NASA is seeking performance improvements to Power Management and Distribution (PMAD) systems through increases to the operating voltages of these electrical components. Specifically, NASA is developing Solar Electric Propulsion systems that use Power Processing Units (PPUs) to convert the 300V solar array output to the 700V-2000V input level of an electric thruster. Although many diodes and transistors exist in the commercial market place that would represent significant improvements over the state of the art space-qualified components, these parts have failed to pass critical tests related to space qualification most importantly in terms of their radiation tolerance. It is believed that the development and integration of high-voltage diodes and transistors that can be space-qualified will lead to increases in system-level performance as they will tend to increase efficiency and decrease mass at the system architecture level.

Proposals are solicited that address the gap for high-power, high-voltage electrical, electronic and electromechanical (EEE) parts suitable for the space environment through design and development of high-voltage, high-power diodes and/or transistors. Proposals must state the initial component state of the art and justify the expected final performance metrics. The proposals must also include plans for validating tolerance to both heavy-ion and total dose radiation. Target radiation performance levels include:

- 300 krad(Si) total ionizing dose tolerance.
- For vertical-field power devices: No heavy-ion induced permanent destructive effects upon irradiation while in blocking configuration (in powered reverse-bias/off state) with ions having a silicon-equivalent surface-incident linear energy transfer (LET) of 40 MeV·cm²/mg and sufficient energy to fully penetrate the epitaxial layer(s) prior to the ions reaching their maximum LET (Bragg peak).
- For all other devices: No heavy-ion induced permanent destructive effects upon irradiation while in blocking configuration (in powered reverse-bias/off state) with ions having a silicon-equivalent surface-incident linear energy transfer (LET) of 75 MeV·cm²/mg and sufficient energy to fully penetrate the active volume prior to the ions reaching their maximum LET (Bragg peak).

Z1.02 Surface Energy Storage

Lead Center: GSFC

Participating Center(s): JPL, JSC

Technology Area: TA15 Aeronautics
NASA is seeking innovative energy storage solutions for surface missions on the moon and Mars. The objective is to develop energy storage systems for landers, construction equipment, crew rovers, and science platforms. Energy requirements for mobile assets are expected to range up to 120 kW-hr with potential for clustering of smaller building blocks to meet the total need. Requirements for energy storage systems used in combination with surface solar arrays range from 500 kW-hr (Mars) to over 14 MW-hr (moon). Applicable technologies such as batteries and regenerative fuel cells should be lightweight, long-lived, and low cost. Of particular interest are technologies that are multi-use (e.g., moon and Mars) or cross-platform (e.g., lander use and rover use). Strong consideration should be given to environmental robustness for surface environments that include day/night thermal cycling, natural radiation, partial gravity, vacuum or very low ambient pressure, reduced solar insolation, dust, and wind. Creative ideas that utilize local materials to store energy would also be considered under this subtopic.

Advanced secondary batteries that go beyond lithium-ion, can safely provide >300-400 watt-hours per kilogram, and have long calendar and shelf lives are highly desired for cross-cutting applications. Secondary batteries that can operate at -60°C with excellent capacity retention as compared to room temperature operation are also highly desired. Additionally, for the Mars Ascent vehicle, secondary batteries that can operate reliably after a 15 year shelf life are highly desired.

Of interest for fuel cells and regenerative fuel cells are technologies that can mature hydrogen-oxygen fuel cells and electrolyzers and can address challenges common to both fuel cells fed by oxygen and methane and electrolyzers fed by carbon dioxide and/or water. Hydrocarbon fuels of interest include, but are not limited to, methane, residual fuel scavenged from lander propulsion tanks, and fuels generated by processing lunar and Mars soils. Components and systems of interest include fuel cells, stack, materials, and system development. For space and Lunar applications, gravity-independent operation should be considered in the design. For Mars applications, cell and stacks capable of Mars atmosphere electrolysis should be considered in the design. High power density for fuel cells, high efficiency for regenerative fuel cells, and designs that are scalable to 1 to 3kW sizes are highly desirable.

Z1.03 Surface Power Generation

Lead Center: GSFC

Participating Center(s): JPL, JSC

Technology Area: TA15 Aeronautics

NASA is seeking novel fission-based power generation technologies for surface missions on the moon and Mars. The objective is to develop power generation systems for landers, crewed habitats, and in-situ resource utilization plants. Power requirements are expected to range up to 40 kW with potential for clustering of smaller building blocks to meet the total need. Applicable thermal energy conversion should be lightweight, long-lived, and low cost. Of particular interest are technologies that are multi-use (e.g., moon and Mars). Strong consideration should be given to environmental robustness for surface environments that include day/night thermal cycling, natural radiation, partial gravity, vacuum or very low ambient pressure, reduced solar insolation, dust, and wind. Recognizing that small businesses are not likely to develop the nuclear fuel core, proposals are solicited for the key non-nuclear components and sub-systems. Specific areas of interest include power conversion technologies that enable system level specific power above 5 W/kg, advanced manufacture of heat exchangers for power conversion, reliable and radiation hard controllers, reactor and power conversion thermal interfaces, neutron reflectors, and radiation shielding.

Z2.01 Thermal Management

Lead Center: JSC

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

Technology Area: TA15 Aeronautics
**Exploration Vehicle Thermal Systems**

**Variable Heat Rejection Technologies**

Exploration vehicles require variable heat rejection due to the potential to operate in environments ranging from full sun on one side to a cold deep space environment, while rejecting a range of waste heat loads. NASA Technology Roadmap Area 14 identifies a turn down goal of 6 to 1 for a thermal control system. Room temperature thermal control systems are sought that are sized for nominal operation in full sun exposure, yet are able to maintain set point control and stable operation at one-sixth of their design heat load when in a deep space (0°K) environment. Solutions for variable heat rejection may include novel architectures, novel thermal control fluids, advanced radiator technologies, and/or variable working fluid/radiator conductance. Radiator-based technologies should have an areal mass no greater than 5.8 kg/m².

