



NASA SBIR 2018 Phase I Solicitation

Space Technology

Z1.01 High Power Arrays for Solar Electric Propulsion

Lead Center: GRC

Participating Center(s): JPL, LaRC

Technology Area: TA15 Aeronautics

NASA is seeking developments in advanced solar array power technology for very high power (500kW) systems to support future NASA missions involving Solar Electric Propulsion (SEP) and other in-space applications. The objective is to develop solar-powered systems and components that are lightweight, reliable, compactly stowed, survivable within the space environment (i.e., minimal degradation due to space particulate radiation, UV, micrometeoroid impacts, thermal cycling, spacecraft contaminants, and space environmental effects), and provide sufficient stiffness to minimize adverse spacecraft dynamics issues. Of particular interest are technologies that:

- Reduce the overall solar array cost through modularity, minimization of part counts, automated fabrication and testing, and reduced material costs.
- Enable high voltage operation of the solar array with minimal space environmental interactions that could lead to degraded array performance.
- Survive long-term exposure within a solar electric propulsion thruster environment.

Technology advancements may include developments in solar cells, blanket technology, array designs, array deployment techniques (including in-space robotic assembly), improved manufacturing processes, and the ability to adequately ground-test and space-qualify these large array designs.

Z1.03 Fission Surface Power Generation

Lead Center: GRC

Participating Center(s): JPL, JSC

Technology Area: TA15 Aeronautics

NASA is considering the use of kilowatt class Fission Power Systems for surface missions to the moon and Mars. Current work in fission power systems is focused on the Kilopower project which uses a highly-enriched Uranium-Molybdenum reactor core with a Beryllium oxide reflector. Depleted uranium, tungsten, and lithium hydride provide shielding of gamma rays and neutrons to the power conversion system, control electronics, payload, and habitat. Heat is removed from the core at approximately 800° C using sodium heat pipes and delivered to dynamic power conversion systems with conversion efficiencies over 25%. Waste heat is removed from the power conversion system at approximately 100° C using water heat pipes coupled to aluminum or composite radiator panels. The Kilopower project targets the 1-10 kW power range with most previous work focused on a demonstration of the 1 kWe design. The current solicitation is focused on innovations that enable the scaling of the 1 kWe design to 10 kWe, with a specific focus on surface power applications. Areas of interest include:

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- Isolation of core, heat pipes, and convertor hot end from Martian environment with minimal impact to neutronics.
 - Thermal interface methods including bonding of heat pipes to the core and direct coupling of heat pipes to power conversion (both hot and cold side).
 - Reduction in shield mass through:
 - Increased radiation tolerance of electronics including power electronics, control electronics, and instrumentation.
 - Increased distance from core with mass effective PMAD and transmission or lightweight possibly retractable booms.
 - Robust and reliable power conversion and controller technology. Power conversion can consist of multiple lower power units which could be combined to create 10 kW of electric power. Power conversion must be reliable and robust while maintaining at least 25% efficiency from heat in to usable electric output from PMAD.
 - Compact/stowable heat rejection. Options could include flexible / deployable heat pipe radiators or alternatives that make use of the Martian atmosphere for cooling.

Z2.01 Thermal Management

Lead Center: JSC

Participating Center(s): GRC, GSFC, JPL, MSFC

Technology Area: TA15 Aeronautics

NASA seeks new technologies that will facilitate low mass and highly reliable thermal control systems for exploration vehicles. Broad topics of interest include development of: high efficiency lightweight radiators, advanced heat exchangers and cold plates, condensate separators with inlet air/water volume ratios greater than 99:1 and outlet separation efficiency of greater than 95%, phase change materials with optimized thermal capacity to structural mass ratios, high heat flux acquisition and transport devices, variable heat rejection technologies, closed-loop space suit thermal systems, high efficiency miniature pumped fluid systems, and improved thermal math modeling tools. Of particular interest in this solicitation are thermal control technologies that serve an integrated vehicle level function at a net mass benefit, those that enable human missions to Mars, and those enabling more than 24 hours of operation on the surface of Venus.

Integrated Spacecraft Solutions

The development of the systems required for spacecraft operations generally focus on providing a single primary function. Here, novel thermal control hardware that provides additional vehicle level functionality at a net mass benefit is sought. A concept of interest is body mounted radiators that provide effective micrometeoroid protection for deep space vehicles. Such a radiator must continuously provide its thermal control function while tolerating the micrometeoroid environment of cis-lunar space. The integrated radiator/micrometeoroid shield should have a radiator fin-efficiency better than 0.95. The shielding approach taken should provide a similar level of module and radiator flow tube protection as is currently in use on the International Space Station (ISS). The shielding configuration for ISS modules is 2 mm thick Al Alloy 6061 T6 stood off from the pressure vessel. The radiator tube shielding is a 1.2 mm thick aluminum bumper above a 4.75 mm gap, followed by a second 0.3 mm aluminum bumper over the flow tube. Another concept of interest includes flexible radiator solutions that could be integrated with existing inflatable structures. Flexible radiator solutions should meet a fin efficiency of at least 0.85 and provide radiative optical properties consistent with the current state of the art.

Enabling Thermal Control Technologies Missions to Mars

Operating large vehicles on the Martian surface presents unique challenges on a number of vehicle systems. During the entry, descent, and landing phase of the mission spacecraft surfaces are expected to experience incident heat loads up to 3.5 W/cm² for up to 5 minutes over the course of entry. These heat fluxes result in radiative equilibrium temperatures between 500 K and 900K. As a result, vehicle components must either be

isolated from these loads or tolerate the loads by design. Large pumped fluid loop radiators, as the currently exist, were not designed to tolerate these types of external loads. Here NASA seeks new highly efficient radiator designs that are capable of surviving the described entry environment. Radiator designs should target mass to area ratios better than 5.4 kg/m². In addition to external loads experienced through the entry phase, the vehicle must also be capable of managing its own heat load. Concepts that incorporate both external environment tolerance and vehicle thermal management are desired.

Thermal Systems for Surface Missions to Venus

Proposals are sought for enabling thermal technology systems for the in-situ planetary exploration of deep atmosphere and surface environments. A driving scenario is exploration of the surface of Venus through the use of long-lived (> day) landers. Venus features a dense, CO₂ atmosphere completely covered by clouds with sulfuric acid aerosols, a surface temperature of 760K, and a surface pressure of 90 atmospheres. Thermal technologies are needed that permit more than 24 hours of operation of internal components within a 1 m diameter pressure vessel while minimizing resources consumed by the thermal system. A total systems approach must be considered that may include, but are not limited to, novel insulation, energy storage, heat pumping, and expendable coolant systems. The thermal system should be capable of providing heat management for 150 W of average internal dissipation. The entire assembly initial temperature can be assumed to be 273K and the maximum allowable temperature of internal equipment is 343K. Proposals must include a detailed description of the assumptions, thermal model, and bases of estimate for mass and power consumption of the technologies being put forward. Phase I results should include analytical proof-of-concept and provide a feasibility and development assessment of novel thermal control technologies. Phase II results should include development and testing of a prototype system or key piece of enabling technology identified in the Phase I effort.

Z3.01 Advanced Metallic Materials and Processes Innovation

Lead Center: MSFC

Participating Center(s): JPL, LaRC

Technology Area: TA15 Aeronautics

This subtopic addresses specific NASA needs in the broad area of metals and metals processes with the focus for this solicitation on solid state welding, additive manufacturing, and processing of specialty materials including bulk metallic glasses and nano-crystalline metallic alloys.

Solid State Joining

Topic areas for solid state welding revolve around joining metallic materials preferably using solid state welding processes such as friction stir, thermal stir, and ultrasonic stir welding. Higher melting point materials of interest include the nickel based super-alloys such as Inconel 718, Inconel 625, titanium alloys such as Ti-6Al-4V, GRCo, and Mondaloy. Lower melting point materials of interest include Aluminum alloys such as 2195 and 2219. The technology needs for solid state welding should be focused on process improvement, structural efficiency, quality, and reliability for propulsion and propulsion-related components and hardware.

For the 2018 solicitation, the solid state joining focus is:

- Advances in process control, temperature monitoring and control, closed loop feedback, and implementing changes to the process parameters such as temperature, power, welding speed, etc.
- Monitoring and controlling processing parameters in real time in order to make quality, defect-free weld joints with desired and optimal grain morphology, mechanical properties and minimal distortion.
- Innovations in in-situ diagnostic and non-destructive testing technologies for solid state welding.
- Decoupling of the stirring, heating, and forging process elements characteristic of thermal or ultrasonic stir welding to achieve greater process control.
- Solid state welding of aluminum alloys plates of thicknesses greater than ½ inch.

Additive Manufacturing

Several NASA programs are embracing metallic Additive Manufacturing (AM) technologies for their potential to increase the affordability of aerospace components by offering significant schedule and cost savings over traditional manufacturing methods. This technology is rapidly evolving and a deeper understanding of the process is needed to support hardware development and the use of AM hardware. For this subtopic AM topic area needs are concentrated on advancing the state of the art for the development powder bed fusion and/or directed energy deposition processes.

For the 2018 solicitation, the AM focus is:

- Surface finish improvements for internal and external AM components targeting a goal of 32 RMS; approaches may include in-situ process modifications to achieve better surface finishes directly from the AM machine, or secondary finishing approaches. The impact on total cycle time and cost from CAD to final part should be assessed as part of the justification for the approach proposed. The goal of work supporting this area is to help build the knowledge needed to support development of AM hardware.
- Development of hardware and/or process modifications to eliminate distortion and thermal residual stresses in as-built AM parts.
- Development of hardware and software tools that enable integrated CAD-to-part digital data capture, comparison, and archival for maintaining a “digital twin” correlation between parts and CAD design, slicing and tool path programming, in-process build information, secondary processing, and inspection data to document a traceable pedigree on parts.

