-blown sand collection.
- Integrated dust mitigation and abatement methods. Dust accumulation is the #1 design risk issue for sustained PV power production on Mars.
- Tolerant of daily thermal cycling from -100° C to 25° C over a lifetime of 10 years.
- Concept of operations (ConOps) including transportation and robotic assembly aids and all design

assumptions must be clearly defined.

This subtopic seeks innovations in the following areas for Mars solar array structures:

- Novel packaging, deployment, retraction, dust-abatement, or in-situ manufacturing concepts.
- Lightweight, compact components including booms, ribs, substrates, and mechanisms.
- Optimized use of advanced ultra-lightweight materials (but not materials development).
- Validated modeling, analysis, and simulation techniques.
- High-fidelity, functioning laboratory models and test methods.

Proposals should emphasize mechanical design innovations, not PV, electrical, or energy storage innovations, although a complete solar array systems analysis is encouraged. If solar concentrators or solar tracking are proposed, strong arguments must be developed to justify why this approach is better from technical, cost, and risk points of view over fixed planar solar arrays. Of special interest are modular designs that are self-supporting in 1 g and can be autonomously deployed, retracted, relocated, and optionally interfaced with other power sources at least twice after months of operation on the Mars surface. Sharing of conceptual CAD models and analyses with NASA for mission studies, and delivery of prototype hardware to NASA at the end of Phase II for independent testing, are highly encouraged.

In Phase I, contractors should prove the feasibility of proposed innovations using suitable analyses and tests. In Phase II, significant hardware or software capabilities that can be tested at NASA should be developed to advance their Technology Readiness Level (TRL). TRLs at the end of Phase II of 3-4 or higher are desired.

References:

- Tom Kerslake, "Solar Electric Power System Analyses for Mars Surface Missions," 1999, <http://ntrs.nasa.gov/search.jsp?R=19990063893> [10].
- Robert Cataldo, "Power Requirements for NASA Mars Design Reference Architecture 5.0," 2009, <http://ntrs.nasa.gov/search.jsp?R=20120012929> [11].
- Mars landing site concept animation, "Mars Exploration Zones," 2015, <https://www.youtube.com/watch?v=94bIW7e1Otg&sns=em> [12].

H5.02 Hot Structure Entry Control Surface Technology

Lead Center: LaRC

Participating Center(s): AFRC, JSC, MSFC

Technology Area: TA15 Aeronautics

The focus of this subtopic is the development of hot structure technology for entry vehicle control surfaces. A hot structure is a type of multifunctional structure that can reduce or eliminate the need for a separate thermal protection system (TPS) to protect the structure. The potential advantages of using a hot structure in place of a cool structure with a separate TPS are: reduced mass, increased mission capability such as reusability, improved aerodynamics, improved structural efficiency, and increased ability to inspect the structure. Hot structures is an enabling technology for reusability between missions or mission phases, such as aerocapture followed by entry, and have been used in many prior NASA programs: Space Shuttle (nosecap and leading edges), HyperX (nose and all-moving control surfaces), X-37 (flaperon and ruddervator control surfaces), and many Department of Defense programs.

This subtopic seeks to develop innovative low-cost, damage tolerant, reusable and lightweight 1450°C to 2200°C hot structure technology applicable to control surfaces for atmospheric entry vehicles such as body flaps, ailerons, and trim tabs. Proposals should address one or more of the following technical challenges:

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- Fabrication technologies for stiffened structures that can be scaled to components as large as 3 meters in span and/or chord.
 - Material/structural architectures providing significant improvements of in-plane and interlaminar mechanical properties, compared to current high-temperature laminated composites.
 - Concepts for reliable integration of control surface deflection functionality (such as hinges and point attachment for actuators) which can integrate with a cool primary structure.
 - Remote monitoring capability for high temperature structures and associated enviro-mechanical models to quantitatively diagnose the state of the structure between missions or mission phases.

For all above technologies, research, testing, and analysis should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware demonstration. Emphasis should be on the delivery of a manufacturing demonstration unit for NASA testing at the completion of the Phase II contract. Opportunities and plans should also be identified and summarized for potential commercialization.

Reference:

Glass, D. E. "Ceramic Matrix Composites (CMC) Thermal Protection Systems (TPS) and Hot Structures for Hypersonic Vehicles," 15th AIAA International Space Planes and Hypersonic Systems and Technologies Conference, Dayton, Ohio, AIAA-2008-2682, April 2008. (<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080017096.pdf> [13]).

H6.01 Integrated System Health Management for Sustainable Habitats

Lead Center: LaRC

Participating Center(s): JSC, MSFC

Technology Area: TA15 Aeronautics

Habitation systems provide a safe place for astronauts to live and work in space and on planetary surfaces. They enable crews to live and work safely in deep space, and include integrated life support systems, radiation protection, fire safety, and systems to reduce logistics and the need for resupply missions. Innovative health management technologies are needed in order to increase the safety and mission-effectiveness for future space habitats on other planets, asteroids, or lunar surfaces. For example, off-nominal or failure conditions occurring in safety-critical life support systems may need to be addressed quickly by the habitat crew without extensive technical support from Earth due to communication delays. If the crew in the habitat must manage, plan and operate much of the mission themselves, operations support must be migrated from Earth to the habitat. Enabling monitoring, tracking, and management capabilities on-board the habitat and related EVA platforms for a small crew to use will require significant automation and decision support software.

This subtopic seeks to broaden the scope of traditional caution and warning systems, which are typically triggered by out-of-bounds sensor values, by including machine learning and data mining techniques. These methods aim to reveal latent, unknown conditions while still retaining and improving the ability to provide highly accurate alerts for known issues. The performance targets for known faults and failures will be based upon false alarm rate, missed detection rate, and detection time (first time prior to the adverse event that the algorithm indicates an impending fault/failure). Methods should explore the trade space for ISHM data and processing needs in order to provide guidance for future habitat sensor and computational resource requirements.

Proposals may address specific system health management capabilities required for habitat system elements (life support systems, etc.). In addition, projects may focus on one or more relevant subsystems such as water recycling systems, photovoltaic systems, electrical power systems, and environmental monitoring systems. Proposals that involve the use of existing testbeds or facilities at one of the participating NASA centers (e.g., Sustainability Base at ARC) for technology validation, verification, and maturation are strongly encouraged. Technology Readiness Levels (TRL) of 4 to 6 or higher are sought.

Key features of Sustainability Base that make it relevant to deep space habitat technology are its use of a grey

water recycling system and a photo-voltaic array. Data logged from other facility management/building automation systems include environmental data (temp, CO₂, etc.) and facility equipment sensors (flowrates, differential pressures, temperatures, etc.). Also, information on power consumption (whole building, plug load, other loads metered at the panel/circuit level) can be made available. These remaining systems, while conventionally "green," have no unique feature that can't be exclusively used for terrestrial purposes. However, the fact that all such systems require less power to support human occupancy can be used as a focal point to serve as a testbed for deep space habitats that will need to operate within finite energy budgets.

Specific technical areas of interest related to integrated systems health management include the following:

- Machine learning and data mining techniques that are capable of learning from operations data to identify statistical anomalies that may represent previously unknown system degradations. Methods should facilitate the incorporation of human feedback on the operational significance of the statistical anomalies using techniques such as active learning.
- Demonstration of advanced predictive capability using machine learning or data mining methods for known system fault or failure modes, within prescribed performance constraints related to detection time and accuracy.
- Prognostic techniques able to predict system degradation, leading to system robustness through automated fault mitigation and improved operational effectiveness. Proposals in this area should focus on systems and components commonly found in space habitats or EVA platforms.
- Innovative human-system integration methods that can convey a wealth of health and status information to mission support staff quickly and effectively, especially under off-nominal and emergency conditions.