**Advanced-Closed Loop Extravehicular Activity Thermal Control**

NASA continues to evolve space suit technology for exploration missions; however, the portable life support system (PLSS) includes a water evaporator to reject waste energy produced by the suit. Closed-loop, non-venting thermal heat rejection systems that are capable of rejecting heat in the Martian atmosphere are needed to create a PLSS that minimizes consumable use and does not impact the Mars environment. NASA seeks novel approaches to close the thermal control system of the space suit, targeting 80% or greater reductions in evaporated water mass for the same heat rejection. However, the mass and volume of the system must be limited as it must be carried on the crewmember's back. Approaches may include novel radiative approaches and/or desiccant systems to reclaim evaporants, as well as other novel solutions. Examples of such technologies and goals are outlined in NASA's Technology Roadmap Area 06, but more innovative concepts are also sought.

**Advanced Heat Exchangers and Coldplates**

Air/liquid heat exchangers (HXs), liquid/liquid HXs, and coldplates are at the core of any active thermal control system for a space vehicle. While these individual components are small, they are found throughout spacecraft vehicles and their cumulative mass and volume is significant. Advances in materials or manufacturing may yield a considerable mass savings over the current state of the art heat exchangers. NASA's Technology Roadmap Area 14 details various points of interest for these heat exchangers, and key goals are listed below:

- Corrosion resistant coldplates with less than the state of the art 8.8 kg/m² mass per area.
- Heat exchangers with minimal structural mass and good thermal performance to reduce mass below 2 kg/kW of heat transfer, assuming delta-T on the order of 5°C.
- Condensing heat exchangers (air/liquid heat exchangers) for closed loop life support, achieving highly reliable 3-year minimum lifetime, not contaminated by microbial growth, and whose coatings do not impact the life support system's water recovery system.

**High Lift Heat Pumping Devices**

Heat pumps are needed to reject spacecraft waste heat to a higher temperature sink. At lunar equatorial locations, lunar surface temperatures can climb to 400°K, making it difficult to reject waste heat at nominal temperatures. A more severe application involves rejecting waste heat for a Venus lander where environmental sink temperatures can exceed 700°K. Ground-based designs that do not rely on gravity for elements of heat pump operation, such as lubricant management, contaminant control, or phase separation, are a reasonable starting point for a high lift heat pump device for extreme environment applications. However, these designs must be adapted or proven to work in space applications. Intermittent operation in microgravity, low gravity, and/or in severe environments, such as hard vacuum, radiation, and extreme temperatures, are significant challenges to viable space-based heat pumps. NASA seeks targeted improvements for space-based heat pump technology, which may include exceptionally long life, low mass, and operation with high temperature lifts (50°C or more) and a coefficient of performance at least at 30% of Carnot efficiency.

**Thermal Insulation for Pressurized Environments**

To enable longer duration missions to the surface of Venus, advanced insulation systems are required. External insulation on a Venus lander pressure vessel allows the system to take advantage of the thermal mass of the
pressure vessel and reduce the heat transfer rate into the pressure vessel. The goal is to extend mission lifetime to collect and transmit more science data by allowing multiple communication passes with an orbiter. In addition to Venus in-situ explorers, this insulation can be used for future deep atmospheric probes for gas giant planets, or even in high temperature and pressure chemical processes in other systems. The current state-of-the-art in insulation systems considered for the Venus atmosphere are heavy, fragile and difficult to implement on the exterior of a pressure vessel. NASA seeks a lightweight, flexible insulation system that can be accommodated on the exterior of a pressure vessel. The insulation thermal conductivity should be less than 0.1 W/m-K at 470°C and 90 bar pressure in a carbon dioxide environment.

Z3.01 In-Situ Sensing of Additive Manufacturing Processes for Safety-Critical Aerospace Applications

Lead Center: MSFC

Participating Center(s): ARC, GRC, LaRC

Technology Area: TA15 Aeronautics

NASA programs are embracing Additive Manufacturing (AM) technologies for their potential to increase the affordability of propulsion parts and components by offering significant schedule and cost savings over traditional manufacturing methods. Many NASA programs baseline AM components in their design, however qualification efforts are complicated by the absence of industry-accepted standards and process controls. The near-term methodology for part quality assurance is to use pre-process and post-process measurements to show that a part design and as-built hardware meet the established requirements to safely and reliably complete the intended mission. This method relies heavily on the ability to non-destructively evaluate parts to identify process escapes resulting in flaws in the AM parts. For parts of complex geometry, which is often the motivation toward AM, post-build inspections can be limited. The long-term goal of part qualification is to "qualify as you go." This concept uses pre-process, in-process, and post-process measurements to demonstrate that a part will perform to requirements. Successful technology demonstration has the potential to reduce scrap rates, and the cost and quantity of post-build NDE required for part qualification.

The principal desired outcome of this subtopic is to develop reliable in-process sensing and monitoring technologies for powder bed fusion (PBF) AM processes to aid in the quality of processes used to produce critical components for aerospace applications. Current AM PBF technologies run with limited or no process feedback; therefore, the ability to rely on process control alone is limited and the ability to non-destructively inspect AM parts is critical to the flight rationale for fracture critical components. The ability to augment AM process controls with verifiable feedback regarding process stability and part quality will significantly reduce the risk associated with complex AM parts that cannot be readily inspected with available non-destructive evaluation methods. The objective of the subtopic is to support activities that provide a foundation for practical application of AM sensing and monitoring technology in the aerospace sector, and also enable and stimulate development and innovation within the topic area. Supported activities will be based on long-term vision and the immediate needs of NASA programs and projects.

Specific research objectives include:

- Sensing technologies for layer-by-layer quality confirmation.
- In-process monitoring and sensing to detect off-nominal process conditions or defects.
- In-process monitoring and sensing for melt pool characterization.
- Predictive modeling of system response to sensing-related process changes.
- Multi-physics modeling of AM process as related to monitored quantities.

Z3.02 Advanced Metallic Materials and Processes Innovation

Lead Center: MSFC
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 boron nitride nanotube (BNNT) reinforced metal matrix composites (MMCs). Topic areas for solid state welding revolve around joining high melting point metallic materials including combinations of these higher melting point metals—preferably using solid state welding processes such as friction stir, thermal stir, and ultrasonic stir welding. Higher melting point materials include the nickel based superalloys such as Inconel 718, Inconel 625, titanium alloys such as Ti-6Al-4V, GRCop, and Mondaloy. The technology needs for solid state welding should be focused on process improvement, structural efficiency, quality, and reliability for higher temperature propulsion and propulsion-related components and hardware.