Specialty Metals

In the specialty materials processing area, the focus for this solicitation is on bulk metallic glasses (BMG) and nano-crystalline metallic alloys. Specific areas of interest relate to optimized processing to fabricate these materials while retaining their unique microstructures and properties.

Specialty Metals: Nano-crystalline

Grain-size strengthening is a well-known phenomenon in metallic materials. The challenge for engineering applications has been maintaining ultrafine-grained microstructures in bulk materials. Processes that can demonstrate the production of stable, nano-grain structures without negative performance impacts are of interest. Exploiting these high-strength microstructures will enable new applications within NASA. One such application of interest is thin-walled structures, such as composite overwrapped pressure vessels (COPVs), where traditional material grain sizes approach the thickness of the part (< 25 grains through the wall). This leads to design challenges and concerns for fracture and fatigue properties. Ideally, nano-grained alloys with sufficient strength, ductility, and fracture/fatigue properties can be used to overcome design issues in thin-gage components.

For the 2018 solicitation of specific interest for nano-grained metallic alloys are innovative processing methods that:

- Produce bulk materials with grain sizes in the nanometer range for alloys of interest to NASA application (e.g., structural Al and titanium alloys).
- Ensure that these nano-grained structures are stable during:
 - Relevant thermal exposures experienced in aerospace applications of interest to NASA and meet typical property requirements for those applications, and/or,
 - post-fabrication heat treatment, if necessary to develop suitable properties, and/or,
 - incorporation into end use items via additive manufacturing methods.

Specialty Metals: Bulk Metallic Glass

Of specific interest for BMGs are innovative processing methods for rapid prototyping of net shape bulk metallic glass components. Product forms of interest are uniformly thin walled structures, structures of high dimensional accuracy and precision (from nm to cm scales), and structures with features larger than the critical casting thickness of the BMG alloy but still amorphous. Consideration must be given to the availability of BMG feedstocks or accommodating the raw materials for in-situ alloy fabrication. Any approach should demonstrate control of

contaminant elements (e.g., oxygen and carbon) or show an immunity to their presence.

For the 2018 solicitation of specific interest for bulk metallic glasses are innovative processing methods that:

- Rapid prototyping, while maintaining high dimensional accuracy.
- Uniform thin walled structures, that again, retain high dimensional accuracy.
- BMG structures with features that are larger than the critical thickness, but still amorphous.

Z4.01 MISSE Experiments

Lead Center: LaRC

Participating Center(s): MSFC

Technology Area: TA15 Aeronautics

Space technology experiments are solicited to fly on a new space environmental effects platform on the outside of the International Space Station (ISS). The new platform is called the MISSE-FF (Materials International Space Station Experiment - Flight Facility). The 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 (2 inches by 2 inches up to 7 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 commercial partner Alpha Space Test and Research Alliance, LLC (Alpha Space) plans to service the MISSE-FF every 6 months. The MISSE-FF data will be made available to the global community of researchers through the NASA MAPTIS (Materials and Processes Technical Information System) database. Phase I deliverables could be data from ground testing the candidate technology and passive samples for flight on the MISSE-FF. Phase II deliverables could include an active technology experiment, packaged and ready for flight on the MISSE-FF. The experiments would fly free of charge with standard services on the NASA surface area allocation of the MISSE-FF. Any optional services desired from Alpha Space should be included in the proposal budget.

Z4.02 In-Space Sub-Modular Assembly

Lead Center: LaRC

Participating Center(s): GSFC, JSC, MSFC

Technology Area: TA15 Aeronautics

NASA envisions that persistent (very long duration) assets in space will require modular assembly architectures and interfaces to facilitate routine expansion, upgrade and refurbishment at the module and submodule level. This subtopic seeks novel approaches to two classes of module interface systems.

First, autonomous (and highly automated) approaches and hardware concepts that support the interconnection of modules in the 100 – 5,000 kg range using some form of space robotics. (Note: The robotic manipulation systems are not the subject of this solicitation.) The objective of this first subtopic area is to minimize the parasitic mass from the joints and modularity features that are required for inter-module assembly. The lightweight connections between modules must include both electrical (power and data) and structural connections. Joining strategies that

support fluid connections are of interest but not necessary to be responsive to this subtopic area. The structural connection should occur at a minimum of 3 discrete locations fixing the rigid body motion of the 2 modules in all 6 degrees of freedom while isolating (minimizing) forces resulting from thermal induced strain between the modules consistent with a LEO orbit. The three (or more) connections do not have to occur simultaneously.

The second assembly need is the development of a lightweight modular, palletizing system to support transport, emplacement and exchange of sub-modules in the 1-100 kg range. The palletizing system must support power and structural connections between the pallet and supporting backbone structure (fluid connections are a plus). Important considerations for the system are structurally efficient approaches that minimize parasitic mass, volume and power necessary to operate the palletizing system while minimizing forces resulting from temperature induced strain consistent with a LEO orbit.

25.01 Augmented Hybrid and Virtual Reality (XR) Technology for Human & Robotics Exploration

Lead Center: JSC

Participating Center(s): AFRC, JPL, KSC

Technology Area: TA15 Aeronautics

Within the ISS Program, maintenance requires well trained crew members and is labor intensive, expensive and inefficient. NASA uses paper and electronic procedures to direct crew through complex maintenance procedures for all on-board systems. Developing and executing procedures are still time consuming and tedious tasks, and substantial training is needed to understand the technical details for troubleshooting defective components, and the performance of critical maintenance and repairs. *X-R* based technology systems could have the potential to support future human exploration missions by providing the type of guidance normally associated with an expert human trainer. The capabilities of envisioned future *X-R* based systems will augment the ability of the crew while being simple and highly intuitive to use.

On board maintenance is one of the potential areas in which *X-R* technology can be a game changing technology. Other areas such as physical and mental health support for long duration mission isolation from family and friends, mission planning, mission data visualization, are also to be considered in the context of this topic.

The objective of this subtopic is to develop and mature *X-R* technology (system/ software) and to impact all aspects of mission operations including planning, execution, training and crew health countermeasures, in order to enable human exploration beyond LEO.

Proposal are sought to address the following Technology Areas:

- TA-4 TABS 4.4 Human Systems Interface: augmenting the natural environment with precise visual cues as well as with audible and tactile alerts to fully engage and guide the human operator through lengthy and complex spaceflight procedures.
- TA-4 TABS 4.5 Autonomy: using *XR* technology to enable crew autonomous operation and reduce dependency for ground support.
- TA-6 TABS 6.3 Human Health and Performance: using *X-R* technology to enhance situational awareness and to reduce cognitive overload while performing complex task.
- TA-7 TABS 7.5 Mission Operations & Safety: using *X-R* technology to reduce human error, improve operational efficiency and mission timeline while reducing prior training requirements.

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 for NASA testing.

25.02 Robotic Systems - Mobile Manipulation

Lead Center: JSC

Participating Center(s): ARC, GRC, KSC

Technology Area: TA15 Aeronautics

NASA seeks innovative robotics solutions for upcoming missions to lunar orbit and the lunar surface. This targeted call seeks unique combinations of mobile manipulation, defined as work systems able to position themselves and then perform work with limbs. This combination of mobility and manipulation is a technical challenge, with static manipulation systems or mobile systems poorly suited to perform work being more common. The intent for this subtopic is to stimulate new solutions to the challenges of mobile manipulation, capturing recent advances in robotics technology in numerous terrestrial sectors that are relevant to space exploration. Broader topics of interest include perception, mobility for extreme terrain, autonomous control, human-robot interaction and dexterous manipulation. Lunar surface challenges involve mobile manipulation in soft soils, extreme thermal conditions, and sustained periods of no or low communication with Earth. Challenges in lunar orbit involve mobile manipulation in zero gravity, positioning work systems for preventive maintenance, logistics handling and contingency operations of a dormant spacecraft with reduced communication. Human interaction with these robotic systems will be limited due to communication blackout periods and time delay, and must be optimized for both mobility phases and manipulation phases of work. These lunar missions require low mass, low power and low volume solutions. All command and control approaches for human interaction should assume limited communication capabilities, requiring supervision of autonomous systems. Surface systems must be robust despite challenges of dust and thermal cycles. Orbital systems must be safe around human crew members and able to work with spacecraft interfaces intended for humans. Technologies proven in near term lunar missions must be scalable for future Mars exploration.

Z5.03 Payload Technologies for Free-Flying Robots

Lead Center: JSC

Participating Center(s): JPL, JSC

Technology Area: TA15 Aeronautics

The objective of this subtopic is to develop technology that can be integrated as payloads (software and/or hardware) on free-flying robots, which operate in human environments and/or assist humans. Current free-flyers include space robots, micro UAVs, quadcopters, etc. Applications of free-flying robots to space exploration include:

- Supporting the caretaking of human spacecraft and habitats by autonomously performing critical maintenance and monitoring functions.
- Supporting astronaut activity (intravehicular or extravehicular) with survey, preparation, real-time support (e.g., tool/sample delivery), and follow-up work.

On the International Space Station (ISS), for example, the SPHERES robots have shown how free-flying robots can perform environment surveys, inspection, and crew support. In addition, STMD is currently developing the "Astrobee" free-flying robot to perform mobile camera, mobile sensor, and microgravity robotics testing on the ISS starting in mid-2018. Proposals are sought to create payloads that can be integrated with small-scale free-flying robots, including the following areas (in order of interest):

- *Human-Robot Interfaces* - Payloads that facilitate communication and coordination between humans (local and remote) and AFFs. This includes displays (3D screens, projectors, etc.), signaling devices (light indicators, sound generation, etc.), and human monitoring (activity recognition, gaze/motion tracking, etc.).
- *Operational Subsystems* - Payloads that can be used to enhance the performance or the capability of AFFs for future deep-space exploration missions. This includes subsystems for extended AFF operations (power systems, efficient propulsion, etc.), supporting crew (e.g., mobile health monitoring), routine maintenance, emergency response, and other use cases.
- *Sensors* - Compact sensors relevant to the scenarios listed above, including functions such as interior environment monitoring, interior/exterior structural inspection, free-flying navigation, 3D environment

modeling, etc.