Proposals that address lower TRL research on the foundational principles of sustainable technologies and systems involving academic partnerships should consider responding to STTR subtopic T6.01 - Closed-Loop Living System for Deep Space ECLSS with Immediate Applications for Sustainable Planet. Proposals that address bio-manufacturing research may also consider the STTR subtopic T7.01 - Advanced Bioreactor Development for in-situ Microbial Manufacturing. For integrated system health management and monitoring capabilities that support these systems, respondents are encouraged to consider the currently listed subtopic - H6.01 - Integrated System Health Management for Sustainable Habitats.

H6.02 Resilient Autonomous Systems

Lead Center: ARC

Participating Center(s): JPL, JSC, MSFC

Technology Area: TA15 Aeronautics

Future human spaceflight missions will place crews at large distances and light-time delays from Earth, requiring novel capabilities for crews with limited ground support to manage spacecraft, habitats, and supporting equipment to prevent Loss of Mission (LOM) or Loss of Crew (LOC) over extended duration missions. In particular, these capabilities are needed to handle faults leading to loss of critical function or unexpected expenditure of consumables. Expanded flight control functionality will be on-board spacecraft to support autonomy with significant automation, autonomy, and decision support software. The increasingly complex interconnectivity of these elements introduces new vulnerabilities within space systems that are sometimes impossible to predict. In that context, one key property of the respective system is its resilience to unforeseen events.

Resilience, as defined by the U.S. National Academy of Sciences [1] (NAS), is the ability to plan and prepare for, absorb, recover from, and more successfully adapt to adverse events. Within this definition, resilience has two manifestations: engineering and ecological. Engineering resilience is focused on the ability of a system to absorb and recover from adverse events, while ecological resilience is focused on understanding how close a system is to collapse and reorganization. The engineering definition brings resilience principles such as robustness, redundancy, and modularity, while the ecological definition supports principles of flexibility, adaptability, and resourcefulness.

To enable resilient behavior of a system (such as a vehicle, a habitat, a rover, etc.), "resilience" needs to be built-in during the design phase of the system development. To that end, the operational states of a system's component need to be considered in conjunction with the intended function of the component and its possible failure modes throughout the vehicle's life cycle. Where possible, critical failures are eliminated during the design stage. For failure modes that cannot be eliminated, a mechanism needs to be designed that considers how to have optimal state awareness during operations and to mitigate the fault. Mitigation can be accomplished through fault avoidance, fault masking, or Fault Detection, Assessment, and Recovery (FDIR). FDIR can be realized through hardware or software solutions as well as by intervention of the mission crew or mission control. The detection / assessment / recovery process will involve identification of:

- Small variations in overall system performance that may "coincide and combine" to produce significant risk.
- Dependencies within the system that contribute to unforeseen increased risk.
- The strategies and solutions used by crew and controllers to run mission operations safely.
- Recovery/fallback mechanisms that help the human/technology system cope with foreseen and unforeseen operational conditions and events.
- The adaptability and flexibility needed to handle unpredictable and uncertain situations.
- The different technical, functional, and procedural features that can interact in a positive way to achieve mission success.

Four processes characterize the emergence of resilience as a system property:

- *Sensing* - measuring new information about a system's operating environment with focus on anomalous data. These data can alert system evaluators of overlooked possibilities. This process connects components in the physical domain to the information domain.
- *Anticipation* - imagining multiple future states without reducing improbability to impossibility; this includes incorporating the uncertainty in the future states and including the impact of such uncertainty on system operation. This process connects components in the information domain to the cognitive domain.
- *Adaptation* - reacting to changing conditions or uncertain states to restore critical functionality under altered conditions or operating environments. This process connects the cognitive domain to the physical domain.
- *Learning* - observing external conditions and system responses to improve understanding of relationships and possible futures, identifying needs for system improvement where applicable. This process links the physical, information, and cognitive domains together and can incorporate the social or human crew domain depending on the system studied.

Since a vehicle is made up of many components, a system-of-system's approach needs to be considered in a multi-objective optimization context to account for interdependencies and to realize possible mutually beneficial mitigation solutions for resiliency.

Proposals to this subtopic should specify innovation and approaches toward two goals:

- Development of methods and tools that allow the assessment and optimization of system resilience during its conceptual design stage, while simultaneously maximizing reliability and safety.
- Development of measures and metrics that quantify the degree of resilience of a system with respect to a mission ConOps and hazard analysis.

Resilience measures and metrics must be general enough to support broad applications, yet precise enough to measure system-specific qualities. Such metrics are necessary to make resource and operations decisions. Risk metrics tend to assess risks to individual components, ignoring system functionality as the result of interacting components. Resilience measures and metrics also need to account for uncertainty in the planned operation of the system, and focus on integrating statistical methods for uncertainty propagation into resilience-based design. Rather than the static view of systems and networks in risk assessment, resilience adopts a dynamic view. This means resilience metrics must also consider the ability of a system to plan, prepare, and adapt as adverse events occur, rather than focus entirely on threat prevention and mitigation. Finally, resilience depends upon specific qualities that risk assessment cannot quantify, such as system flexibility and interconnectedness.

Proposed solutions are expected to have characteristics including (but not limited to):

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- Life-cycle models (i.e., models that assess the resilience of the system over its entire life-cycle) that encapsulate cost/benefit of envisioned design solution and that can be used to inform about the resilience of the system.
 - Models may need to be built at the appropriate fidelity level to capture relevant fault behavior.
 - Models may need to assess behavior and consequences during degraded (or faulted) state.
 - Models should also be able to assess mitigation actions that are part of an integrated health management approach.
 - Design optimization methodology that can systematically incorporate health management solutions.
 - Methods that integrate optimal decision-making into the design concept.
 - Methods that make use of both system health models and observations to provide the best decision given the information available.
 - Methodology to allow bi-directional exchange between a model and the analysis tool.
 - Methods that systemically include desired levels of resilience in the design optimization process.
 - Uncertainty management.
 - Identify the various sources of uncertainty that affect system performance, and quantify their combined effect on both system failure and resilience.
 - Systematically incorporate uncertainty in the design process, thereby incorporating both resilience and likelihood of failure directly during the design stage.

This SBIR work aims to generate a practical toolkit for space systems that can deliver solutions with assured levels of performance, reliability and resilience, while accommodating: uncertainty; incomplete knowledge; sparsity, or high volumes, of data; and humans in the loop.

Metrics for success include:

- Development of generic quantitative measures and metrics that evaluate system resilience, and their application to space relevant systems or subsystems.
- Demonstrated improvement of resilience over baseline design for at least two different space relevant systems or subsystems.
- Consideration of at least 3 different fault modes.
- Software tools must be able to accept other systems or subsystems through appropriate interface.

SBIR work is expected to deliver mainly software in the form of tools used during the design stage and also prototype software that would manage resiliency during autonomous operations. For the latter, the SBIR effort should analyze sensors, computational hardware, and software stack:

- Resiliency for the computational system should also be addressed.
- In-space applications are preferred, but terrestrial analogues will be considered.

Proposals must demonstrate mission operations risk reduction through appropriate metrics;

Deliverables: tools developed, algorithms and any data generated in simulations or experiments.

Below are a few links to documents on resilience that may be useful to understand the context:

- Resilience Engineering and Quantification for Sustainable Systems Development and Assessment: Socio-technical Systems and Critical Infrastructure: <https://www.irgc.org/wp-content/uploads/2016/04/Haering-et-al.-Resilience-Engineering-and-Quantification.pdf> [14].
- The New Resilience Paradigm - Essential Strategies for a Changing Risk Landscape: <https://www.irgc.org/wp-content/uploads/2016/04/Fiksel-The-New-Resilience-Paradigm.pdf> [15].

References:

Kash Barker, Jose Emmanuel Ramirez-Marquez, Claudio M. Rocco, "Resilience-based network component importance measures", Reliability Engineering and System Safety 117 (2013) pp.89–97.

Daniel A. Eisenberg, Igor Linkov, Jeryang Park, Matthew E. Bates, Cate Fox-Lent, Thomas P. Seager, Resilience Metrics: Lessons from Military Doctrines: <http://www.thesolutionsjournal.org/node/237200> [16].