The primary objectives of this technology area include:

- 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.

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 certification and the use of AM hardware. The metallic AM topic area needs are concentrated on advancing the state of the art for powder bed fusion and/or directed energy wire deposition processes.

The primary objectives are focused on process improvements and include:

- 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.
- Linking process parameters to mechanical properties, microstructure, grain texture and grain size through empirical observations, real time process monitoring, or modeling.
- In-situ assessment or process monitoring of grain size, defect detection, build anomalies, and defect repair.
- Improved thermal monitoring and control hardware and methods to minimize build-to-build variations and microstructural anomalies.
- 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 for certification.

The goal of work supporting this area is to help build the knowledge needed to support certification of AM hardware. In the specialty materials processing area, the focus for this solicitation is on bulk metallic glasses (BMG) and BNNT reinforced MMCs. Specific areas of interest relate to optimized processing to fabricate these materials while retaining their unique microstructures and properties.

Of specific interest for BNNT MMCs are innovative processing methods that:
• Achieve uniform distribution and alignment of BNNTs within the metal matrix.
• Minimize the formation of brittle phases at the “reinforcing agent / metal” interface.

Product forms of interest include continuously- or discontinuously- reinforced nano-composites, and hybrid laminate materials. Improved processing may involve modifying incumbent methods such as powder metallurgy, melting/solidification, thermal spray, and electrochemical deposition or introduction of new method. The success of proposed processing improvements will be measured by increases in tensile strength achieved over existing alloys. Consequently, proposals must include characterization and testing of the fabricated materials.

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 and structures of high dimensional accuracy and precision (from nm to cm scales). 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.

Z4.01 In-Space Structural Assembly and Construction

Lead Center: LaRC
Participating Center(s): GSFC, MSFC

Technology Area: TA15 Aeronautics

Spacecraft that use modularity can be adaptable to changing needs particularly when open architectures with common interfaces are employed in the design. The ability to join spacecraft components autonomously in-space allows for the assembly of vehicles (perhaps aggregated from multiple launches) and for re-use of vehicle subsystems. Modular “plug and play” interfaces permit rapid assembly, upgrade and reconfiguration of spacecraft subsystems and instruments. The joining technology used for module interfaces should be reversible for maximum flexibility and utilize simple approaches (electro-mechanical or other) amenable to robotic assembly and disassembly. In addition, the joining technology must provide for mechanical, electrical and optionally thermal load transfer.

This subtopic seeks innovative spacecraft open architectures enabled by modularity and common interfaces that can be joined using autonomous robotic operations. Innovative joining technologies and capabilities are sought for in-space assembly, disassembly, and re-use of space exploration vehicles. Additionally, joint designs that support modular “plug and play” interfaces for upgrade and reconfiguration of spacecraft subsystems are sought. In-space joining of structural trusses that support multiple solar arrays for solar electric propulsion is one class of needed joint technology. The assembled truss must provide power connections either integral to the structural joint or as a non-mechanical load bearing harness with connectors. The second class of in-space joining is for modular subsystems nominally three-dimensional platforms (square or rectangular) with power, data, and mechanical load carrying connections. While these modules could represent orbital replacement units (ORUs), the modules could serve to construct an entire space vehicle.

Specific Research Objectives include:

• Innovative connection approaches/architectures that enable on-orbit geometry adaptation. Areas of interest include structural connections, electrical connections, fluid connections, thermal connections or combinations of these.
• Methods for in-situ connection verification (smart joints).
• Innovative reversible joining systems for robotic operations that minimize mass, energy and complexity while maximizing assembled stiffness, strength, stability, heat transfer, power density, etc.

Application orbits include LEO/GEO/Lunar. Nominal mechanical joining requirements are:
• Class 1: Structural Truss Joints.
  ◦ Strength: 100N to 500N axial target

• Class 2: Module Joints.
  ◦ Strength: > 0.4 g (Mars Extensible) with 0.25 meter cubic module connected on one face with uniform density of 640 Kg/m3.
• Current from milliamp to amps per contact.
  ◦ Voltage 28 to 100V DC
• Assembly/Disassembly: 20-50 times.

References:

• Barnhart, David; Will, Peter; Sullivan, Brook; Hunter, Roger; and Hill, Lisa: “Creating a Sustainable Assembly Architecture for Next-Gen Space: The Phoenix Effect,” 30th Space Symposium, May 2014, Colorado Springs CO.

• Erkorkmaz, Catherine; Nimelman, Menachem; and Ogilvie, Andrew: “Spacecraft Payload Modularization for Operationally Responsive Space,” 6th Responsive Space Conference, April 28-May 1, 2008, Los Angeles, CA.


Z5.01 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 external payloads on free-flying robots that operate in human environments and/or assist humans performing structured tasks. Current free-flyers include space robots, micro UAVs, quadcopters, etc. Applications of free-flying robots to space exploration include:

• Supporting deep-space human exploration spacecraft and habitats (operating inside or outside to support critical maintenance and monitoring functions).
• Supporting astronaut extra-vehicular activity (EVA) with scouting, follow-up sensing, and tool/sample delivery.

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 2018. Proposals are sought to create payloads that can be integrated with small-scale free-flying robots, including (but not limited to) the following areas:

• **Sensors** - Compact sensors relevant to the scenarios listed above, including functions such as interior environment monitoring (e.g., air quality), interior/exterior structural inspection, free-flying navigation (obstacle detection and localization), 3D environment modeling, etc.

• **End Effectors** - Small, lightweight mechanisms that can be used for docking/perching, prodding/pushing, tool carrying, and deployment of RFID tags. 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.

- **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.).

- **Novel 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), spacecraft "caretaking" (routine maintenance and emergency response), and other use cases.

Proposers are encouraged to target the development of these payload technologies to the Astrobot free-flying robot. For Astrobot, 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 (e.g., in terms of power) may still target Astrobot, but may require special accommodations (e.g., independent power). 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.