- *End Effectors* - Small, lightweight mechanisms that can be used for docking/perching, prodding/pushing, tool carrying, etc. This may include deployable structures, universal end-effectors (e.g., jamming granular gripper), devices incorporating gecko or electrostatic adhesion, and devices that can interact with handles, storage lockers, and small IVA tools. Note: complete robot manipulator arms are NOT being solicited.

Proposers are encouraged to target the development of these payload technologies to the Astrobee free-flying robot. For Astrobee, payloads should ideally be less than 1 kg in mass, consume less than 5 W electrical power (5 VDC @ 1 A), interface via USB 2.0, and stow within a 10x10x10 cm volume. Payloads that exceed these specifications may still target Astrobee, but may require special accommodations. Proposals must describe how the technology will make a significant improvement over the current state of the art, rather than just an incremental enhancement, for a specific free-flying robotic application.

Z7.01 Entry Descent & Landing Sensors for Environment Characterization, Vehicle Performance, and Guidance, Navigation and Control

Lead Center: LaRC

Participating Center(s): JPL, JSC, LaRC

Technology Area: TA15 Aeronautics

NASA manned and robotic missions to the surface of planetary or airless bodies require Entry, Descent, and Landing (EDL). For many of these missions, EDL represents one of the riskiest phases of the mission. Despite the criticality of the EDL phase, NASA has historically gathered limited engineering data from such missions, and use of the data for real-time Guidance, Navigation and Control (GN&C) during EDL for precise landing (aside from Earth) has also been limited. Recent notable exceptions are the Orion EFT-1 flight test, MSL MEDLI sensor suite, and the planned sensor capabilities for Mars 2020 (MEDLI2 and map-relative navigation). NASA requires EDL sensors to:

- Understand the in-situ entry environment.
- Characterize the performance of entry vehicles.
- Make autonomous and real-time onboard GN&C decisions to ensure a precise landing.

This subtopic describes three related technology areas where innovative sensor technologies would enable or enhance future NASA EDL missions. Candidate solutions are sought that can be made compatible with the environmental conditions of deep spaceflight, the rigors of landing on planetary bodies both with and without atmospheres. Proposers may submit to topic areas 1, 2 or 3 below:

- High accuracy, light weight, low power fiber optic sensing system for EDL instrumentation systems.
- Miniaturized spectrometers for vacuum ultraviolet & mid-wave infrared radiation in-situ measurements during atmospheric entry.
- Novel sensing technologies for EDL GN&C and small body proximity operations.

High Accuracy, Light Weight, Low Power Fiber Optic Sensing System for EDL Instrumentation Systems

Current NASA state-of-the-art EDL sensing systems are very expensive to design and incorporate on planetary missions. Commercial fiber optic systems offer an alternative that could result in a lower overall cost and weight, while actually increasing the number of measurements. Fiber optic systems are also immune to Electro-Magnetic Interference (EMI) which reduces design and qualification efforts. This would be highly beneficial to future planetary missions requiring thermal protection system (TPS).

Fiber optic sensing systems can offer benefits over traditional sensing system like MEDLI and MEDLI2, and can be used for both rigid and flexible TPS. To be considered against NASA state-of-the-art TPS sensing systems for future flight missions, fiber optic systems must be competitive in sensing capability (measurement type, accuracy, quantity), and sensor support electronics (SSE) mass, size and power.

The upcoming Mars 2020 mission will fly the Mars Entry, Descent, and Landing Instrumentation II (MEDLI2) sensor suite consisting of a total of 24 thermocouples, 8 pressure transducers, 2 heat flux sensors, and a radiometer embedded in the TPS. This set of instrumentation will directly inform the large performance uncertainties that contribute to the design and validation of a Mars entry system. A better understanding of the entry environment and TPS performance could lead to reduced design margins enabling a greater payload mass fraction and smaller landing ellipses. Fiber optic sensing systems can offer benefits over traditional sensing system like MEDLI and MEDLI2, and can be used for both rigid and flexible TPS. Fiber optic sensing benefits include, but are not limited to; sensor immunity to EMI, the ability to have thousands of measurements per fiber using Fiber Bragg grating (FBG), multiple types of measurements per fiber (i.e., temperature, strain, and pressure), and resistance to metallic corrosion.

To be considered against NASA state-of-the-art TPS sensing systems for future flight missions, fiber optic systems must be competitive in sensing capability (measurement type, accuracy, quantity), and sensor support electronics (SSE) mass, size and power. Therefore, NASA is looking for a fiber optic system that can meet the following requirements:

- Sensing Requirements:
 - TPS Temperature: Measurement Range: -200 to 1250° C (up to 2000° C preferred), Accuracy: +/- 5° C desired.
 - Surface Pressure: Measurement Range: 0-15 psi, Accuracy: +/-1%

- Sensor Support Electronics Requirements (including enclosure):
 - Weight: 12 lbs or less,
 - Size: 240 cubic inches or smaller,
 - Power: 15W or less,
 - Measurement Resolution: 14-bit or Higher,
 - Acquisition Rate per Measurement: 16 Hz or Higher,
 - Compatibility with other sensors types (e.g.) Heat Flux, Strain, Radiometer, TPS recession.

Miniaturized Spectrometers for Vacuum Ultraviolet & Mid-Wave Infrared Radiation In-Situ Measurements During Atmospheric Entry

The current state-of-the-art for flight radiation measurements includes radiometers and spectrometers. Radiometers can measure heating integrated over a wide wavelength range (e.g., MEDLI2 Radiometer), or over a narrow-wavelength bands (COMARS+ ICOTOM at 2900 nm and 4500 nm). Spectrometers gather spectrally resolved signal and have been developed for Orion EM-2 (combined Ocean Optics STS units with range of 190-1100 nm). A spectrometer provides the gold standard for improving predictive models and improving future entry vehicle designs.

For NASA missions through CO₂ atmospheres (Venus and Mars), a majority of the radiative heating occurs in the midwave infrared range (MWIR: 1500 nm - 6000 nm) [Brandis, AIAA 2015-3111]. Similarly, for entries to Earth, the radiation is dominated by the Vacuum Ultraviolet range (VUV: 100 - 190 nm) [Cruden, AIAA 2009-4240]. Both of these ranges are outside of those detectable by available miniaturized spectrometers. While laboratory scale spectrometers and detectors are available to measure these spectral ranges, there are no versions of these spectrometers which would be suitable for integration into a flight vehicle due to lack of miniaturization. This SBIR calls for miniaturization of VUV and MWIR spectrometers to extend the current state of the art for flight diagnostics.

Advancements in either VUV or MWIR measurements are sought, preferably for sensors with:

- Self-contained with a maximum dimension of ~10 cm or less.
- No active liquid cooling.
- Simple interfaces compatible with spacecraft electronics, such as RS232, RS422, or Spacewire.

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- Survival to military spec temperature ranges [-55 to 125C].
 - Power usage of order 5W or less.

Novel Sensing Technologies for EDL GN&C and Small Body Proximity Operations

NASA seeks innovative sensor technologies to enhance success for EDL operations on missions to other planetary bodies (including Earth's Moon, Mars, Venus, Titan, and Europa). Sensor technologies are also desired to enhance proximity operations (including sampling and landing) on small bodies such as asteroids and comets. NASA is also looking for high-fidelity real-time simulation and stimulation of passive and active optical sensors for computer vision at update rates greater than 2 Hz to be used for signal injection in terrestrial spacecraft system test beds. These solutions are to be focused on improving system-level performance Verification and Validation during spacecraft assembly and test.

Sensing technologies are desired that determine any number of the following:

- Terrain relative translational state (altimetry/3-axis velocimetry).
- Spacecraft absolute state in planetary/small-body frame (either attitude, translation, or both).
- Terrain characterization (e.g., 3D point cloud) for hazard detection, absolute and/or relative state estimation, landing/sampling site selection, and/or body shape characterization.
- Wind-relative vehicle state and environment during atmospheric entry (e.g., velocity, density, surface pressure, temperature).

Successful candidate sensor technologies can address this call by:

- Extending the dynamic range over which such measurements are collected (e.g., providing a single surface topology sensor that works over a large altitude range such as 1m to >10km, and high altitude rates such as greater than 45° /sec).
- Improving the state-of-the-art in measurement accuracy/precision/resolution for the above sensor needs.
- Substantially reducing the amount of external processing needed by the host vehicle to calculate the measurements.
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of Size, Weight, and Power (SWaP), spacecraft accommodation complexity, and/or cost.
- Providing sensors that are robust to environmental dust/sand/illumination effects.
- Mitigation technologies for dust/particle contamination of optical surfaces such as sensor optics, with possible extensibility to solar panels and thermal surfaces for Lunar, asteroid, and comet missions.
- Sensing for wind-relative vehicle velocity, local atmospheric density, and vehicle aerodynamics (e.g., surface pressures and temperatures).