[1] Committee on Increasing National Resilience to Hazards and Disasters; Committee on Science, Engineering, and Public Policy (COSEPUP); Policy and Global Affairs (PGA); The National Academies. . Disaster Resilience: A National Imperative: http://www.nap.edu/catalog.php?record_id=13457 [17]. The National Academies Press. (2012).

H6.03 Spacecraft Autonomous Agent Cognitive Architectures for Human Exploration

Lead Center: ARC

Participating Center(s): JSC, MSFC

Technology Area: TA15 Aeronautics

Future human spaceflight missions will place crews at long distances from Earth causing significant communication lag due to the light distance as well as occasional complete loss of communication with Earth. Novel artificial intelligence capabilities augmenting crews will be required for them to autonomously manage spacecraft operations and interact with Earth mission control under these conditions, including spacecraft and systems health, crew health, maintenance, consumable management, payload management, training, as well as activities such as food production and recycling.

Autonomous agents with cognitive architectures would be able to interface directly with the crew as well as with the onboard systems and mission control, thus reducing the cognitive loads on the crew as well as performing many tasks that would otherwise require scheduling crew time. In addition, this cognitive computing capability is necessary in many circumstances to respond to off-nominal events that overload the crew; particularly when the event limits crew activity, such as high-radiation or loss of atmospheric pressure events.

In deep space, crews will be required to manage, plan, and execute the mission more autonomously than is currently done on the International Space Station (ISS); which from Low Earth Orbit has instantaneous ground support. NASA expects to migrate significant portions of current operations functionality from Earth flight control to deep-space spacecraft to be performed autonomously. These functionalities will be performed jointly by the crew and cognitive agents supervised by the crew; so the crew is not overburdened. Cognitive agents that can effectively communicate with the crew could perform tasks that would otherwise require crew time by providing assistance, directly operating spacecraft systems, providing training, performing inspections, and providing crew consulting among other tasks.

Due to the complexity of such cognitive agents and the need for them to be continually updated, their software architecture is required to be modular. A requirement for the cognitive software architecture is that modules can dynamically be added, removed, and enhanced. Types of modules would likely include a smart executive, state estimator, planner/scheduler, diagnostics and prognostics, goal manager, etc. Other modules that may be supported include a dialog manager, risk manager, image recognition, instructional drawing, crew task manager, etc. This type of modular cognitive architecture is consistent with that proposed by Prof. Marvin Minsky in "The Society of Mind", 1988, and subsequent proposals and realizations of cognitive agents. Recent venues for cognitive architectures include: ICCM (<http://acs.ist.psu.edu/iccm2016/> [18]) and CogArch 2016 @ ASPLOS (http://researcher.watson.ibm.com/researcher/view_group.php?id=5848 [19]).

Due to NASA's need for fail-safe capabilities, such as continued functionality during high-radiation events, the cognitive architecture will be required to be capable of supporting multiple processes executing on multiple processors, in order to meet the expected computational loads as well as be robust to processor failure. Cognitive architectures capable of being certified for crew support on spacecraft are also required to be open to NASA with interfaces open to NASA partners who develop modules that integrate with other modules on the cognitive agent in

contrast to proprietary black-box agents. Note that a cognitive agent suitable to provide crew support on spacecraft may also be suitable for a variety of Earth applications, but the converse is not true; thus requiring this NASA investment.

The emphasis of proposed efforts are expected to be on analyzing and demonstrating the feasibility of various configurations, capabilities, and limitations of a cognitive architecture suitable for crew support on deep space missions. The software engineering of a cognitive architecture is to be documented and demonstrated by implementing a prototype goal-directed cognitive agent that interacts with simulated spacecraft systems and humans.

For Phase I, a preliminary cognitive architecture, preliminary feasibility study, a cognitive agent prototype that supports a human operating a simulate complex system that illustrates a candidate cognitive agent architecture, and a detailed plan to develop a comprehensive cognitive architecture feasibility study are expected. For Phase II, it is expected that the proposed detailed feasibility study plan is executed. In Phase II it is expected that a comprehensive cognitive architecture will be generated, along with a demonstration of an agent prototype that instantiates the architecture. The agent prototype should interact with a spacecraft simulator and humans executing a plausible HEOMD design reference mission beyond cis-lunar (e.g., Human Exploration of Mars Design Reference Mission: https://www.nasa.gov/pdf/373665main_NASA-SP-2009-566.pdf [20]). Phase II deliverables are also expected to include a comprehensive feasibility study report, and a detailed plan to develop a fully instantiated robust cognitive architecture suitable for proposing to NASA and other organizations interested in funding a flight capability. A Phase II prototype suitable for a compelling flight experiment or simulation interfacing with the ISS or a spacecraft-relevant robotic system is encouraged.

H7.01 In-Space Manufacturing of Electronics and Avionics

Lead Center: MSFC

Participating Center(s): ARC

Technology Area: TA15 Aeronautics

The purpose of this subtopic is to encourage highly collaborative research and development in the area of In-Space Printable Electronics capabilities geared towards laying the foundation and infrastructure for the next generation of in-space advanced electronics manufacturing technologies.

Hardware

3D Electronics Manufacturing Hardware Miniaturization and Adaptation for Microgravity Environment including but not limited to:

- Repackaging and modularization of commercially available state-of-the-art electronics printer platforms such as: aerosol jet, ink-jet, poly-jet, and fluidic dispensing systems.
- Addition of in-line 3D scanning metrology processes to existing printer platforms.
- Implementation of in-line laser and photonic sintering processes into existing electronics manufacturing platforms.
- Integration of advanced robotic and automation processes into printing processes to facilitate hybrid electronic manufacturing and assembly.
- Introduction of advance automated multi-material handling and delivery into electronics manufacturing processes.
- Incorporation of open source flexible hardware architectures into existing printer platforms to promote highly specialized and advance electronics manufacturing solutions.

Software

Advanced Software Development for Ultimate Portability and Autonomy for use in Microgravity based 3D Electronics Printers and Manufacturing Systems:

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- Development of open-source flexible intuitive software environments and applications that integrate multiple electronic printing methodologies including but not limited to: aerosol jet, ink-jet, plasma-jet, FDM, fluidic and laser assisted dispensing.
 - Improving existing open-source software platforms to support advanced open electronics printer hardware configurations and architectures to support the addition of cutting-edge metrology and digital manufacturing solutions.
 - Introduction of advanced integrated design and manufacturing graphical user environments that support autonomous and tele-operation of 3D electronics printers and manufacturing systems.
 - Implementation of Graphical user-friendly utilization cataloging and database software to support organization, classification, and utilization of in-space manufactured avionics.
 - Development of new versatile algorithms and software processes geared towards 3D electronics printer robotic tool-path planning and routine development from inside electrical and mechanical design environment.
 - Advance the state-of-the-art in portable mechanical and electrical design packages for in-space manufacturing through the development of integrated electrical and mechanical design software and tools that include support for in-space multi-material avionics parts production.

Phase I Objectives - Near term performance targets consist of electronics printer prototypes aimed at the in-space production of novel avionics products that are commonly based on passive electronic elements such as: resistors, capacitors, inductors, transformers, and diodes to supply on-orbit non-critical avionics parts production. Near term software targets will focus primarily on increasing portability and reliability of existing open software architectures for 3D printing to include support for in-space 3D electronics printing and multi-material advanced manufacturing processes. *Ending TRL 4 for Hardware and Software Prototypes.

Phase II Objectives - Mid-term objectives will seek to improve existing in-space electronics manufacturing capabilities to include higher complexity active electronic elements such as semiconductor based avionics products. *Ending TRL 5-6.

Phase III Objectives - Far-term objectives will include continued development of advanced in-space electronics manufacturing infrastructure and seek to introduce feasible concepts for deployable self-replicating and self-supporting avionics manufacturing architectures and systems. *Ending TRL 6-9.