**Z5.02 Robotic Systems - Mobility Subsystems**

**Lead Center:** JSC

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

**Technology Area:** TA15 Aeronautics

In the coming decades, robots will continue to change the way space is explored. Robots will be used in all mission phases: as independent explorers operating in environments too distant or hostile for humans, as precursor systems operating before crewed missions, as crew helpers working alongside and supporting humans, and as caretakers of assets left behind. As humans continue to work and live in space, they will increasingly rely on intelligent and versatile robots to perform mundane activities, freeing human and ground control teams to tend to more challenging tasks that call for human cognition and judgment.

Innovative robot technologies provide a critical capability for space exploration. Multiple forms of mobility, manipulation and human robot interaction offer great promise in exploring planetary bodies for science investigations and to support human missions. Enhancements and potentially new forms of robotic systems can be realized through advances in component technologies, such as actuation and structures. Manipulation provides a critical capability for positioning crew members and instruments in space and on planetary bodies, it allows for the handling of tools, interfaces, and materials not specifically designed for robots, and it provides a capability for drilling, extracting, handling and processing samples of multiple forms and scales. This increases the range of beneficial tasks robots can perform and allows for improved efficiency of operations across mission scenarios. Manipulation is important for human missions, human precursor missions, and unmanned science missions. Future space missions may rely on co-located and distributed teams of humans and robots that have complementary capabilities. Tasks that are considered "dull, dirty, or dangerous" can be transferred to robots, thus relieving human crew members to perform more complex tasks or those requiring real-time modifications due to contingencies. Additionally, due to the limited number of astronauts anticipated to crew planetary exploration missions, as well as their constrained schedules, ground control will need to remotely supervise and assist robots using time-delayed and limited bandwidth communications.

Proposals are sought to research and develop the following robotic technologies including mobility, manipulation and human robot interaction technologies as described by the 2015 NASA Technology Roadmap for Robotics and Autonomous Systems (Tech Area 4):

- **Extreme Terrain Mobility** - Technology to access and traverse extreme terrain topographies, such as highly-sloped crater walls, gullies, and canyons; soft terrains; or terrains with large rock densities. Key technologies include rappelling and climbing systems and systems that can traverse soft and friable terrains.

- **Below-Surface Mobility** - Technology to access through naturally-occurring terrain cavities, such as lava
technology to provide longer range and greater coverage of planetary surfaces, independent of the terrain topography. This includes improvements to payload capacity, power, speed, and endurance in terms of time or distance. The type of above-surface mobility used on planetary bodies will be driven by environmental considerations and mission-specific requirements, which would include operation duration, coasting attitude, and the frequency of contacts with the surface.

- **Small-Body and Microgravity Mobility** - Technology to provide surface coverage and in-situ access to designated targets on small bodies with low gravity, as well as in-space mobility inside and around the ISS or other future space assets. Key technologies include human-safe gas propulsion, fan-based propulsion, hopping, flying, anchoring, wheel/track/limb hybrids, and electromagnetic formation flight.

- **Surface Mobility** - Technology to transport payloads, equipment, and other surface assets at much higher traverse speed for both manned and unmanned missions and increase the robustness of their onboard sensing, control, and navigation software. Key technologies include active suspension, traction control, realtime embedding/slip detection, and tractive elements (wheels, tracks, etc.)

- **Robot Navigation** - Technology to provide a highly reliable, well-characterized, and autonomous or semi-autonomous mobility capability to navigate to targets of interest on planetary surfaces. Key technologies include perception algorithms, pose and state estimation algorithms, and on-board autonomy (motion/path planning, target/waypoint selection, etc.).

- **Mobility Components** - Provide critical component technologies, such as compliant long-life wheels, high-torque at low speed actuators, energy-efficient and miniaturized actuators, strong abrasion-resistant tethers, and all-terrain anchors to meet future mobility needs. Provide larger payload and mobility mass fractions. Provide safe movement at speeds that are power-limited, not computation-limited, and yet do not tax human attention.

- **Manipulator Components** - Technologies should address improving kinematic configuration (serial, parallel, hybrids), dynamic performance (variable structural stiffness or compliant actuation), packaging efficiency (stowed and deployed), power density, or payload to mass ratio. This includes actuators tailored for manipulation (in terms of speed and torque range, compliance, size, and mass), lightweight structures (soft mechanisms, tendon systems, etc.), sensors and sensing approaches (both proprioceptive and exteroceptive), and embedded controllers (impedance, compliance, torque, etc.).

- **Dexterous Manipulation** - Technologies to generate smooth, human-like arm trajectories and fine endeffector motions that can flexibly manipulate objects; systems and control approaches capable of interacting with unstructured environments and human arm/hand scale interfaces; and approaches to incorporating or leveraging redundancy for robust manipulation. This includes manipulators and end-effectors, as well as the algorithms that control their motions.

- **Collaborative Manipulation** - Technologies to enable the use of multiple robotic manipulators that are either rigidly connected to a common base or to independent mobile bases. This includes algorithms and software for coordinated and cooperative motion, multi-point contact management (for highly dexterous robots or multi-robot systems), and distributed safety.

- **Grappling** - Technologies to handle large objects in microgravity environments. This includes components to grapple natural and human-made free-flying objects using surface features, and then to berth these objects to the robot’s spacecraft through a rigidized interface.

- **Multi-Modal Interaction** - Technology that employs multiple display modalities and multiple communication channels to enhance human situation awareness and enable more efficient interaction. In particular, tools and techniques that combine interactive 3D computer graphics, multi-modal dialogue, haptics, spatialized sound, and other non-visual displays to create an increased sense of presence are of strong interest.

- **Distributed Collaboration and Coordination** - Technology that improves the operational efficiency of a distributed team of humans and robots. This includes performance monitoring systems for real-time evaluation of task execution; summarization and notification systems to help humans understand robot state and trends over time; and physics-based modeling and modeling/simulation of robots and their operational environments.

- **Variable Autonomy Robotic Interaction** - Technology that enables humans, both on Earth and in-mission to more effectively operate and supervise robots that may be remote or proximal. This includes decision support tools to monitor system status, assess task progress, observe the remote environment, and make informed operational decisions; interaction techniques that inspire humans to trust robot team members that are proximal and/or remote; techniques to mitigate the effects of latency on manual control; and methods to reduce dependency on high-bandwidth, high-availability communication links.
Proposals must describe how the technology will make a significant improvement over the current state of the art, rather than just an incremental enhancement. Proposals must also describe how the technology will be employed for a specific application and how performance will be quantitatively assessed.