27.03 Deployable Aerodynamic Decelerator Technology

Lead Center: LaRC

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

Technology Area: TA15 Aeronautics

Background: NASA is developing deployable aerodynamic decelerators to enhance, and enable, robotic and human missions to destinations such as Mars, Venus, and Titan, as well as returning payloads to Earth from Low Earth Orbit (LEO). The biggest challenge facing Entry, Descent and Landing systems is the delivery of human class missions to the surface of Mars. One benefit of deployable decelerators is that a relatively large atmospheric entry vehicle can be packed into, and deployed from, a comparatively small space transit vehicle. Eliminating these entry vehicle size constraints imposed by the launch system enables delivery of very large (20 metric tons or more) of usable payload required to support Mars human exploration. For reference, it is estimated that safely landing 20 metric tons may need a deployable diameter as large as 20 meters. The technology also allows for the return of payloads from LEO and recovery of launch assets that will reduce the cost of space access. This subtopic area

solicits innovative technology solutions applicable to deployable entry vehicles. Specific technology development areas include:

- Advancements in woven and non-woven textile technologies that can be used in the design and production of mass efficient flexible thermal protection systems (TPS) such as durable, high-temperature fibrous insulators capable of efficiently suppressing both radiation and convective heat transfer at temperatures above 1200° C. TPS concepts must be flexible to allow compact stowage. They can be passive approaches that do not rely on decomposition to manage heat loads, or active systems, such as phase change approaches, that enhance thermal management capability. Reusable concepts and/or materials, capable of surviving multiple atmospheric entries, are of particular interest. Focus of Phase I development can be subscale manufacturing demonstrations that lead to Phase II manufacturing scale up that is relevant to Mars human exploration.
- Concepts that augment the drag of rigid or deployable hypersonic aerodynamic decelerators subsequent to the hypersonic entry phase. Envisioned secondary decelerator systems would be activated after the entry heat pulse during the earliest stages of the supersonic regime. Devices can be either deployable or rigid design concepts, but must be suitable for, and scalable to, a Mars human exploration architecture. Inflatable structural designs and deployment methods for a secondary decelerator that augment drag over the primary decelerator by a factor of 2 to 4 are to be considered. Phase I proof of concept and preliminary design requirements that will lead to a demonstration under a Phase II effort are of interest.
- Inflatable structural concepts with non-axisymmetric geometries, or features, that provide lift for flight control during atmospheric entry. Envisioned concepts can be deployed or adjusted to provide active flight control to improve landing accuracy. Concepts that provide lift-to-drag ratios of 0.1 to 0.2 during hypersonic flight conditions appear to be sufficient for human exploration of Mars. Lift-to-drag ratios of 0.8 or more may provide benefit, or may be enabling, for other destinations with atmospheres. Innovations can include morphing concepts, drag modulators, or center of gravity offset approaches. Thermal management and response time should be addressed. Phase I proof of concept and preliminary design requirements that will lead to a demonstration under a Phase II effort are of interest.

Z8.01 Cubesat Propulsion Systems

Lead Center: ARC

Participating Center(s): GSFC, JPL, MSFC

Technology Area: TA15 Aeronautics

The CubeSat market shows significant promise to enable low cost science and exploration missions. However, at present many CubeSat technology development activities do not reach flight, and missions that are flown are often selected for concept or component demonstration activities as the primary objectives. Several technology limitations challenge high value science from low-cost CubeSat missions. Limitations include, but are not limited to, post-deployment propulsion capabilities, radiation hardened flight computers, deep space communication, and available instruments. Additionally, propulsion systems often place restrictions on handling, storage, and operations that may limit a CubeSat's ability to launch as a secondary payload. Nevertheless, opportunities are anticipated in the near future to conduct a larger percentage of CubeSat missions based on application goals and pursue exploration and science return as the primary objectives.

Towards that end, this subtopic seeks to develop innovative long-life, reliable, and low-cost electric/chemical propulsion technologies that can enable small satellite science and exploration missions. This year, proposals are specifically sought for complete propulsion system solutions (thrusters, valves, propellant, sensors, electronics, etc.) capable of full scale flight demonstration on 27U, 12U, 6U, or 3U CubeSats in support of deep space and/or swarm topology missions. Proposers should place special emphasis on propulsion system solutions offering long life, reliability, and minimalistic use of CubeSat resources (power, energy, volume, and mass), while delivering propulsion capabilities within the scope of interests described below. Proposals will not be considered that focus purely on features, benefits, and advantages of a new technology, without addressing how their innovative propulsion solution supports improved mission outcome, cost, and productivity.

Proposers are expected to show a clear understanding of the current state-of-the-art (SOA) and quantitatively (not qualitatively) describe improvements over relevant SOA technologies that will substantiate the investments in the new technology. Quantification of improvement over the SOA should include any significant advancements that improves the capability of a CubeSat to carry out high-value science missions. For example, advancements are desirable in propulsion system lifetime, reliability, radiation tolerance, cost, energy utilization, miniaturization, thermal management, safety, propellant storage, etc. Potential opportunities for mission infusion for both technology demonstration and long-term mission application should be identified along with potential technology gaps that need to be addressed or assessed. Extensibility of technologies up to 180 kg satellites may be identified, though extensibility beyond 27U CubeSats is not required.

Green propellants are a subset of the propulsion technologies of interest. Green considerations may aid in reducing system mass, increase system safety, reduce cost of handling, and reduce integration risks in secondary payloads. Regardless of toxicity or propellant hazards, propulsion systems must show clear consideration for safe containment of the propellant through launch and system operations. These considerations may include the number of inhibits, post-launch pressurization schemes, etc.

Proposals are sought that can deliver hardware products and proof-of-concept demonstrations in Phase I. Proposals are sought that can deliver hardware at or greater than TRL 6 suitable for flight demonstration within the Phase II resources provided. Propulsion systems requiring Phase II-E or II-X funding will be considered if justified through mission enabling capabilities. Component level development proposals shall be considered, but must enable important new CubeSat mission capability and identify opportunities for near-term infusion. While component level development shall be considered, preference will be given to complete propulsion system solutions.

Specific propulsion capabilities of interest follow below. Metrics are provided either per unit of anticipated spacecraft volume (Usc) or per unit of propulsion system volume (Up). Where one unit of volume is defined as 10 cm cubed. Assume CubeSat wet mass as 2 kg/Usc. Proposers should specify to what S/C size (27U, 12U, 6U, and/or 3U) their propulsion system solution scales to meet or exceed the metrics below. If the propulsion solution can scale to satisfy multiple needs, proposers should quantitatively evaluate their solutions at each applicable scale and concisely present those capabilities in tables or figures. Proposers should also specify at what scale they intend to develop their demonstration hardware. Propulsion systems proposed should conceptually utilize no more than 1/3 the S/C total volume (e.g., propulsion system solutions for a 12U S/C should fit in 4U or less):

- High impulse propulsion systems meeting the following criteria:
 - Example applications: deep space, interplanetary, orbit capture.
 - Total impulse per unit of propulsion system volume > 4000 N-sec/Up.
 - Electric propulsion with thrust per S/C volume > 0.1 mN/Usc.
 - Lifetime > 2 years.
 - Propulsion system peak power per S/C volume < 5 W/Usc.
 - Design for deep space application (radiation tolerance, thermal attributes, etc.).
 - Propulsion systems including ACS.
- High thrust propulsion systems meeting the following criteria:
 - Example applications: Orbit raising (MEO, GEO), long life LEO.
 - Total impulse per unit of propulsion system volume > 750 N-sec/Up.
 - Chemical propulsion thrust per S/C volume > 5 mN/Usc.
 - Electric propulsion thrust per S/C volume > 0.5 mN/Usc.
 - Lifetime > 2 years.
 - Propulsion system peak power per S/C volume < 5 W/Usc.
 - Low soakback (i.e., minimal increase to local bus temperature).
 - Propulsion systems including ACS.
- Precision Control:
 - Example applications: formation flying, tight pointing requirements.
 - Minimum impulse bit per S/C volume < 0.1 microN-sec/Usc.
 - Lifetime > 2 years.
 - Propulsion system peak power per S/C volume < 5 W/Usc.

Preference for systems:

- Optimized for the rigors of interplanetary / deep space missions (i.e., radiation, thermal, etc.).
- placing no demanding storage or handling requirements prior to launch.
- Remaining quiescent under ambient conditions for > 6 months prior to launch.
- remaining quiescent under post-deployment conditions.

For small satellite propulsion technologies applicable to satellites larger than 27U (54 kg), please see subtopic Z10.02, "Propulsion Systems for Robotic Science Missions."

Z8.02 Communications for Distributed Small Spacecraft Beyond LEO

Lead Center: ARC

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

Technology Area: TA15 Aeronautics

Space communications and position knowledge and control are enabling capabilities required by spacecraft to conduct all NASA missions. The concept of distributed spacecraft missions (DSM) involves the use of multiple spacecraft to achieve one or more science mission goals. DSM configurations include widely dispersed configurations of spacecraft, constellations, free-flying swarms, formation flying swarms clusters, swarms of common elements, and disaggregated science mission elements, all operating in the space environments beyond low Earth orbit (LEO). The term, "swarm" refers to a configuration of spacecraft that communicate and exchange data and location information with each other and act as one controllable entity. In contrast, 'constellations' are loosely grouped spacecraft which may communicate with other but are flown individually. A swarm of dozens to hundreds of spacecraft located 10s to 100s km apart must be able to act as one unit. Small distributed spacecraft acting in cooperation can execute science and exploration missions that would be impossible by traditional large spacecraft, and offer the potential for new concepts in mission design. Innovations in communications and navigation technologies for distributed small spacecraft are essential to fulfill the envisioned science missions within the decadal surveys and contribute to the success of human exploration missions. The goal of this subtopic is to develop DSM-enabling technologies for communications, relative and/or absolute position knowledge, and control of small spacecraft (or other directly related technologies) for configurations of small spacecraft operating over large distances beyond LEO. This subtopic is a direct enabler of deep space distributed spacecraft science missions.

DSM Communications

Communications among spacecraft in the DSM configuration and between the configuration and the Earth become more challenging beyond LEO distances. Collaborative configurations of widely distributed (10s to 100s km apart) small spacecraft (180 kg or less) will operate far into the near-Earth region of space and beyond into deep space, further stressing the already limited communications capabilities of small spacecraft. The communications links to/from DSM spacecraft beyond LEO distances are closed via either NASA's near-Earth network (NEN) or deep space network (DSN) ground station infrastructure, depending on the distance of the spacecraft from Earth (i.e., NEN for < 2 million km, DSN for > 2million km).