H7.02 In-Space Manufacturing of Precision Parts

Lead Center: MSFC

Participating Center(s): GRC, LaRC

Technology Area: TA15 Aeronautics

Currently, both 3D Printers onboard the International Space Station (ISS) use Fused Deposition Modeling (FDM), an additive manufacturing extrusion based process that builds up a plastic part layer by layer. Since this process is not dependent on buoyancy driven convection to achieve material consolidation, it is highly functional in the microgravity environment and no microgravity effects on material outcomes have been observed to date. To expand material capabilities and impart an ability to produce high-strength, precision components on-orbit, candidate metal manufacturing technologies are currently being investigated for adaptation to microgravity.

This part of the subtopic seeks to develop concepts for innovative manufacturing technologies for on-demand production of precision parts in the microgravity environment. For example, an innovative manufacturing solution could be a hybrid system that consists of an additive manufacturing process that can produce near-net shape parts and a traditional subtractive process that finishes the parts to the desired net shape. The quality of fabricated parts (dimensional accuracy, surface finish, etc.) should be comparable to what is achievable by a commercial off the shelf CNC machine.

This subtopic seeks innovative technologies in the following areas for in-space use:

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- Innovative on-demand manufacturing technologies and techniques adaptable for use in the microgravity environment (such as hybrid additive and subtractive systems or other novel manufacturing techniques).
 - Systems that address microgravity considerations such as debris / cutting fluid management and control of feedstock are of special interest.
 - Preferred feedstock materials are aerospace metal alloys, however other materials such as high strength polymers, composites, and ceramics are also of interest.
 - Easily scalable manufacturing technologies that can function using minimal power, mass, and volume due to operational constraints on space missions.

Phase I Deliverables - Feasibility study with proposed path forward to develop a full scale engineering unit in Phase II. Study should address operational constraints for system deployment on ISS such as system mass, volume, and power, as well as initial safety considerations such as material flammability, toxicity, and handling. It is desirable to have a bench top proof-of-concept/laboratory demonstration, including samples and test data, proving the proposed approach to develop an engineering unit in Phase II (TRL 3-5).

Phase II Deliverables - Functional Engineering Unit of proposed product. Full report of development and test data, including relevant material test data for samples produced by the Engineering Unit (TRL 5-6). Report should also address how the design will meet flight certification and safety requirements

Phase III Deliverables - Flight Unit for International Space Station Technology Demonstration Payload. Phase III deliverable includes all supporting documentation for flight certification, safety requirements, and operations.

H8.01 ISS Utilization and Microgravity Research

Lead Center: JSC

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

Technology Area: TA15 Aeronautics

NASA continues to invest in the near- and mid-term development of highly-desirable systems and technologies that provide innovative ways to leverage existing ISS facilities for new scientific payloads and to provide on orbit analysis to enhance capabilities. Additionally, NASA is supporting commercial science, engineering, and technology to provide low earth orbit commercial opportunities utilizing the ISS. Utilization of the ISS is limited by available up-mass, down-mass, and crew time as well as by the capabilities of the interfaces and hardware already developed and in use. Innovative interfaces between existing hardware and systems, which are common to ground research, could facilitate both increased and faster payload development and subsequent utilization. Technologies that are portable and that can be matured rapidly for flight demonstration on the International Space Station are of particular interest.

Desired capabilities that will continue to enhance improvements to existing ISS research and support hardware, with the potential of reducing crew time needs, and those that promote commercial enterprise ventures include but are not limited to, the below focus areas:

- Projects leading to the development of new research facilities and the enhancement of others in focus areas involving granular material research, material science for polymerization, soldering, thermal diffusivity of organic liquids, particles suspension in plasma, and safe containment of samples while undergoing microscopy imaging. Additionally, projects that address enabling on-orbit capability for utilization of larger rodents for neuroscience research are of high interest.
- Technologies and flight projects that can enable significant terrestrial applications from microgravity development and lead to private sector and/or government agency product development within a number of discipline areas, including biotechnology, medical applications, material sciences, electronics, and pharmaceuticals. This includes modifications to existing flight instruments as well as the development of novel flight hardware for deployment on the ISS.

- Innovative software and hardware to facilitate enhanced station operations. The technology should increase the efficiency of crew operations by simplifying training and procedures, and provide teleoperation and tele-collaboration capabilities within the station, and between the station and ground operations.
- Instruments that can be used as inspection tools for locating and diagnosing material defects, leaks of fluids and gases, and abnormal heating or electrical circuits. The technology should be suitable for hand-held portable use. Battery powered wireless operation is desirable. Specific issues to be addressed include: pitting from micro-meteoroid impacts, stress fractures, leaking of cooling gases and liquids and detection of abnormal hot spots in power electronics and circuit boards.
- Mid-TRL space technology experiments are solicited to fly on a new space environmental effects platform on the outside of the ISS. The new platform is called MISSE-FF (MISSE-Flight Facility). MISSE-FF provides experiment accommodations for both active experiments (requires power and communications) and passive experiments. The technology can be materials or non-materials (devices). The physical size of the experiments can vary depending on the technology being demonstrated (1 inch by 1 inch up to 7.84 inches by 14 inches). Of special interest are space technologies already developed under the NASA SBIR Program, particularly technologies that would mature in TRL due to successful demonstration in the space environment. The proposal should justify the need for spaceflight exposure and justify that the ISS environment is adequate to gather the data they need. The MISSE-FF commercial partner, Alpha Space Test & Research Alliance, LLC, plans to service MISSE-FF every 6 months. The MISSE-FF data will be made available to the global community of researchers through the NASA Physical Sciences Informatics (PSI) system. Phase I deliverables could be data from ground testing the candidate technology and passive specimens for flight on MISSE-FF. Phase II deliverables could include an active technology experiment, packaged and ready for flight on MISSE-FF.

For the above, research should be conducted to demonstrate technical feasibility and prototype hardware development during Phase I and show a path toward Phase II hardware and software demonstration and delivering an engineering development unit or software package for NASA testing at the completion of the Phase II contract that could be turned into a proof-of-concept system which can be demonstrated in flight.

H9.01 Long Range Optical Telecommunications

Lead Center: JPL

Participating Center(s): GRC, GSFC

Technology Area: TA15 Aeronautics

The Long Range Optical Communications subtopic seeks innovative technologies in free-space optical communications for increased data volume returns from space missions in multiple domains: >100 gigabit/s cis-lunar (Earth or lunar orbit to ground), >10 gigabit/s Earth-sun L1 and L2, >1 gigabit/s per AU-squared deep space, and >100 megabit/s planetary lander to orbiter.

Proposals are sought in the following specific areas (TRL3 Phase I to mature to TRL4 to 5 in Phase II):

Flight Laser Transceivers

- Low-mass, high-effective isotropic radiated power (EIRP) laser transceivers: 30 to 100 cm clear aperture diameter telescopes for laser communications. Targeted mass less than 65 kg/square-meter with wavefront errors less than 1/25th of a wavelength at 1550 nm. Cumulative wavefront error and transmission loss not to exceed 3-dB in the far field. Advanced thermal and stray light design so that transceiver can survive direct sun-pointing and operate while pointing 3-degrees from the edge of the sun; wide range of allowable flight temperatures by the optics and structure, at least -20° C to 50° C operational range, wider range is preferred.
- Diffraction limited field-of-view at focal plane of at least 1 milliradian radius, provision for point-ahead implementation from space.
- Beaconless pointing subsystems for operations beyond 3 A.U.: Point 20 to 100 cm lasercomm transmitter aperture to an Earth-based receiver with a 1-sigma accuracy of better than 100 nanoradians with an

assumed integrated spacecraft micro-vibration angular disturbance of 150 micro-radians (<0.1 Hz to ~500 Hz) without requiring a dedicated laser beacon transmission from Earth; lowest subsystem mass and power is a primary selection factor.

- Low mass/low power/cold survivable optical transceivers for planetary lander to orbiter links [7]: bi-directional optical terminals with data rates from >100 megabit/second at a nominal link range of 1000 km, with an individual terminal mass <5 kg and operational power < 25W, including a pointing system for at least full hemisphere coverage.
- Terminals shall be capable of operationally surviving >500 cycles of unpowered temperature cycling from -40°C to +40°C and a 100 krad TID. Discussion of acquisition and tracking con-ops and requirements is a must.