Z6.01 High Performance Space Computing Technology

Lead Center: JPL

Participating Center(s): GSFC, JSC

Technology Area: TA15 Aeronautics

The NASA state-of-the-art in space computing is currently lagging commercial capabilities in both the hardware and software capabilities. Presently, NASA is investing in the development of a radiation-hardened multi-core General Purpose Processor (GPP) that is scalable for a variety of space computing application.

The GPP will require additional support components and software to enable it to function as a multi-application device. Also, the GPP may not be the best approach to specific specialized applications that require niche-processing approaches. This subtopic is seeking flight-computing enhancements in the following areas:

- GPP parallel processing support libraries such as: real-time and fault-tolerant Message Passing Interface (MPI), the Vector, Signal, and Image Processing Library (VSIPL), the Fastest Fourier Transform in the West (FFTW), and other parallel I/O and math libraries.
- Computing accelerators/co-processors that will connect to the HPSC processor via the Serial Rapid I/O (SRIO) ports for supporting specific applications such as cyber-physical/robotics and autonomous systems.
- Generic I/O expander chips for a GPP that provide typical serial data communications support suitable for use in subsystems and instruments such as TIA/EIA-422, SpaceWire, SpaceFiber, MIL-STD-1553, wireless RFID-based device interfaces, and Time Triggered Ethernet (TTE)/Time-Triggered Gigabit Ethernet (TTGbE).
- Interconnect switches and end points for SRIO with integral micro-controllers, suitable for use in subsystems and instruments including components, IP for FPGA and SOC implementation and associated software.
- Low-power Graphics Processor Units and related display technologies.
- General purpose SIMD engines.
- Neuromorphic processors, especially those using >2D topologies.
- Board-support technologies, such as fault tolerant, multiple voltage, high efficiency, Point-of-Load converters, that reduce the SWaP burden of the overall computing board to permit higher system power efficiency and smaller computing system form factors.
- High Performance, low power/power manageable, fault tolerant, memory components, both volatile and non-volatile, especially those using >2D topologies and high speed, low power interfaces such as SRIO.
- Middleware that provides machine configuration management and resource allocation for GPP and extended GPP (incorporating co-processors, accelerators and expanded I/O).

Z7.01 Supersonic Parachute Inflation Materials Testing, And Instrumentation

Lead Center: LaRC

Participating Center(s): LaRC

Technology Area: TA15 Aeronautics

Mars landed missions have traditionally relied on large (nominal diameter between 11.5 and 21.5 m) disk-gap-band (DGB) parachutes that must be inflated between Mach 1.2 and 2.2 at dynamic pressures between 300 and 850 Pa to ensure that the terminal landing phase occurs before hitting the ground. For robotic payloads larger than the
Curiosity rover, larger parachutes will be required. These parachutes need to be tested under the low-density supersonic conditions that match Mars conditions. However understanding the shape history, dynamics, and induced stresses in the parachute structure and broadcloth during the inflation event is needed to ensure that minimum strength margin requirements are met. Further understanding the strength capability of materials under bi-axial and shear stress is essential. The measured material capabilities and stress conditions during inflation will be matched with computer models that will eventually be used as predictive tools in the parachute design process. This SBIR asks for help inventing and utilizing techniques for measuring parachute materials strength capabilities under flight-like loading conditions, and measuring, or inferring, parachute material stress and shape histories found during the inflation process during supersonic parachute inflation testing planned for the 2018 timeframe.

**Parachute Materials Testing**

Low mass, high strength parachute fabrics typically are constructed using various woven low mass Dacron or nylon broadcloth (e.g., 1.2 oz./yd2) that are sewn as gores onto Kevlar (or other high strength) webbing that forms a circumferential and radial skeleton primary structure. These materials as well as associated seams and joints are typically strength tested uni-axially. In some cases bi-axial testing has occurred however test fixtures and test facilities that attempt to reproduce the bi-axial and shear-induced stresses and strain associated with the dynamic inflation event do not appear to exist.

Proposers to this subtopic should suggest ideas and provide the capability for determining the strength of these classes of materials including joints and seams under various bi-axial stress and shear conditions (materials, sample joints and seams will be provided) that are representative of the manner in which the materials are loading during and after inflation.

Phase I will be expected to deliver: Measurement detailed design (and design review), Details of material test requirements (to be worked with the lead center in this phase), Implementation and cost plan, and Test facility and calibration plan.

Phase II will be expected to deliver: Tested and calibrated material test instrumentation and/or facility, Material testing (using samples provided by parachute manufacturers), Test data analysis and results.

**In-situ Instrumentation**

Ultimately, to prove that sufficient strength margin exists in the parachute design we need to determine the stresses or strains of the materials, seams and joints during the supersonic inflation event(s). Computer models that attempt to predict these stresses have not been validated due to an absence of data to ground the simulation results. NASA may execute supersonic, high-altitude inflation testing using various sized DGB parachutes in the 2018 timeframe. Plans include the use of high-speed stereo machine vision cameras that will allow shape history reconstruction of the very fast (< 1 sec) inflation event. Load cells on the riser(s) will provide estimates of the integrated tension during the event. After the test, the parachute and its instrumentation will be recovered and data extracted to gain understanding of the event. Some strain might be observable. What is missing are means to more directly measure or infer the peak stresses in the skeleton and broadcloth during the inflation event. Creative solutions have been proposed in the past, to instrument the parachute directly but these suffer from immaturity, use unproven integration techniques, and/or have questionable accuracies. These past solutions include: stress paint, strain threads that act as peak strain telltales, ultra-low-mass miniature self-contained strain gauges, and passive peak stress detection sewn into the circumferential and radial skeleton webbing (ball-strain yielding). These and other ideas are encouraged.

Proposers should suggest and have the ability to deliver various types of in-situ or remote instrumentation. Care should be taken to ensure that the incorporation of these devices do not excessively interfere with the operation of the parachute during the mortar-launched parachute inflation.