The DSM communications portion of this subtopic invites innovative system level communications architecture and concepts of operation and an integrated communications payload design taking into consideration the following capabilities:

- *DSM configuration control* – For distributed operations of the DSM configuration and of individual small spacecraft. Identify alternatives, provide rationale for selection, and develop proposed approaches for: science data time and location stamping; temporary data storage; distributed network control and data planes; networking protocols; and any other considerations associated with control of the configuration.
- *Inter-satellite links (space-space)* – For coordinated exchange of science instrument data and spacecraft telemetry and command (T&C) data among small spacecraft in the DSM configuration. Identify alternatives and provide rationale for selection of proposed: frequency band(s) of operation or optical communications; multiple access and addressing techniques; minimum and maximum data rates; expected link bit error rate, maximum expected range between spacecraft, maximum spacecraft field of regard; and pointing stability

requirements.

- *Uplinks (Earth-space) and Downlinks (space-Earth)* – For coordinated command and control of the DSM configuration and individual small spacecraft from Earth and return of science and telemetry data to Earth. Identify alternatives and provide rationale for selection of proposed: frequency band(s) of operation or optical communications; ground terminal network; coordination with other users of the band(s); multiple access and addressing techniques; minimum and maximum data rates; expected link bit error rate, maximum expected range between spacecraft, ground terminal and maximum spacecraft field of regard; and pointing stability requirements.
- *Integrated communications payload*– For the common and unique capabilities of each small spacecraft in the DSM configuration. Identify proposed hardware and software designs of the small spacecraft communications payload(s) required to implement the proposed communications links and operational controls.

In addition to the system level concepts of operation and integrated communications payload design, innovations and advancements in technology readiness in one or more of the following constituent small distributed spacecraft technologies is also requested:

- *Small Spacecraft Antennas* – Development of antennas optimized for either inter-satellite or uplink/downlink communications are sought across a broad range of technologies including but not limited to deployable parabolic or planar arrays, active electronically steered arrays, novel antenna steering/positioning subsystems, and others suitable for use in high data rate transmission among small spacecraft over large distances. Operations compatible with NASA's space communications infrastructure [1] and Government exclusive or Government/non-Government shared frequency spectrum allocations is required. [See References for applicable Government frequency spectrum allocations in the near Earth and deep space regions].
- *Optical Communications* – Point-to-point communications are the most common approach for optical communications. This focus area seeks innovations that enable optical communications among many spacecraft simultaneously operating in a distributed spacecraft network. Technologies and integrated solutions for beaconless one-way and/or bidirectional two-way optical communications from beyond LEO to Earth-based optical terminals are also sought. Technology advancements in integrated solutions are sought that increase the data rate or availability of optical communications for small spacecraft, or reduce mission risk, pointing requirements, complexity or cost at a minimally-acceptable Quality of Service.
- *Transceivers and Radios* – This area includes but is not limited to: multiple access techniques; radio frequency (RF) transmitters; amplifiers; low noise receivers, full duplex frequency selectable RF front-ends, integrated navigation and communications receivers, software defined or reconfigurable radios, or integrated transceivers and radios for inter-satellite links among distributed spacecraft and/or uplink/downlink via the NEN or DSN. Small satellites are particularly constrained in terms of power, mass and volume, therefore significant improvements in these areas are highly effective. In addition to reductions in mass, power consumption, volume and cost, increases in power and bandwidth efficiency, operational flexibility and frequency select-ability are sought. Small spacecraft transceivers and radios must be compatible with the operations of NASA's space communications infrastructure. [1] [See References for applicable NASA near Earth and deep space infrastructure guidelines and specifications].
- *Networking Protocols and Processing* – Standard Internet protocols don't work well over communication links that are subject to the frequent, transient service outages and/or long signal propagation delays that are characteristic of missions beyond LEO. Innovations or advancements are sought in networking protocols and distributed data processing (routing/switching) and storage systems that enable secure, low-power networked communications among small spacecraft within the DSM configuration and/or between the configuration or individual spacecraft and network service users and operators on Earth and/or on the surfaces of other Solar System objects. Implementation of NASA's delay/disruption tolerant networking (DTN) standards to support scalable, robust and secure mission communications for small spacecraft links from beyond LEO to Earth are also invited. Interoperability between spacecraft operating with NASA and commercial space networks is an additional opportunity for innovation. [See References for applicable NASA and commercial networking standards].

Low mass, power, volume, cost and complexity are overarching goals. Leverage of commercial technologies or best commercial standards and practices (e.g., DVB-S2 standard, CubeSat form factors, 5G wireless technologies) that can demonstrably improve performance and be applied or adapted for use in Government, non-Government or commercial networks is also desirable.

Note: Proposed Earth-Space and Earth-Space communications links must be designed to operate in and comply with the frequency spectrum bands implemented by the NEN and/or DSN and/or comply with other frequency spectrum bands allocated by the U.S. National Telecommunications Information Administration (NTIA) tables of frequency allocations for space research. Links among distributed spacecraft must use frequency spectrum allocated by the NTIA in the U.S. for inter-satellite communications service (e.g., ~23 GHz, ~24.5 GHz, ~26 GHz, ~60 GHz).

Finally, small spacecraft communication systems operating beyond LEO must be robust, flexible and diverse to support a wide variety of interconnected configurations of spacecraft used by NASA to conduct space science, Earth science and exploration of the universe. Communication system components need to be able to operate over a range of environmental conditions, such as those imposed by launch vehicles and operations in space with appropriate levels of radiation tolerance in the space environment beyond LEO. A clear path to space qualification for potential operation in those regions of space is required of all proposed technologies.

DSM Position Knowledge and Control

Science measurements of DSMs are based on temporal and spatially distributed measurements where position knowledge and control are fundamental to the science interpretation. Current space navigation technologies are not adequate when relative or absolute position knowledge of multiple spacecraft are involved. Global navigation satellite services like the U.S. global positioning satellites (GPS) provide very limited services beyond GEO distances and no practical services in deep space. Autonomous navigation capabilities are fundamental to DSMs to ensure topography of the configuration is known at the time of data acquisition. Control of the distributed configuration requires robust absolute and relative position knowledge of each spacecraft within the configuration and the ability to control spacecraft position and movement according to mission needs.

The navigation portion of this subtopic solicits methods for determining and maintaining spacecraft position within a configuration of small spacecraft. DSM navigation solutions may be addressed via hardware or software solutions, or combinations of the two. Innovations and advancements in technologies for determining relative and absolute position knowledge include but are not limited to:

- *Radiometric measurements* - Exploitation of intersatellite communication links allows for measurements via one-, two-, or three-way ranging and/or Doppler shift measurements. Such measurements may allow for accurate estimation of the relative satellite position and velocity vectors in certain DSM topographies. Alternatively, solutions may adapt the proven signal designs of the Global Navigation Satellite Systems (GNSS, i.e., GPS, GLONASS, Galileo) for the purpose of deep space relative navigation. Novel estimation techniques that are feasible for small satellite processing platforms are also opportunities for innovation.
- *Laser based measurements* - Similar to the exploitation of radio communication systems mentioned above, an optical communication system may also provide range and/or range-rate measurements for relative orbit estimation. Innovations that leverage LIDAR technology for relative navigation of small satellites are also invited. Proposals that include satellite design enhancements for improved tracking are sought.
- *Optical navigation* - Solutions are sought for visual based systems that leverage advances in optical sensors (i.e., cameras, star trackers) to observe and track a target spacecraft and perform pose and relative position estimation. Opportunities for innovation include methods that do not require the execution of satellite maneuvers and/or the design of external satellite features that enhance observability. Innovations may be appropriate for only certain regimes, such as near, medium, or far range; this context should be described. Solutions for various mission operations concepts are of interest.
- *Other novel navigation methods* - Stellar navigation aids, such as navigation via quasars, X-rays and pulsars, may provide enabling capabilities in deep space. Earth-based navigation aids, such as systems detecting radio beacons or terrestrial landmarks, are invited.

Methods for autonomous position control are also of interest. Note: Small spacecraft propulsion technologies are not included in this subtopic as those are addressed in subtopic Z8.01, Cubesat Propulsion Systems. Technologies that accomplish autonomous relative orbit control among the spacecraft are invited. Control may be accomplished as part of an integrated system that includes one or more of the measurement techniques described above. Of particular interest are autonomous control solutions that do not require operator commanding for individual spacecraft. That is, control solutions should accept as input swarm-level constraints and parameters, and provide control for individual spacecraft. Opportunities for innovation include the application of optimization techniques that

are feasible for small satellite platforms and do not assume particular orbit eccentricities.

Phased Development Guidance to Proposers

A typical approach to advance the technology readiness level (TRL) leading to future flight hardware/ software demonstration of any of the DSM small spacecraft communications and navigation technologies intended for the beyond LEO environment would include:

Phase I - Identify and explore options for the DSM configuration control, conduct trade analysis and simulations, define operating concepts, and provide justification for proposed multiple access techniques, frequency bands of operation, command and data handling and networking solutions. Also identify, evaluate and develop design for integrated communications payload(s) and one or more constituent technologies that enable distributed spacecraft operations in the relevant space environment beyond LEO. Integrated communications system solutions and constituent components offer potential advantages over the state of the art, demonstrate their technical feasibility, and show a path towards a hardware/software infusion into practice. Bench-level or lab-environment level demonstrations or simulations are anticipated deliverables. The Phase I proposal should outline a path that shows how the technology can be developed into space-qualifiable and commercially available small spacecraft communications payloads through Phase II efforts and beyond.

Phase II - Emphasis should be placed on developing and demonstrating the candidate integrated communications payload and/or selected technologies under simulated constellations or swarms of small distributed spacecraft in the relevant beyond LEO environment. A demonstration unit for functional and environmental testing is an anticipated deliverable at the completion of the Phase II contract. Some of the products resulting from this subtopic may be included in a future flight opportunity for on-orbit testing or application demonstration.

All integrated communications systems and constituent technologies developed under this subtopic area should be compatible with existing NASA space communications infrastructure [1], frequency spectrum allocations, and applicable standards. However, applicability or adaptability to non-Government and commercial use as well is desirable.