Flight Laser Transmitters and Receivers

- High-gigabit/s laser transmitter and receiver optical-electronic subsystems: space qualifiable 1550 nm laser transmitter and receiver optoelectronic modulator, detection, and forward-error-correction (FEC) assemblies for data rates from 1 gigabits/s to >200 gigabits/s with power efficiencies better than 10W per gigabit/s and mass efficiencies better than 100 g per gigabit/s.
- Radiation tolerance better than 50 Krad is required.
- Technologies for efficient waveform modulation, detection, and synchronization and on-board low-gap-to-capacity forward-error-correction decoding are of interest.
- Also of interest are hybrid RF-optical technologies.
- Integrated photonic circuit solutions are strongly desired.
- High efficiency (>20% DC-to-optical, including support electronics) space qualifiable (including resilience to photo-darkening) multi-watt Erbium Doped Fiber Amplifier (EDFA) with high gain bandwidth (> 30nm, 0.5 dB flatness) concepts will be considered. Detailed description of approaches to achieve the stated efficiency is a must. High peak-to-average powers for supporting 7-ary to 8-ary pulse position modulation (PPM).
- Space qualifiable wavelength division multiplexing transmitters and amplifiers with 4 to 20 channels and average output power > 20W and peak-to-average power ratios >200 with >10 Gb/s channel modulation capability are also desired.

Narrow Band Pass Optical Filters

- Flight qualified optical narrow band pass filters with 1 to 2 cm clear aperture and 0.5 – 1 nm noise equivalent bandwidth with less than 1 dB transmission loss around 1064 nm or optical c-band are also required.

Ground Assets for Optical Communication

- Large aperture receivers for faint optical communication signals from deep space, subsystem technologies: Demonstrate innovative subsystem technologies for >10 m diameter deep space ground collector capable of operating to within 3 degrees of solar limb with a better than 10 microradian spot size (excluding atmospheric seeing contribution). Desire demonstration of low-cost primary mirror segment fabrication to meet a cost goal of less than \$35K per square meter and low-cost techniques for segment alignment and control, including daytime operations.
- 1550 nm sensitive photon counting detector arrays compatible with large aperture ground collectors with integrated time tagging readout electronics for >5 gigaphotons/s incident rate. Time resolution <100 ps 1-sigma and highest possible single photon detection efficiency, at least 50% at highest incident rate, and total detector active area > 0.2 mm². Integrated dark rate < 5 megacount/s.
- Cryogenic optical filters for operation at 40K with sub-nanometer noise equivalent bandwidths in the 1550 nm spectral region, transmission losses < 0.5 dB, clear aperture >35 mm, and acceptance angle >40 milliradians with out-of-band rejection of >65 dB from 0.4 to 5 microns.

For all technologies lowest cost for small volume production (5 to 20 units) is a driver. Research must convincingly prove technical feasibility (proof-of-concept) during Phase I, ideally with hardware deliverables that can be tested to

validate performance claims, with a clear path to demonstrating and delivering functional hardware meeting all objectives and specifications in Phase II.

H9.02 Intelligent Communication Systems

Lead Center: JPL

Participating Center(s): JPL

Technology Area: TA15 Aeronautics

NASA's RF and optical systems require increased levels of adaptive, cognitive, and autonomous system technologies to improve mission communication for science and exploration. Goals of this capability are to improve communications efficiency, mitigate impairments (e.g., scintillation, interference), and reduce operations complexity and costs through intelligent and autonomous communications and data handling. Cognition and automation have the potential to improve system performance, increase data volume return, and reduce user spacecraft burden to improve science return from NASA missions. These goals are further described in the TA05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems Roadmap, Sections 5.2.1, 5.3.1, 5.3.2, 5.3.3, 5.3.4, 5.5.1, 5.5.2, and 5.5.3.

This solicitation seeks advancements in cognitive and automation communication systems, components, and platforms. While there are a number of acceptable definitions of cognitive systems/radio, for simplicity, a cognitive system should sense, detect, adapt, and learn from its environment to optimize the communications capabilities and situational awareness for the network infrastructure and/or the mission. Areas of interest to develop and/or demonstrate are as follows:

- *Flexible and Adaptive Space Hardware Systems* - Signal processing platforms (transceivers) with novel (e.g., low power, small volume, high capacity) processing technology, wideband (e.g., across or among frequency bands of interest), tunable, and adaptive front ends for RF (S-, X-, and Ka-bands) or optical communications, and other intelligent electronics/avionics which advances or enables flexible, cognitive, and intelligent operations.
- *System Wide Intelligence* - while much of the current research often describes negotiations and link improvements between two radio nodes, the subtopic also seeks to understand system wide, architectural aspects and impacts of this new technology. Areas of interest include (but not limited to): cognitive architectures considering mission spacecraft, relay satellites, other user spacecraft, and ground stations. System wide effects to decisions made by one or more communication/navigation elements, handling unexpected or undesired decisions, self-configuring networks, coordination among multiple spacecraft nodes in a multiple access scheme, cooperation and planning among networked space elements to efficiently and securely move data through the system to optimize data throughput and reduce operations costs.
- *Network Operation* - Optimization of the various layers of the Open Systems Interconnection (OSI) model has several aspects applicable to cognitive applications. Knowledge from one layer may be useful to optimize performance at a different layer. As the future space communication architecture progresses towards a more on-demand, ad-hoc, network-based architecture for data delivery among user spacecraft and relay satellite or from user spacecraft direct to ground stations new technologies are needed to securely provide assured data delivery through the network. Areas of interest include intelligent network routing (best route selection) through quality of service metrics and learning, store and forward data protocols over cognitive links, and advanced network management.
- *Node-to-Node Link Adaptation* - New capabilities for communication radios (hardware and software) to sense and adapt to the mission environment (for both RF and optical systems). Areas of interest include interference mitigation, spectrum cooperation, signal identification, maximizing data throughput and efficiency, learned operation between user spacecraft and relay (or ground) or direct to ground station communications.

For all technologies, Phase I will emphasize aspects for technical feasibility, clear and achievable benefits (e.g., 2x-5x increase in throughput, 25-50% reduction in power, improved quality of service or efficiency, reduction in

operations staff or costs) and show a path towards Phase II hardware/software development with delivery of specific hardware or software product for NASA. Demonstrate and explain how and where cognitive and automation technologies could be applied to NASA space systems.

Phase I Deliverables - Feasibility study and concept of operations of the research topic, including simulations and measurements, validating the proposed approach to develop a given product (TRL 3-4). Early development and delivery of the simulation and prototype software and platform(s) to NASA. Plan for further development and verification of specific capabilities or products to be performed at the end of Phase II.

Phase II Deliverables - Working engineering model of proposed product/platform or software delivery, along with documentation of development, capabilities, and measurements (showing specific improvement metrics). Proposed prototypes (TRL-5) shall demonstrate a path towards a flight capable platform. User's guide and other documents and tools as necessary for NASA to recreate, modify, and use the cognitive software capability or hardware component(s). Commercialization plan.

Software applications and platform/infrastructure deliverables for SDR platforms shall be compliant with the NASA standard for software defined radios, the Space Telecommunications Radio System (STRS), NASA-STD-4009 and NASA-HNBK-4009, found at: <https://standards.nasa.gov/standard/nasa/nasa-std-4009> [21] and <https://standards.nasa.gov/standard/nasa/nasa-hdbk-4009> [22], respectively.

H9.03 Flight Dynamics and Navigation Technology

Lead Center: JPL

Participating Center(s): MSFC

Technology Area: TA15 Aeronautics

Future NASA missions will require precision landing, rendezvous, formation flying, cooperative robotics, proximity operations (e.g., servicing), and coordinated platform operations. This drives the need for increased precision in absolute and relative navigation solutions, and more advanced algorithms for both ground and onboard guidance, navigation, and control. This subtopic seeks advancements in flight dynamics and navigation technology for applications in Earth orbit, lunar, and deep space that enables future NASA missions. In particular, technology relating to navigation, autonomous onboard guidance, navigation and control, and trajectory optimization are solicited.