Phase I will be expected to deliver: Detailed design concepts, Implementation and cost plan, Details of accommodation (to be worked with the lead NASA center), and Instrument test and calibration plan.

Phase II will be expected to deliver: Tested and calibrated instrumentation, System test support (use of instrument in a ground or flight test), and Instrument data analysis.
Z7.02 Deployable 3D Woven Thermal Protection Materials

Lead Center: LaRC

Technology Area: TA15 Aeronautics

Large scale mechanically deployed decelerator skirts are expected to experience 50-100 W/cm² in various planetary oxidizing environments and are currently designed using flat panels of 3-D woven carbon fibers with sacrificial ablating outer layers over structural layers. The flat panels currently require cutting and joining at each structural rib.

Technologies Sought Include:

- Advancements are sought in weaving carbon fabric-based decelerator skirts that minimize stitched joints (maximum of 1 stitched joint) through the use of polar weaving or spider weave based designs. The weave thickness should be ~0.1 inches with a finished skirt diameter in the 1-3 meter range.
- Development of alternate 3D weave architectures that utilize multiple fiber types, including but not limited to non-ablating fibers on the outer mold line side that transition to structural and/or insulating fiber types. Development of such a capability could provide significant mass savings and performance benefits over pure carbon fiber-based fabric designs.
- Fabric joint development. Improvements are sought in the design of high temperature capable, stitched structural joints to improve post heated failure loads while minimizing conductive heat transfer into underlying deployable structure elements.
- Advancements in integrating 3D features into woven carbon fabrics to reduce manufacture and integration complexity. Examples include incorporation of rounded trailing edge radii into acreage material such that a trailing edge radius is 2-4x the acreage thickness without requiring multiple piece parts and stitching.

For all above technologies, research should be conducted to demonstrate technical feasibility and design during Phase I and show a path towards Phase II demonstration with delivery of a ~1-m diameter demonstration unit for NASA evaluation at the completion of the Phase II contract.

Z7.03 Deployable Aerodynamic Decelerator Technology

Lead Center: LaRC

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

Technology Area: TA15 Aeronautics

Background: NASA is developing deployable aerodynamic decelarators to enhance, and enable, robotic and scientific missions to destinations with atmospheres such as Mars, Venus, and Titan, as well as returning payloads to Earth from Low Earth Orbit (LEO). The benefit to deployable decelarators is that relatively large atmospheric entry vehicles can be designed to fit within a comparatively small vehicle launch fairing. Deployable decelerator technology will enable delivery of an estimated 20 metric tons of payload required to support human exploration of Mars, and will also enable return of large payloads from Low Earth Orbit as well as launch asset recovery for reduced cost of space access. For Mars human exploration it is estimated that a deployable may have a diameter of 18 meters which, for an inflatable system, will require over 100 cubic meters of hydrogen gas at a weight of nearly 700 kilograms.

This subtopic area solicits innovative technology solutions applicable to deployable entry vehicles. Specific technology areas included in the subtopic can include the development of gas generator technologies used as inflation systems that result in improved mass efficiency and system complexity over current pressurized cold gas systems. Inflation gas technologies can include warm or hot gas generators, sublimating powder systems, or hybrid systems. Proposed approaches should clearly demonstrate that the inflation technology can be scaled to inflated aero-shells at a size relevant to human scale Mars exploration missions. These lightweight, high efficiency
gas inflation technologies should be capable of delivering gas at 10,000 standard liters per minute.

Another research area included in the subtopic advancements in woven and non-woven textile technologies that can be used in the design and production of mass efficient flexible thermal protection systems such as durable high temperature fibrous insulators capable of operating above 1200°C that efficiently suppress both radiation and convective heat transfer. Thermal protection systems can be passive systems that do not rely on decomposition to manage heat loads, or more active systems where phase changes or material decomposition enhances thermal management capability.

Proposals in this area must clearly demonstrate large scale manufacturing capability together with durability against multiple packing and deployment cycles without loss of expected performance. Phase I products should include gas generator design and integration concepts, with Phase II delivering a prototype system at a scale capable of inflating a 3-6 m demonstration article.

**Z8.01 Small Spacecraft Propulsion Systems**

*Lead Center: MSFC*

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

*Technology Area: TA15 Aeronautics*

There are currently a wide range of technologies for propulsion systems, however the miniaturization of these systems for small spacecraft is a particular challenge. While cold gas or pulsed plasma systems are targeted for small delta-v, ?v application, modules that can provide more demanding maneuvers still need development. Small spacecraft buses other than cubesats have more flexibility to accommodate systems with several thruster units to provide more attitude control and also large single axis maneuvers. Missions have demonstrated these technologies successfully and performance data gathered has paved the way for future modifications of the existing hardware in order to re-adapt the designs to satisfy demanding constraints.

Specifically, proposals are solicited in the following areas:

- **High Impulse per unit volume (>2000 Ns/U):**
  - Example applications: Interplanetary/Deep space, orbit capture.
  - Electric Propulsion with thrust greater than 1.25 mN.
  - Long life Chemical Propulsion.
  - High thrust/power ratio.
  - Delta-v > 1 km/sec.
  - Includes ACS functionality
- **High Thrust per unit volume (>750 Ns/U):**
  - Example applications: Orbit raising (MEO, GEO), long life LEO.
  - Electric Propulsion with thrust greater than 1.25 mN.
  - Chemical Propulsion thrust > 100 mN.
  - Includes ACS functionality.
  - Low soakback temps, (i.e., minimal increase to local bus temperature).
- **Precision Control (I-bit < 0.2 microN-sec) for spacecraft < 180 kg:**
  - Example applications: Formation flying, tight pointing requirements.
  - Sub-microN thrust levels.

Proposers are expected to quantify improvements over relevant SOA technologies that will substantiate the investments in the new technology. Key metrics for that comparison can include, but is not limited to, recurring cost, total impulse, thrust, life, sail characteristic acceleration, 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.

For concept/component development, proposals are solicited to mature propulsion concepts of TRL 2 or higher and
mature them to TRL 6 at the component level. For system level maturation, proposals are solicited to mature integrated system solutions capable of delivering potential qualification or flight hardware within the constraints of a Phase II SBIR with no or minimal need for enhancements or Phase III investments.