[1] NASA's space communications infrastructure includes the Near-Earth network (NEN) of ground stations, the Space Network (SN) of tracking and data relay satellites in geostationary Earth orbit, and the Deep Space Network (DSN) of ground stations.

References:

- National Telecommunications and Information Administration Frequency Allocation Chart: <https://www.ntia.doc.gov/page/2011/united-states-frequency-allocation-chart> [1].
- National Telecommunications and Information Administration Tables of Frequency Allocations: <https://www.ntia.doc.gov/legacy/osmhome/allotbl/allotbl.html> [2].
- NASA Spectrum Policy: http://www.nasa.gov/directorates/heo/scan/spectrum/policy_and_guidance.html [3].
- Spectrum Guidance for NASA Small Satellite Missions: http://www.nasa.gov/sites/default/files/atoms/files/spectrum_guidance_smallsats_cubesats_2015.pdf [4].
- Near Earth Network (NEN) Users Guide: <https://sbir.gsfc.nasa.gov/sites/default/files/453-NENUG%20R2.pdf> [5].
- Space Network Users Guide (SNUG): <https://evt.grc.nasa.gov/rfp-industry-briefing-2016/wp-content/blogs.dir/52/files/sites/10/Space-Network-Users-Guide-SNUG-Rev-10.pdf> [6].
- Deep Space Network (DSN): <http://deepspace.jpl.nasa.gov/advmiss/missiondesigndocs/> [7].
- Delay/Disruption Tolerant Networking (DTN):
 - NASA DTN: <http://www.nasa.gov/content/dtn> [8].
 - InterPlanetary Networking Special Interest Group (IPNSIG) DTN www.ipnsig.org [9].

28.03 Low Cost Radiation Hardened Integrated Circuit Technology

Lead Center: ARC

Participating Center(s): ARC, GRC, GSFC, JPL

Technology Area: TA15 Aeronautics

As small spacecraft develop in capability, they have the need for more advanced supporting electronics. Low-cost, capable Integrated Circuit (IC) core chipsets are needed that are suitable for use in government and commercial small spacecraft, and other radiation-affected environments. In keeping with the small spacecraft design philosophy and general mission costing profiles, chipsets associated with state-of-the-art IC devices offer a significant potential for improved functionality in space capabilities and cost reduction. However, these devices usually have not been certified for use in the space environment and often have issues with the radiation found in space. As small satellite designers consider mission opportunities beyond low Earth orbit, there is a growing need for IC approaches that provide the functionality found in terrestrial applications and are able to perform their functions over the lifetime of a small satellite mission. Advancing commercial-type functionality to meet these operational needs is desired.

There are multiple potential development areas within the suite of spacecraft avionics functions, power systems, and instrument support functions can benefit from taking commercial IC concepts and making them space-ready, specific core chipset capabilities and requirements are not specified in this subtopic. Proposers should consider functions normally found within spacecraft systems (such as avionics, power systems, etc.) and propose solutions to make available for new spacecraft designers. Examples of technology development areas include, but are not limited to:

- *Fault tolerant FPGA/ASIC IP Cores* – To enable low cost radiation hardened integrated circuit development, fault tolerant intellectual property cores are sought that can be used to compose fault tolerant System-On-a-Chip (SOC) devices. These SOC devices may be used for spaceflight applications including, command and data handling, embedded power system controllers, embedded motor/actuator controllers, and instrument controllers. IP cores should be AMBA bus compatible, incorporate built-in test, and employ fault tolerance techniques. The IP cores should be sufficiently modular and reusable to allow the implementation of a wide variety of applications.
- *Software Mitigation for Single Event Upset Recovery* – Advanced methods to improve Single Event Upset (SEU) recovery in devices that can be demonstrated to comparable or better performance than hardware techniques across several metrics, such as mass and power, and have minimal impact to system speed performance.
- *ASIC Demonstrator* - Show how a specific rad hard IC for a defined application can be developed and evaluated by using a low-cost ASIC development approach.

In response to this topic, the proposer should:

- Identify the specific function to be advanced and demonstrate how it is not currently available at the full level performance needed.
- Identify the intended application environment(s), e.g., GEO, Cis-lunar space, deep space, etc.
- Explain how the proposed approach exceeds the state of the art in key metrics such as available functionality, power requirements, mass, radiation resistance, temperature range, etc.
- Identify the technology development necessary to get the proposed IC to the performance needed for the proposed environment and application.

The technology development plan needs to include test and verification to include full environmental testing so that the end customer can readily incorporate the chipsets into new vehicles without additional testing. Low-cost chipsets that are used both for space applications as well as terrestrial applications such as DoD, commercial aircraft, etc. are the primary emphasis for this call.

General purpose computing processors are explicitly excluded in this call.

Proposers are referred to topics S3.08 Command, Data Handling, and Electronics and S4.04 Extreme Environments Technology for related topics of potential interest.

29.01 Small Launch Vehicle Technologies and Demonstrations

Lead Center: ARC

Participating Center(s): KSC, LaRC, MSFC

Technology Area: TA15 Aeronautics

NASA is recognizing a growing demand for dedicated, responsive small spacecraft launch systems and seeks to facilitate the establishment of a robust launch service provider market sector. The movement toward small spacecraft missions is largely driven by rising development/launch costs associated with conventional spacecraft, which poses severe threats to future science/commercial mission cadence, and by rapidly evolving miniaturization innovations that are revolutionizing small spacecraft platform capabilities. This topic seeks innovative technologies, subsystems, and efficient streamlined processes that will support the development of affordable small spacecraft launch systems having a 5-180 kg payload delivery capacity to 350 to 700 km at inclinations between 28 to 98.2 degrees to support both CONUS and sun synchronous operations. Affordability objectives are focused on reducing launch costs to below \$1.5M/launch for payloads ranging up to 50 kg or below \$30,000/kg for payloads in excess of 50 kg. It is recognized that no single enabling technology is likely to achieve this goal and that a combination of multiple technologies and production practices are likely to be needed. Therefore, it is highly desirable that disparate but complementary technologies formulate and use standardized plug-and-play interfaces to better allow for transition and integration into small spacecraft launch systems.

Technology areas of specific interest are as follows:

- Innovative Propulsion Technologies & Prototype Stages.
- Affordable Guidance, Navigation & Control.
- Manufacturing Innovations for Launch Vehicle Structures & Components.
- Reusability Innovations.
- Dual Use Hypersonic Flight Testbeds.

Proposers are expected to quantify improvements over relevant SOA technologies and substantiate the basis for investment. Potential opportunities for technology demonstration and commercialization should be identified along with associated technology gaps. Ideally, proposed technologies would be matured to TRL 4 to 6 by the end of Phase II effort. Efforts leading to Phase II delivery of integrated prototype stages that could either be ground tested or flight-testing as part of a post-Phase II effort are of particular interest. A brief descriptive summary of desired technical objectives and goals are provided below.

Innovative Propulsion Technologies & Prototype Stages

Innovative chemical propulsion technologies/subsystem and integrated stage concepts are sought that can serve as the foundational basis of an affordable ground-launch or air-launch system architecture. The scope of interest includes main propulsion systems and novel reaction control systems based on conventional or novel propellants. Technologies or subsystems are expected to demonstrate proof-of-concept by the end of Phase II as a minimum and proposals should include a development roadmap for achieving this goal. Efforts aimed at Phase II delivery of integrated prototype stages that could either be ground tested or flight tested as part of a post Phase II effort are highly encouraged and desired. Technical approaches that address the critical challenges associated with downward scaling of launch vehicles are also highly sought. Solutions that directly address staging sensitivities on deliverable payload mass, for instance, would be of keen interest. Design simplicity, reliability, and reduced development and recurring costs are all important factors. Proposers should explain how their technology works and provide a quantitative assessment of State-of-Art (SOA) in terms of key performance and/or cost metrics. The degree to which the proposed technology or concept is new, different, and important should also be made evident.

Affordable Guidance, Navigation, & Control

Affordable guidance, navigation & control (GN&C) is a critical enabling capability for achieving small launch vehicle performance and cost goals. Innovative GN&C technologies and concepts are therefore sought to reduce the significant costs associated with avionics hardware, software, sensors, and actuators. The scope of interest

includes embedded computing systems, sensors, actuators, algorithms, as well as modeling & design tools. Low cost commercially available components and miniaturized devices that can be repurposed as a basis for low-SWaP GN&C systems are of particular interest. Special needs include sensors that can function during prolonged periods of high-g and high-angular rate (i.e., spin-stabilized) flight, while meeting the stringent launch system environment requirements pertaining to stability and noise. A low-cost GPS receiver capable of maintaining lock, precision, and accuracy during ascent would be broadly beneficial, for example. Sensors that can withstand these conditions might be sourced from industrial and tactical applications, and performance requirements may be achievable by fusing multiple measurements, e.g., inertial and optical (sun, horizon) sensors. Modular actuator systems are also needed that can support de-spin and turn-over maneuvers during ascent. These can include cold-gas or yo-yo type mechanisms. Improved designs are needed to reduce the overall power and volume requirements of these types of actuator systems, while still providing enough physical force to achieve the desired maneuver and enable orbital insertion. Programmable sequencers are required to trigger actuators for events such as stage sequencing, yo-yo and shroud deployment. In addition to hardware, software algorithms for autonomous vehicle control are needed to support in-flight guidance and steering. Robust control laws and health management software are of interest, particularly those that address performance and reliability limitations of affordable hardware. This is especially important in the typical high dynamics (acceleration and angular velocity) conditions of proposed small launch vehicles. Algorithms that are able to merge data from redundant onboard sensors could improve reliability compared to expensive single-string sensors. Similarly, advanced ground-alignment, initialization, and state estimation routines that integrate noisy data are desired to support ascent flight. These algorithms take advantage of improved onboard computational capability in order to process observations from lower accuracy sensors to provide higher fidelity information. Implementations of state-of-the-art Unscented Kalman Filters, and Square-Root-Information Filters with robust noise and sensor models are particularly applicable. Successful technologies should eventually be tested in relevant environments and at relevant flight conditions. Potential testbeds include a variety of spacecraft and aircraft at a variety of scales. Capabilities include reduced gravity, suborbital reusable launch vehicles, high altitude balloons, subscale to ultra-high-altitude aircraft, and in-flight simulation.