Autonomous, On-Board Guidance, Navigation and Control

- Advanced autonomous navigation techniques including devices and systems that support significant advances in independence from Earth supervision while minimizing spacecraft burden by requiring low power and minimal mass and volume.
- Onboard trajectory planning and optimization algorithms, for real-time mission re-sequencing, on-board computation of large divert maneuvers (TA 5.4.2.3, TA 5.4.2.5, TA 5.4.2.6, TA 9.2.6) primitive body/lunar proximity operations and pinpoint landing (TA 5.4.6.1).
- Rendezvous targeting (TA 4.6.2.1) Proximity Operations/Capture/ Docking Guidance (TA 4.6.2.2).

Advanced Techniques for Trajectory Optimization

- Tools and techniques for distributed space missions including constellations and formations (TA 11.2.6).
- Low-thrust trajectory optimization in a multi-body dynamical environment (TA 5.4.2.1).
- Advanced deep-space trajectory design techniques. (TA 5.4.2.7) and rapid trajectory design near small bodies (TA 5.4.5.1).

Additional Scope Clarification

Efforts must demonstrate significant risk or cost reduction, significant performance benefit, or enabling capability. Note that implementation of well understood GN&C algorithms into hardware/software, and high TRL activities, are not in scope.

Proposals that leverage state-of-the-art capabilities already developed by NASA, or that can optionally integrate with those packages, such as the General Mission Analysis Tool (<http://sourceforge.net/projects/gmat/> [23]), Goddard Enhanced Onboard Navigation System (GEONS) (<https://software.nasa.gov/software/GSC-14687-1> [24]), GPS-Inferred Positioning System and Orbit Analysis Simulation Software, (<http://gipsy.jpl.nasa.gov/orms/goa/> [25]), Optimal Trajectories by Implicit Simulation (<http://otis.grc.nasa.gov/> [26]), and Navigator (http://itpo.gsfc.nasa.gov/wp-content/uploads/gsc_14793_1_navigator.pdf [27]), or other available hardware and software tools are encouraged. Proposers who contemplate licensing NASA technologies are highly encouraged to coordinate with the appropriate NASA technology transfer offices prior to submission of their proposals.

Phase I research should be conducted to demonstrate technical feasibility, with preliminary software being delivered for NASA testing, as well as show a plan towards Phase II integration. For proposals that include hardware development, delivery of a prototype under the Phase I contract is preferred, but not necessary. Phase II new technology development efforts shall deliver components at the TRL 5-6 level with mature algorithms and software components complete and preliminary integration and testing in an operational environment.

H9.04 Advanced RF Communications

Lead Center: JPL

Participating Center(s): GRC, GSFC, MSFC

Technology Area: TA15 Aeronautics

This subtopic is focused on development of innovative Advanced RF Platform technologies, at the physical layer, supporting the needs of space missions in the areas of both communications and RF sensors.

In the future, robotic and human exploration vehicles with increasingly capable instruments producing large quantities of data will be investigating Earth, extraterrestrial moons, planets and asteroids. These vehicles, especially those that visit the surfaces of these myriad destinations, will be tightly constrained in the areas of mass, volume and energy. Our historical method of implementing single function elements such as short and long range data and voice radios as well as short range radar sensors does not lend itself to mass, volume or energy efficiencies that can support future resource challenged platforms.

One method of enhancing limited resources is to leverage recent advances in the areas of Reconfigurable Software Defined Radio (SDR) Digital Signal Processing (DSP) technologies as well as RF components, materials and packaging to create advanced multifunction RF platforms. Recent advances in high speed digital electronics, especially where clock speeds exist in the range of several GHz, have blurred the lines between what was traditionally considered "analog" and digital". Digital signal processing techniques with multi-GHz clock rates can generate arbitrary user-defined analog waveforms at RF frequencies as never before. These waveforms, when coupled with advanced RF electronics focused on S-Band through Ka-Band frequencies, greatly improve the functionality, performance and utility of space-based communications devices. This naturally leads to advanced multi-function RF platforms; platforms that serve more than one user or function and are reconfigurable, on-demand, by the user for arbitrary applications. The commercial cellphone and wireless industries have been highly successful in developing multifunction RF and wireless platforms that serve a broad range of customers. NASA can leverage these techniques, hardware, algorithms and waveforms developed by industry for use in space applications. However, in order to leverage this increased level of configurability, functionality and performance, NASA needs to further invest in technologies for two key areas:

- Advanced waveform development in the digital domain. Specifically: the foundation has been laid through prior NASA investments in the area of generating the infrastructure for software-based algorithms. These

investments led to the development and demonstration of the Space Telecommunication Radio System (STRS) architectural standard for software-defined radios. Now that the architecture has been instantiated, the next logical step in NASA's investment portfolio is the development of actual application backend platforms and waveforms that meet this architectural standard. Advanced backend platforms generate (for transmission) or process (from reception) the appropriate waveform at a common Intermediate Frequency (IF) for transmission to, or reception from, an appropriate RF front-end. In addition, the backend processor is reconfigurable, by the user, for a specific application at a given time (radar vs. short range communications link, etc.).

- The development and demonstration of advanced RF Front-Ends that cover NASA RF bands of interest; specifically, S-Band, X-Band and/or Ka-Band. These RF front-ends may support time multiplexed waveforms such as radar or (digitized) half-duplex voice transmissions as well as frequency duplexed waveforms such as full-duplex two-way navigation and data communications. Specifically, these front-ends are expected to leverage state-of-the-art RF materials (e.g., GaN, SiC, CMOS, etc.), packaging (e.g., MIC, SMT, etc.), device (e.g., MMIC, MEMS, etc.) and component techniques to minimize mass, volume and energy resource usage while supporting multi-functionality. In implementing these multifunction RF Front-Ends, we must note that there are three key functions embedded within these front-ends that require further development:
 - *High Efficiency Microwave Power Amplifiers* - Compact, lightweight, space qualifiable Ka-band solid-state power amplifiers (SSPAs) with integrated electronic power conditioner that can deliver an output power on the order of 10 to 20 Watts (CW) with bandwidth on the order of 1% to 2% and mass less than 1 kg is of interest to NASA. In addition, low-noise amplifiers (LNAs) with noise figures on the order of a dB or less is of interest to NASA. Since overall efficiency is of paramount importance for low dc power consumption, efficiency enhancement techniques are of interest. Furthermore, SSPAs with good linearity and capable of functioning in tandem with software defined radios (SDRs) for amplifying spectrally efficient digital modulation format signals are also of interest.
 - *Electronically Steered Antennas* - Electronically steered antennas, especially at Ka-Band, are of interest. Applications include large, high-performance electronically steered antennas required for a dedicated communications relay spacecraft with multiple simultaneous connections, advanced multifunction antennas to support science missions that utilize a multifunction antenna to both communicate and conduct science, and small, lightweight antennas for communications only that provide moderate gain without the use of mechanical steering. Antennas that are reconfigurable in frequency, polarization, and radiation pattern that reduce the number of antennas needed to meet the communication requirements of NASA missions are desired.
 - *Ultrawideband (UWB) Antennas and Electronics* - Recent developments in commercial chipsets and antennas that implement UWB modulation techniques are of interest to NASA. Advanced signal processing techniques that can leverage investments made in the commercial communications industry for space applications as well as UWB antennas that function in the standard NASA S/X/Ka-Band frequency ranges are of interest to NASA. This includes modulation and demodulation techniques and algorithms for UWB signal transmission and reception.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables - Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 3-4). Verification matrix of measurements to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

Phase II Deliverables - Working engineering model of proposed product, along with full report of development and measurements, including populated verification matrix from Phase I (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.