The desired features for a SmallSat propulsion system is one that balances reliability, high performance (i.e., relatively high specific impulse [Isp] and thrust), has no/minimal chemical or electromagnetic contamination issues, is low pressure (or pressurizes post deployment), safely contains propellant (hazardous or non-hazardous), low cost, and has the simplest design feasible in order to meet performance requirements.

Z8.02 Small Spacecraft Communication Systems

Lead Center: MSFC

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

Technology Area: TA15 Aeronautics

Space communications is an enabling capability to conduct NASA missions. Communications systems should impose the least possible constraints on mission spacecraft in order to meet required performance. Innovations and novel approaches are sought to reduce the mass, power consumption, volume, and operational constraints in order to increase the total data return, advance the technology readiness level, and reduce the cost and risk of communications systems for small spacecraft (generally considered to be on the order of 180 kg or less). Small spacecraft communication systems must be increasingly robust, flexible and diverse to support a wide variety of stand-alone and interconnected missions 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. Infusion of new technologies or best commercial standards and practices (e.g., DVB-S2 standard, CubeSat form factors) that can demonstrably improve performance and be applied or adapted for use in Government, non-Government or commercial networks is desirable.

Proposals for innovations and advancements in technology readiness are sought in any of the following areas of small spacecraft communications systems:

- **High-gain Antennas (HGAs)** - Development of HGAs 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 to, from and among small spacecraft. Operations compatible with NASA's space communications infrastructure1 and Government exclusive or Government/non-Government shared frequency spectrum allocations (e.g., 25.5-27.0 GHz) is required. However, applicability or adaptability of the HGA technologies to non-Government use spectrum is also desirable [See References for applicable Government frequency spectrum allocations in the near Earth and deep space regions].

- **Transceivers and Radios** - This area includes but is not limited to: radio frequency (RF) transmitters; amplifiers; low noise receivers, full duplex frequency selectable RF front-ends, integrated Global Navigation Satellite Service (GNSS) receivers, software defined or reconfigurable radios, or integrated transceivers and radios for links to relay satellites or direct to ground stations. 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].

- **Network and Application Service Protocols** - 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 space flight communications. Innovations or advancements are sought in software and hardware systems that implement NASA's delay/disruption tolerant networking (DTN) standards to support scalable, robust mission communications for small spacecraft missions. Implementation of protocols to enable low-power application communications among clusters of small spacecraft are also invited [e.g., Constrained Application Protocols, CoAP] [See References for applicable
NASA and commercial networking standards.

- **Optical Communications** - One-way optical communications for direct data downlink from small spacecraft can provide a useful communications mode for NASA and non-government missions while avoiding some of the complications associated with a two-way optical link (i.e., requiring an uplink beacon). Technology advancements or system-level solutions (i.e., space and ground segment components) are sought that increase the data rate or availability of optical communications for small spacecraft, or reduce mission risk, complexity or cost.

A typical approach to advance the technology readiness level (TRL) leading to future flight hardware/software demonstration of any of the small spacecraft communications technologies would include:

**Phase I** - Identify, evaluate and develop candidate small spacecraft communications technologies that 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 systems through Phase II efforts and beyond.

**Phase II** - Emphasis should be placed on developing and demonstrating the candidate technologies under simulated small spacecraft spaceflight conditions or in the relevant 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 technologies developed under this subtopic area should be compatible with existing NASA space communications infrastructure, 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, NASA’s Deep Space Network (DSN) of ground stations, and other assets such as the Wallops range ground station.

**References** – Please see the following references for more details:

- Delay/Disruption Tolerant Networking (DTN):  
  - NASA DTN: [http://www.nasa.gov/content/dtn](http://www.nasa.gov/content/dtn) [5].
  - InterPlanetary Networking Special Interest Group (IPNSIG) DTN [www.ipnsig.org](http://www.ipnsig.org) [6].
- Constrained Application Protocol (CoAP):  

**Z8.03 Small Spacecraft Power and Thermal Control**

Lead Center: MSFC

Participating Center(s): GSFC, JPL, MSFC
SmallSats and CubeSats offer several new opportunities for space science, including multipoint in-situ measurements and disaggregation of larger science missions into constellations. These missions require reliable operation for several years in potentially harsh radiation environments. Industry has developed numerous cubesat components, but they lack the robustness needed for long duration missions. To address this capability gap, this subtopic will develop high reliability smallsat power generation and storage and thermal control systems that meet the performance and resource requirements of upcoming missions, while maximizing flexibility. An emphasis should be considered for energy management systems that combine power generation, storage and heat rejection in the compact cubesat platform as well as systems that enable electric propulsion.

The development of advanced power generation and energy storage technologies are critical to enabling and expanding the use of future small satellite missions. Proposed research may focus on the development of new power generation and storage technologies, with particular interest in technologies that are approaching readiness for spacecraft testing. This subtopic solicits the development of modular, highly-reliable solar array, battery, power system electronics technologies that enable scalable smallsat and cubesat power systems with the following specifications:

- Solar array input power ranging from 15 W to 100 W.
- Battery capacity ranging from 5 Amp-hours to 20 Amp-hours (volume dependent).
- Provides from 12 to 20 switched power services to users, with output voltages configurable to meet mission-specific requirements.
- Maximum board size of 90 mm x 90 mm for power system electronics.
- Configurable via I2C, SPI, or CAN bus interface.
- Simple/modular power component designs ("plug and play").
- Supports body mounted or deployed solar arrays.
- Supports power system reset initiated by external command (typically received from radio).
- Tolerant of extreme thermal and/or radiation environments.
- Ability to be stored in space for several years prior to use.
- Novel and/or integrated power with other subsystems (i.e., power and communications, energy storage and satellite structure, combined power/propulsion subsystems, etc.).

Integration of the power and thermal subsystems is a synergistic combination that can result in mission-enabling resource savings. For example, batteries often carry the most restrictive temperature range of all spacecraft hardware, which can drive the thermal design. An integrated heat transfer turn-down device that helps to regulate temperature in extreme environments is a technology sought in this solicitation. Examples include miniaturized heat switches and lightweight thermal capacitance devices that are integrated into the battery assembly, each being scalable and tunable to a specific mission’s requirements.