Manufacturing Innovations for Launch Vehicle Structures & Components

The development of more efficient vehicle structures and components are sought to improve small launch vehicle affordability. This may include the adoption and utilization of modern lightweight materials, advanced manufacturing inspired design innovations, or systems for actively alleviating launch loads and environments. Approaches for achieving life-cycle cost reductions might also include reduced part count by substitution of multifunctional components; additive and/or combined additive and subtractive manufacturing; repurposing launch structure for post-launch mission needs; incorporating design features that reduce operating costs; adoption of lean best practices for production and manufacturing; and shifting towards commercial practices and/or componentry. Alternatively, approaches based on the utilization of heavier materials could lead to simpler parts, fewer components, and more robust design margins. Although this could yield a larger rocket and impose performance penalties, significantly reduced life-cycle costs could be realized due to overall lower manufacturing and integration cost. Proposers should provide a quantitative assessment of State-of-Art (SOA) in terms of key performance and/or cost metrics. The degree to which the proposed technology or concept is new, different, and important should also be made evident.

Reusability Innovations

Reusability innovations and subsystem concepts are sought that can serve as the foundational basis of a high flight rate, gas-and-go launch system architecture. Various subsystem technologies are amenable to development and testing via the SBIR program that could then be infused into commercial RLV developments. The scope of interest includes highly reusable propulsion systems that are capable of multiple flights without significant degradation and with minimal inspection/refurbishment requirements. Reusability solutions that directly address vehicle integration, mission profile/transition sensitivities and projected life cycle effects would be of keen interest. This could include quick turnaround ground servicing technologies that enable rapid inspection, maintenance/repair, reloading, and re-flight of stages. Design simplicity, reliability, and reduced development and recurring costs are all important factors. Proposers should explain how their technology works and provide a quantitative assessment of State-of-Art (SOA) in terms of key performance and/or cost metrics. The degree to which the proposed technology or concept is new, different, and important should also be made evident.

Dual Use Hypersonic Flight Testbeds

The potential repurposing and dual use applications of small launch vehicles as hypersonic flight technology

testbeds is of great interest. If low cost small launch vehicle concepts can be dual purposed as affordable hypersonic flight testing platforms with a high degree of commonality, it would open up a highly lucrative sector with significant commercial and defense market potential. The scope of interest is on launch vehicle derived concepts that could boost or gravity turn into a cruise altitude in the range of 75-100 Kft and accelerate a hypersonic testbed stage to a speed of Mach 4 or higher. Because small launch vehicle boosters typically undergo stage-1 to stage-2 separation in the Mach 8-10 range, it is conceivable that these vehicles could serve as low-cost boost phase systems for hypersonic flight testbeds equal in weight to the fully loaded orbital upper stage. Testbed concepts adaptable for a wide range of hypersonic technology investigations, including air breathing propulsion systems and thermal protection systems, while also offering payload recovery and partial testbed stage reusability, are strongly encouraged.

Z10.01 Cryogenic Fluid Management

Lead Center: GRC

Participating Center(s): JSC, MSFC

Technology Area: TA15 Aeronautics

This subtopic solicits technologies related to cryogenic propellants (such as hydrogen, oxygen, and methane) storage, and transfer to support NASA's exploration goals. This includes a wide range of applications, scales, and environments consistent with future NASA missions. Such missions include but are not limited to a Methane Upper Stage, Nuclear Thermal Propulsion, Lander Propulsion, and In-Situ Resource Utilization in support of the Evolvable Mars Campaign.

Specifically, listed in order of importance:

- Develop reliable cryogenic screen channel acquisition devices (NASA is mainly interested in screens with pore sizes < 100 μm) using innovative manufacturing techniques to minimize stresses of cryogenic screen channels to improve screen-to-window manufacturing reliability. Reliability should be based on changes in bubble point pressure before and after thermal cycling the elements (> 10 times) at or below 77 K.
- New and improved technologies that provide for the densification (or sub-cooling) of cryogenic propellants. Propellant conditioning systems that allow for the production and maintenance of densified propellants that support operations including transfer and low-loss storage are of prime interest for future space vehicle and ground launch processing facilities.
- Advanced numerical design tools are sought for cryogenic propellant management systems accounting for large EUS-scale operations in relevant low-gravity (low-acceleration) environments. Ideally, such a tool should consider thermal gradients, acceleration gradients, perturbations due to docking, and orbital maneuvers in order to help system designers evaluate the impacts of these various environments to the propellant management system. Advanced numerical design tools are sought for fuels/cryogenic management systems accounting for large EUS-scale operations in relevant low-gravity (low-acceleration) environments considering the impacts of thermal gradients, gravity gradients, perturbations due to docking, orbital maneuvers, self-gravitation, and others.
- Develop an insulation to reduce the heat leak in the annulus space of approximately $\frac{3}{4}$ " which is located over a liquid hydrogen tank but under a broad area cooled (BAC) shield at 90 K for space applications. The insulation concept has the dual function of structurally supporting the 5 mil thick broad area cooled shield and roughly 35-40 outer layers of traditional multi-layer insulation (MLI) (or less with high performing MLI) and reducing the heat leak from the 90K surface to the LH₂ tank. Analysis shall focus on the thermal design's reduction of conductive and radiative heat transfer in the vacuum of space to minimize heat load (> 70% reduction in insulation heat load compared to equivalent MLI system without BAC shield) to the tank while being lightweight for flight.
- System/stage cryogenic valves sized for 3 in. (7.62 cm) tube size for low pressure (<50 psia; 3.4 bar), scalable to 10 in. (25.4 cm) size, with Cv > 200, low internal (~ 1 sccm, goal of < 0.1 sccm) and external (~ 3 sccm, goal of < 0.1 sccm) leakage, > 500 cycles with a goal of 5,000 cycles, low heat leak (<3 W/valve), low actuation power. The valve should have a clear path to combine with an actuator and its requirements.
- Electric Pump technologies with low power (<40-50 kW) at flowrates suitable for feeding iRCS accumulator(s) supplying a bank of four (4) 1000-lb RCS engines operating at total oxygen or

methane mass flowrates of ~8-10 lb/s (3.6-4.5 kg/s), or Low power (<4-6 kW) supplying a bank of four (4) 100-lb RCS engines, operating at a total flowrate of ~1 lb/s (0.45 kg/s). The pumps will operate between low pressure (<50 psia; <3.4 bar) propellant tanks, up to supercritical pressures >667 psia (>46 bar) under varying duty cycle demand regimes. Note actual duty cycle requirements will be mission specific – proposers should describe scalability to handle changes in demand, and changes in the scale of thrusters per thruster bank (e.g., 3x100-lb & 1x1000-lb, etc.).

Phase I proposals should at a minimum deliver proof of the concept including some sort of testing or physical demonstration (not just a paper study). Phase II proposals will be expected to provide component validation in a laboratory environment preferably with a hardware deliverable to NASA.

Z10.02 Propulsion Systems for Robotic Science Missions

Lead Center: GRC

Participating Center(s): JPL, MSFC

Technology Area: TA15 Aeronautics

The Science Mission Directorate (SMD) needs spacecraft with more demanding propulsive performance and flexibility for more ambitious missions requiring high duty cycles, more challenging environmental conditions, and extended operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in-situ exploration of planets, moons, and other small bodies in the solar system. Mission priorities are outlined in the decadal surveys for each of the SMD Divisions. (<https://science.nasa.gov/about-us/science-strategy/decadal-surveys> [10]) Future spacecraft and constellations of spacecraft will have high-precision propulsion requirements, usually in volume-, mass-, and power-limited envelopes.

This subtopic seeks innovations to meet SMD propulsion in chemical and electric propulsion systems related to sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus. Additional electric propulsion technology innovations are also sought to enable low-cost systems for Discovery class missions, and low-power, nuclear electric propulsion (NEP) missions. The roadmap for in space propulsion technologies can be found at the following Office of Chief Technologist website (https://www.nasa.gov/sites/default/files/atoms/files/2015_nasa_technology_roadmaps_ta_2_in-space_propulsion_final.pdf [11]).

Proposals should show an understanding of the state-of-the-art (SOA), how their technology is superior, and of one or more relevant science needs. The proposals should provide a feasible plan to fully develop a technology and infuse it into a NASA program. In addressing technology requirements, proposers should identify potential mission applications and quantify the expected advancement over SOA alternatives.

Advanced Electric Propulsion Components

Towards that end, this subtopic seeks proposals that explore uses of technologies that will provide superior performance, reduce complexity, increase reliability, and/or lower cost for high specific impulse/low mass electric propulsion systems. These technologies include:

- Long-life heaters for hollow cathodes made with lanthanum hexaboride (LaB₆) or other materials. In order to achieve reliable cathode ignition, the LaB₆ heaters typically must operate at 1500 – 1700° C. Reproducible fabrication processes that minimize unit-to-unit variations in performance and lifetime will be critical for the practical adaptation of a new heater technology.
- High-temperature electromagnets for Hall thrusters, capable of operating reliably at >500° C.
- 3D printing of magnetic materials for Hall thruster magnetic circuits.
- Low-cost gas distributors capable of achieving a high degree of flow uniformity in Hall thruster anode gas feeds.
- Advanced ceramics for Hall thruster discharge chambers.
- Feed systems for ultra-high-Isp gridded ion thrusters running on lithium propellant.