H9.05 Transformational/Over-the-Horizon Communications Technology

Lead Center: JPL

Participating Center(s): GSFC, JPL

Technology Area: TA15 Aeronautics

NASA seeks revolutionary, transformational communications technologies that emphasize not only dramatic reduction in system size, mass, and power but also dramatic implementation and operational cost savings while improving overall communications architecture performance. The proposer is expected to identify new ideas, create novel solutions and execute feasibility demonstrations. Emphasis for this subtopic is on the far-term (?10yrs.) insofar as mission insertion and commercialization but it is expected that the proposer proves fundamental feasibility via prototyping within the normal scope of the SBIR program. The over-the-horizon communications technology development will focus research in the following areas:

- Systems optimized for energy efficiency (information bits per unit energy).
- Advanced materials; smart materials; electronics embedded in structures; functional materials.
- Technologies that address flexible, scalable digital/optical core processing topologies to support both RF and optical communications in a single terminal.
- Nanoelectronics and nanomagnetics; quantum logic gates; single electron computing; superconducting devices; technologies to leapfrog Moore's law.
- Quantum communications, methods for probing quantum phenomenon, methods for exploiting exotic aspects of quantum theory.
- Human/machine and brain-machine interfacing; the convergence of electronic engineering and bio-engineering; neural signal interfacing.

The research should be conducted to demonstrate theoretical and technical feasibility during the Phase I and Phase II development cycles and be able to demonstrate an evolutionary path to insertion within approximately 10 years. Delivery of a prototype of the most critically enabling element of the technology for NASA testing at the completion of the Phase II contract is expected.

Phase I deliverables shall include a final report describing theoretical analysis and prototyping concepts. The technology should have eventual commercialization potential. For Phase II consideration, the final report should include a detailed path towards Phase II prototype hardware.

H10.01 Advanced Propulsion Systems Ground Test Technology

Lead Center: SSC

Participating Center(s): KSC

Technology Area: TA15 Aeronautics

Rocket propulsion development is enabled by rigorous ground testing to mitigate the propulsion system risks that are inherent in spaceflight. This is true for virtually all propulsive devices of a space vehicle including liquid and solid rocket propulsion, chemical and non-chemical propulsion, boost stage and in-space propulsion and so forth. It involves a combination of component-level and engine-level testing to demonstrate the propulsion devices were designed to meet the specified requirements for a specified operational envelope and over robust margins and shown to be sufficiently reliable, prior to its first flight.

This topic area seeks to develop advanced ground test technology components and system level ground test systems that enhance Chemical and Advanced Propulsion technology development and certification. The goal is to advance propulsion ground test technologies to enhance environment simulation, minimize test program time, cost and risk and meet existing environmental and safety regulations. It is focused on near-term products that augment and enhance proven, state-of-the-art propulsion test facilities. This project is especially interested in ground test and launch environment technologies with potential to substantially reduce the costs and improve safety/reliability of NASA's test and launch operations.

In particular, technology needs include producing large quantities of hot hydrogen, and developing robust materials, advanced instruments and monitoring systems capable of operating in extreme temperature and harsh environments.

This subtopic seeks innovative technologies in the following areas:

- Efficient generation of high temperature (>2500°R), high flowrate (<60 lb/sec) hydrogen
- Devices for measurement of pressure, temperature, strain and radiation in a high temperature and/or harsh environment.
- Development of innovative rocket test facility components (e.g., valves, flowmeters, actuators, tanks, etc.) for ultra-high pressure (>8000 psi), high flow rate (>100 lbfm/sec) and cryogenic environments.
- Robust and reliable component designs which are oxygen compatible and can operate efficiency in high vibro-acoustic, environments.
- Advanced materials to resist high-temperature (<4400°F), hydrogen embrittlement and harsh environments.
- Tools using computational methods to accurately model and predict system performance are required that integrate simple interfaces with detailed design and/or analysis software. SSC is interested in improving capabilities and methods to accurately predict and model the transient fluid structure interaction between cryogenic fluids and immersed components to predict the dynamic loads, frequency response of facilities.
- Improved capabilities to predict and model the behavior of components (valves, check valves, chokes, etc.) during the facility design process are needed. This capability is required for modeling components in high pressure (to 12,000 psi), with flow rates up to several thousand lb/sec, in cryogenic environments and must address two-phase flows. Challenges include: accurate, efficient, thermodynamic state models; cavitation models for propellant tanks, valve flows, and run lines; reduction in solution time; improved stability; acoustic interactions; fluid-structure interactions in internal flows.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

H10.02 Improved Operations via Interface Design

Lead Center: SSC

Participating Center(s): AFRC, SSC

Technology Area: TA15 Aeronautics

This subtopic seeks to simplify prelaunch and surface operations through improved interface design concepts. Development and adoption of improved, standardized interfaces holds the potential of reducing the cost and complexity of future space systems and their related design and implementation, which can increase the funding available for additional flight hardware.

NASA is interested in areas of interface technology that lower launch vehicle operations costs and provide evolution paths for in-space exploration. This includes interfaces between systems normally present within a launch system. For the purpose of this subtopic a launch system includes a vehicle ready for flight with payload, and includes all related support systems and infrastructure.

A substantial portion of pre-launch processing involves the integration of spacecraft assemblies to each other or to the ground/surface systems that supply the commodities, power or data. Each assembly requires a reliable interface that connects it to the adjacent hardware which includes flight critical seals or connectors and other components.

The benefits of standardized, simplified interfaces are particularly strong for small launch vehicles. Due to a lack of common specifications and standards, each launch vehicle system may impose different interface requirements thereby resulting in unique components/subsystems tailored for each vehicle. This complicates recent efforts to

establish a multi-user capability within the existing launch infrastructure. For the launch provider, unique interface requirements result in higher recurring cost per launch vehicle and reduced ability to incorporate newer subsystems as the vehicle matures.

Future activities at exploration destinations in space and on other surfaces will rely on a combination of structures and systems working together with a high degree of reliability. The impact of these interface-dependent tasks are of particular concern for surface systems where the additional work must be accomplished by crew performing Extra-Vehicular Activities (EVAs) or by purpose-built robotic systems. Areas of interface technology development relevant for surface operations may include (but are not limited to) cryogenics, modular systems, dust tolerance, standardized disconnects, and embedded intelligence.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II demonstration, and delivering a demonstration package for NASA testing in operational or analog test environments at the completion of the Phase II contract.

Phase I Deliverables - Research to identify and evaluate candidate technology applications, demonstrate the technical feasibility, and show a path towards a demonstration. Concept methodology should include the path for adaptation of the technology, infusion strategies (including risk trades), and business model. Identify improvements over the current state of the art for both operations and systems development and the feasibility of the approach in a multi-customer environment. Bench or lab-level demonstrations are desirable.

Phase II Deliverables - Emphasis should be placed on developing and demonstrating the technology under simulated operational conditions with analog earth-based systems including dynamic events such as commodity loading, disconnect or engine testing. The proposal shall outline a path showing how the technology could be developed into or applied to mission-worthy systems. The contract should deliver demonstration hardware for functional and environmental testing at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a TRL of 5 or higher.

H10.03 Cryogenic Purge Gas Recovery and Reclamation

Lead Center: SSC

Participating Center(s): GRC, KSC

Technology Area: TA15 Aeronautics

Helium is becoming a major issue for NASA and the country. Helium is used as a purge gas to reduce the concentration of hydrogen below the flammable threshold at test and launch complexes. Most of the Nation's helium comes from the National Helium Reserve operated by the Bureau of Land Management (BLM). The statutory authority for BLM to operate is expiring and responsibility is being transferred to the commercial sector. Helium is a non-renewable gas that is in limited supply. There are already helium supply constrictions and prices are going up. Conservation and/or reuse of this non-renewable resource would substantially reduce the cost of operating NASA's test and launch facilities.

Specific areas of interest include the following technologies:

- Development of non-proton exchange helium/hydrogen gas separation technologies.
- Technologies for the rapid capture and safe storage of high volumes of mixed helium/hydrogen gas mixtures.
- Development of zero trapped gas system technologies to improve purge effectiveness.
- Development of sensor technologies that can validate that recycled gases meet stringent cleanliness levels of Table 2 of MSFC-STD-3535. _

H11.01 Radiation Shielding Technologies for Human Protection

Lead Center: LaRC

Participating Center(s): JSC, MSFC

Technology Area: TA15 Aeronautics

Advanced radiation shielding technologies are needed to protect humans from the hazards of space radiation during future NASA missions. All space radiation environments in which humans may travel in the foreseeable future are considered, including the Moon, Mars, asteroids, geosynchronous orbit (GEO), and low Earth orbit (LEO). All particulate radiations are considered, particularly galactic cosmic radiation (GCR), solar energetic particles (SEP), and secondary neutrons.