This subtopic also seeks to mature and demonstrate iodine electric propulsion technologies. Iodine propellant has two key advantages over the SOA xenon propellant: (i) increased storage density and (ii) reduced storage pressure. These key advantages permit iodine propulsion systems with conformal storage tanks, reduced structural mass, and reduced volume compared with the SOA xenon, while retaining similar thrust, specific impulse, and thruster efficiency. Technologies of interest include, but are not limited to:

- Robust and electrically efficient iodine storage and delivery technology (scalable 1 kg to 100 kg iodine) for sub-kilowatt Hall Effect and Ion thrusters:
 - Computational models are desired to evaluate novel iodine feed system concepts and CONOPS. Modeling capabilities of interest include, but are not limited to:
 - Optimizing power consumption and iodine mass transport.
 - Predicting sublimation rate and system pressures.
 - Understanding expected anomalies such as iodine deposition, clog formation, clog recovery, and material interactions.
 - Proposals are desired that systematically validate new modeling predictive capabilities with appropriate experimental demonstrations and perform investigations where existing literature is insufficient.
 - High-reliability, long-life iodine storage and delivery systems are desired that package efficiently in volume-limited spacecraft, minimize spacecraft energy consumption, minimize thermal loading on spacecraft structures and neighboring components, and can remain quiescent for long periods with minimal or no maintenance or degenerative material interactions. Proposals are desired that offer supporting analysis or experimental evidence that a concept has merit. Proposals should provide a plan to theoretically refine the design concept, construct a prototype with a minimum 1 kg iodine capacity, perform experimental analysis in a relevant environment, refine the concept as necessary, and demonstrate. Demonstrations need not be performed with an operational thruster, but should be integrated in a test apparatus that reasonably replicates the fluid-dynamic and thermodynamic loads expected when integrated in a complete system. Given the current lack of demonstrated high life iodine compatible cathodes, hybrid feed systems are preferentially desired, which accommodate an iodine thruster matched with a xenon cathode (High life iodine compatible cathodes are also sought in this subtopic).
- High-reliability, long-life, compact, low-power iodine feed subsystem technologies are desired, including:
 - Iodine compatible high-accuracy pressure sensors, novel propellant flow control and metering technologies, filtration, propellant management devices, etc.
 - New iodine-compatible materials, coating, or otherwise innovative construction techniques leading to long-life, reliable, and corrosion resistant components.
- Iodine compatible cathodes with lifetimes of at least 2,000 hours, goal of greater than 10,000 hours.

Solar/Electric Sail Propulsion

This subtopic seeks sail propulsion innovations in three areas for future robotic science and exploration missions:

- Large solar sail propulsion systems with at least 1000 square meters of deployed surface area for small (<150 kg) spacecraft to enable multiple Heliophysics missions of interest.
- Electric sail propulsion systems capable of achieving at least 1 mm/sec² characteristic acceleration to support Heliophysics missions of interest and rapid outer solar system exploration.
- Electrodynamics tether/sail propulsion systems capable of generating from the Lorentz Force ΔV sufficient to de-orbit from altitudes up to 2,000 km and to maintain a small (< 500 kg) spacecraft in LEO at altitudes up to 400 km for 5 years enabling Earth ionospheric and plasmasphere investigations.

Design solutions must demonstrate high deployment reliability and predictability with minimum mass and launch volume and maximum strength, stiffness, stability, and durability. In the case of tethers, advancements are needed for tether deployment and control, and for dynamic modeling/simulation and ground test methods, due to the high rate of space mission failures and anomalies for tether systems. For electric sail concepts and related future flight demonstrations, wire/tether deployment and control is considered one of the highest risk areas for successful flight.

Innovations are sought in the following areas:

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- Novel design, packaging, and deployment/control concepts.
 - Lightweight, compact components including booms, substrates, and mechanisms.
 - Validated modeling, analysis, and simulation techniques.
 - Ground and in-space test methods.
 - High-fidelity, functioning laboratory models.

Note: Cubesat propulsion technologies for spacecraft smaller than 27U should be submitted to STMD subtopic: Z8.01 - Cubesat Propulsion Systems

Z10.03 Nuclear Thermal Propulsion (NTP)

Lead Center: GRC

Participating Center(s): GRC, SSC

Technology Area: TA15 Aeronautics

Solid core NTP has been identified as an advanced propulsion concept which could provide the fastest trip times with fewer SLS launches than other propulsion concepts for human missions to Mars over a variety of mission years. NTP had major technical work done between 1955-1973 as part of the Rover and Nuclear Engine for Rocket Vehicle Application (NERVA) programs. A few other NTP programs followed including the Space Nuclear Thermal Propulsion (SNTP) program in the early 1990's. The NTP concept is similar to a liquid chemical propulsion system, except instead of combustion in the thrust chamber, a monopropellant is heated with a fission reactor (heat exchanger) in the thrust chamber and exposes the engine components and surrounding structures to a radiation environment.

Engine System Design

Focus is on a range of modern technologies associated with NTP using solid core nuclear fission reactors and technologies needed to ground test the engine system and components. The engines are pump fed ~25,000 lbf with a specific impulse goal of 900 seconds (using hydrogen), and are used individually or in clusters for the spacecraft's primary propulsion system. The NTP can have multiple start-ups (>4) with cumulative run time >100 minutes in a single mission, which can last a few years. The Rover/NERVA program ground tested a variety of engine sizes, for a variety of burn durations and start-ups with the engine exhaust released to the open air. Current regulations require exhaust filtering of any radioactive noble gases and particulates. The NTP primary test requirements can have multiple start-ups (>8) with the longest single burn time ~50 minutes.

Technologies being sought include:

- Low Enriched Uranium reactor fuel element designs with high temperature (> 2600 K), high power density (>5 MW/L) to optimize hydrogen propellant heating.
- New advanced manufacturing processes to quickly manufacture the fuel with uniform channel coatings and/or claddings that reduce fission product gas release and reactor particulates into the engines exhaust stream. Fuels are focused on Ceramic-metallic (cermet) designs:
 - New fuel element geometries which are easy to manufacture and coat, and better performing than the traditional prismatic fuel geometries with small through holes with coatings.
 - Best joining and manufacturing processes for tungsten, molybdenum, and molybdenum/tungsten alloys.
- Insulator design (one application is for tie tubes and the other is for interface with the pressure vessel) which has very low thermal conductivity and neutron absorption, withstands high temperatures, compatible with hot hydrogen and radiation environment, and light weight.

Operations and Safety

Engine operation involves start-up, full thrust operation, shutdown, coast, and restart. Technologies being sought

include advanced instrumentation and special reactor safety design features which prevent uncontrolled reactor criticality accidents. Specific areas of interest include:

- Concepts to cool down the reactor decay heat after shutdown to minimize the amount of open cycle propellant used in each engine shutdown (Depending on the engine run time for a single burn, cool down time can take many hours).
- Low risk reactor design features which allow more criticality control flexibility during burns beyond the reactor circumferential rotating control drums, and/or provide nuclear safety for ground processing, launch, and possible launch aborts:
 - Control of criticality with water submersion and compaction accidents.

Ground Test Technologies

Included in this area of technology development needs are identification and application of robust materials, advanced instruments and monitoring systems capable of operating in extreme temperature, pressure and radiation environments. Specific areas of interest include:

- Efficient generation of high temperature, high flow rate hydrogen (<30 lb/sec).
- Devices for measurement of radiation, pressure, temperature and strain in a high temperature and radiation environment:
 - Non-intrusive diagnostic technology to monitor engine exhaust for fuel element erosion/failure and release of radioactive particulates.

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 2-3). 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 component and/or breadboard validation measurements, including populated verification matrix from Phase I (TRL 4-5). Opportunities and plans should also be identified and summarized for potential commercialization.

Z11.01 NDE Sensors

Lead Center: LaRC

Participating Center(s): ARC, JSC

Technology Area: TA15 Aeronautics

Technologies sought under this SBIR program can be defined as advanced sensors, sensor systems, sensor techniques or software that enhance or expand NASAs current sensor capability. It is desirable but not necessary to target structural components of space flight hardware. Examples of space flight hardware will include light weight structural materials including composites and thin metals. Technologies sought include modular, smart, advanced Nondestructive Evaluation (NDE) sensor systems and associated capture and analysis software. It is advantageous for techniques to include the development on quantum, meta- and nano sensor technologies for deployment. Technologies enabling the ability to perform inspections on large complex structures will be encouraged. Technologies should provide reliable assessments of the location and extent of damage. Methods are desired to perform inspections in areas with difficult access in pressurized habitable compartments and external environments for flight hardware. Many applications require the ability to see through assembled conductive and/or thermal insulating materials without contacting the surface. Techniques that can dynamically and accurately determine position and orientation of the NDE sensor are needed to automatically register NDE results to precise locations on the structure. Advanced processing and displays are needed to reduce the complexity of operations

for astronaut crews who need to make important assessments quickly. NDE inspection sensors are needed for potential use on free-flying inspection platforms. Integration of wireless systems with NDE may be of significant utility. It is strongly encouraged to provide explanation of how proposed techniques and sensors will be applied to a complex structure. Examples of structural components include but are not limited to multi-wall pressure vessels, batteries, tile, thermal blankets, micrometeoroid shielding, International Space Station (ISS) Radiators or aerospace structural components.

Phase I Deliverables - Lab prototype, feasibility study or software package including applicable data or observation of a measurable phenomenon on which the prototype will be built. Inclusion of a proposed approach to develop a given methodology to Technology Readiness Level (TRL) of 2-4. All Phase Is will include minimum of short description for Phase II prototype. It will be highly favorable to include description of how the Phase II prototype or methodology will be applied to structures.

Phase II Deliverables - Working prototype or software of proposed product, along with full report of development and test results. Prototype or software of proposed product should be of Technology Readiness Level (TRL 5-6). Proposal should include plan of how to apply prototype or software on applicable structure or material system. Opportunities and plans should also be identified and summarized for potential commercialization.

For proposers with an interest in airframes, please see Subtopic A1.01 - Structural Efficiency - Tailored Airframes and Structures.