For this 2017 solicitation, technologies of specific interest include, but are not limited to, the following:

- Computational tools that enable the evaluation of the transport of space radiation through highly complex vehicle architectures as represented in detailed computer-aided design (CAD) models are needed. The needed tools are the following:
 - An easy way to manipulate metadata for CAD or CAD-derived geometries, such as materials and densities for input into radiation transport codes;
 - A general method of scoring/tallying that can be equated across multiple radiation transport codes and validating these equivalencies;
 - A general method/interface of radiation transport problem setup that can be used for many different radiation transport codes. This would include (1) and (2) above, as well as allow for radiation source selection for various spectral and special distributions common to space radiation problems, provide this setup data to create input files for many different radiation transport codes (HZETRN, PHITS, FLUKA, GEANT4, etc.), and provide error checking for incompatible user inputs;
 - Provide a tool for visualizing vast numbers of complex radiation transport data sets allowing the user to evaluate quickly scored/tallied parameters in the context of the three-dimensional geometry used in the problem setup. The tool should also be able to move quickly through any or all parameters that were scored/tallied in the problem setup. Phase I deliverables are alpha-tested computer codes. Phase II deliverables are beta-tested computer codes.
- Processing/manufacturing/construction technologies for habitation that utilize in-situ resources (atmosphere, water, regolith, etc.) for radiation shielding on Mars are also of interest. Phase I deliverables are detailed conceptual designs. Phase II deliverables are initial prototypes.
- Credible “out-of-the-box” solutions for space radiation shielding. This could include passive or active radiation shielding solutions. Phase I deliverables are detailed conceptual designs. Phase II deliverables are initial prototypes.

H12.01 Radioprotectors and Mitigators of Space Radiation-induced Health Risks

Lead Center: LaRC

Participating Center(s): JSC

Technology Area: TA15 Aeronautics

Space radiation is a significant obstacle to sending humans on long duration missions beyond low earth orbit. NASA is concerned with the health risks to astronauts following exposures to galactic cosmic rays (GCR), the high energy particles found outside Earth’s atmosphere. Astronaut health risks from GCR are categorized into cancer, late and early central nervous systems (CNS) effects, and degenerative risks, which includes cardiovascular diseases and cataracts (see references below for more detail).

This subtopic is for biological countermeasures to minimize or prevent adverse health effects from space radiation: chronic, low dose, low dose-rate, mixed field (high LET and low LET) and mission relevant doses (0.25 to 0.5 Gy). Radioprotectors or mitigators are needed that can target common pathways (e.g., inflammation) across cancer, cardiovascular disease, and neurodegeneration.

This subtopic will consider:

- FDA approved drugs.
- FDA Off-label usage drugs.
- FDA IND Status drugs.
- Dietary supplements.

Biological countermeasures under development for acute radiation syndrome or prevention of secondary radiation-induced diseases from radiation therapy may be ideal for this topic and allow the company to expand its product line to space radiation, carbon ion therapy and ground based late effects from nuclear fallout.

The biological countermeasure criteria:

- Medical products and regimens that prevent and/or mitigate adverse health effects due to space radiation with emphasis on broad activity (i.e., multi-tissue)
- Mechanism of action well known
- Independent of sex
- Capable of being delivered chronically for the period of the mission (potentially up to 3 years)
- Easily administered; capable of self-administration (e.g., Oral, inhaled)
- Known/potential benefits greater than known potential risks; minimal adverse events
- No contraindications with other drugs used for treating other symptoms or diseases during the mission
- Long shelf-life

Phase I will test radioprotectors or mitigators using mixed radiation fields that must include a low LET source such as gamma combined with high LET radiation such as neutrons or alpha particles to determine efficacy in mixed fields at space relevant doses. This testing can be done at the location of choice. Companies should provide a test plan that will demonstrate the compound being proposed provides protection or mitigation of radiation-induced injury for normal tissues and does not protect cancer cells. A kickoff meeting with NASA is mandatory prior to the start of this award.

Phase II will test effective radioprotectors or mitigators in space radiation simulated environments (HZE) to determine if they are able to minimize or prevent late effects directly related to the development of cancer, neurodegeneration or cardiovascular disease. Companies should provide a test plan for in vivo evaluation that describes the expected effect from the compound. Access and funding to support testing in space radiation simulated facilities will be provided for Phase II in addition to the standard award.

The following references discuss the different health effects NASA has identified as areas of concern as a result of space radiation:

- Evidence report on central nervous systems effects: <https://humanresearchroadmap.nasa.gov/evidence/reports/CNS.pdf> [28].
- Evidence report on degenerative tissue effects: <https://humanresearchroadmap.nasa.gov/evidence/reports/Degen.pdf> [29].
- Evidence report on carcinogenesis: <https://humanresearchroadmap.nasa.gov/evidence/reports/Cancer.pdf> [30].

H12.02 Advanced Model-based Adaptive Interfaces and Augmented Reality

Lead Center: LaRC

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

Technology Area: TA15 Aeronautics

NASA is seeking innovative solutions for the design of adaptive interfaces for complex information systems that will be used on autonomous missions by crewmembers in various states of workload, stress, and fatigue.

Adaptive user interfaces, also called intelligent user interfaces, can decrease workload in cases of high attentional loads by presenting the information needed in simpler forms or in different formats. For example, to decrease attentional load, the interface may be modified from text to icons, or the interaction may change from written procedures to voice commands. There is evidence that workload can be reduced if some of the visual information is presented in a different modality or format in high attentional demand situations. Adaptive user interfaces can also provide displays that offer improved and optimized navigation tailored for the current state of the user. Interfaces can be augmented with visual and auditory elements that, again, adapt based on the needs of the user. Thus, the adaptability of the interface is increased in a different dimension. The augmented reality (AR) technology holds the promise to improve crew performance to execute complex procedures in a deep-space human spaceflight missions where communication back to the Earth-based mission control is limited and delayed.

In Phase I, a proof-of-concept prototype for an adaptive interface system with augmented reality should be developed and tested for a high workload (e.g., fault management or critical time constraints) scenario. The work should include a literature review on the effects of modality (visual, auditory, tactile, and combination of these) and format (e. g., text, icons, graphs) on workload. A model should be developed based on these principles, as well as an adaptive interface framework for a selected system used for spaceflight. Example scenarios and displays will be provided by NASA for this purpose. Model inputs can be simulated or emulated with hardware. The key technology areas are image registration, new software approaches to integrate augmented reality content from multimedia and multiple modalities, fusion of vision, human tracking, and integration of digital data with live sensor data and models.

In Phase II, the prototype adaptive interface system with augmented reality should be designed and validated for the selected high workload use case, as well as a procedure-based task. Display components should dynamically change as a function of the cognitive state and the level of expertise of the operator. The cognitive states (stress, fatigue, and workload) do not need to be measured or prototype; they can be simulated with various levels and treated as input parameters to the prototype. The usability of the prototype should be tested, including trigger events and timing of adaptation.

The team should include expertise on augmented reality, interface design, task analysis, and workload.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II system/software demonstration and delivering a demonstration system/software package including source code for NASA testing.

This technology will support NASA's Human Spaceflight Architecture Team List of Critical Technologies, including HAT 4.7.a-E Crew Autonomy Beyond LEO (systems and tools to provide the crew with independence from Earth-based ground support) and HAT 6.3.e-E Deep Space Mission Human Factors and Habitability (human factors technology in design).

For proposers who may be interested in applying these concepts to Aeronautics systems, please see Subtopic A3.01 - Advanced Air Traffic Management Systems Concepts.