Deployable solar array systems are associated with higher waste heat dissipations, which in turn leads to higher volumetric heat fluxes for the small spacecraft. With limited area for suitable radiator placement, deployed radiator systems will also become necessary. Combining the radiator with the solar array will reduce the need for another deployment while also taking advantage of the environmental views. Technologies are sought to provide efficient heat transfer across the deployment mechanism. Thin radiator assemblies are needed to minimize increases in solar array thickness while also providing thermal isolation from the side with solar cells. Radiator concepts can be passive (e.g., solid-state material or heat pipes) or active (e.g., integrated fluid tubing is assumed to interface with a spacecraft-provided pumped loop).

Integrating high thermal conductivity pathways from high heat flux power electronics components to chassis interfaces can provide incremental reductions in radiator sizes. Order of magnitude improvements over copper thermal ground plane/card-lock technologies are sought.

In Phase I, contractors should prove the feasibility of proposed innovations using suitable analyses and tests. In Phase II, significant hardware or software capabilities that can be tested at NASA should be developed to advance their Technology Readiness Level (TRL). TRLs at the end of Phase II of 3-4 or higher are desired. NASA’s Small Spacecraft Technology Program will consider promising SBIR technologies for spaceflight demonstration missions and seek partnerships to accelerate spaceflight testing and commercial infusion.
Z8.04 Small Spacecraft Structures, Mechanisms, and Manufacturing

Lead Center: MSFC

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

Technology Area: TA15 Aeronautics

Smallsats, including cubesats, are quickly maturing technologically towards advanced capabilities, which will result in significant contributions to the achievement of NASA's scientific and exploration missions. In fact, smallsats are seriously being considered for complex, long duration missions to deep space locations and for Earth observing constellations. However, while smallsats have the benefit of small size and mass making them generally easier and cheaper to launch, many space applications require larger physical sizes or alternate structural architectures. These applications can be realized through the innovative blending of structural elements with other functional elements; reconfigurable, reusable structures; reliable deployment mechanisms and aggregation techniques; and novel manufacturing techniques driving the utility of smallsats even further. Three main thrust areas are envisioned for this subtopic.

Structures

In the area of smallsat structures, NASA is interested in materials and structural systems that optimize component or instrument packaging. This includes techniques to integrate or combine structural elements with other subsystem elements (multi-functionality; i.e., spacecraft chassis with electrical power management, or internal spacecraft communications). See related discussion below on Manufacturing on embedded systems into structures.

Also of interest are technologies that can allow aggregation of smaller elements in space to create larger structures that cannot be launched as a single element, or that do not have to be designed to withstand launch loads. This implies integrative structural technologies that can share or distribute power, communications or thermal resources between the individual building blocks that can be arranged to perform a specific function in space. Further, these systems of building blocks can be reconfigured once launched to enable in space assembly architectures.

Mechanisms

This area focuses on the stowage (during launch) and deployment (during space operations) of various elements and subsystems. Included in this category are deployable solar cell arrays, radiators, antennas or other mission-enabling elements. These deployable mechanisms should be reliable in a wide variety of space environments (LEO and/or deep space) and be compatible with existing smallsat architectures. Ideally, deployable mechanisms should include methods to verify proper deployment (i.e., latch sensors, etc.) and should also employ robust technologies such as motorized actuators versus passive stored energy systems such as springs. Inflatable and on-orbit reconfigurable systems are also of interest.

Manufacturing and Materials

NASA is interested in technologies that take advantages of manufacturing advances as they apply to small spacecraft. Examples include model-based additive manufacturing technologies that can create fluid manifolds, propellant tanks, small thrusters, or unique geometries not currently possible via traditional manufacturing techniques. A related dimension to this area is multiple (or mass) production technologies that can be applied for the manufacturing of large numbers of spacecraft such as swarms or constellations. Other concepts involve integrating electrical components and interconnects within structural elements, especially when such integration results not only in mass savings, but also decreased integration and test flow timelines and increased overall systems reliability through the use of built-in-test approaches.

Finally, NASA is interested in manufacturing technologies using novel materials that are low mass/density yet compatible with high radiation and extreme temperature deep space environments.
**Z8.05 Small Spacecraft Avionics and Control**

Lead Center: MSFC

Participating Center(s): ARC, JPL, MSFC

**Technology Area: TA15 Aeronautics**

Smallsats and cubesats offer several new opportunities for space science, including multipoint in-situ measurements and disaggregation of larger science missions into constellations. These missions require reliable operation for several years in potentially harsh radiation environments. Industry has developed numerous cubesat components, but they lack the robustness needed for long duration missions in harsh mission environments. To address this capability gap, this subtopic will develop high reliability smallsat avionics and control technologies that meet the performance and resource requirements of upcoming missions, while maximizing flexibility.

This subtopic solicits the development of smallsat and cubesat single board avionics with the following specifications:

- Minimum 100 DMIPS processing performance.
- 3W power dissipation.
- Maximum board size of 90 mm x 90 mm.
- 16 Mbytes of EDAC protected RAM.
- 4 Gbytes of non-volatile memory storage.
- 256 kbytes on non-volatile memory for boot software.
- Optionally supports I2C, CAN, SPI, and SpaceWire busses.
- 4 8b/10b SERDES interfaces.
- Provides FPGA to implement mission specific processing functions and interfaces (including general purpose I/O), either in combined in a System-On-a-Chip (SOC) or separate from the processor package.
- Accepts and digitizes 16 thermistor inputs and 8 active analog inputs.
- Provides watchdog timer and external reset signal.

This subtopic also solicits ACS/GN&C component hardware that has a minimum of 3-year operational life as well as radiation-hard and low mass implementation to survive the typical LEO radiation environment for the same duration. Specific component technologies include:

- **Integrated Attitude Detection and Control Systems (ADCS) for 3U and 6U CubeSat:**
  - Minimum Target Pointing Spec:
    - Knowledge 10.0 arc-second - 3 sigma.
    - Control 40.0 arcsec - 3 sigma.
    - Stability 0.3 arcsec over 1.0 sec - 3 sigma.
  - Desired Target Pointing Spec:
    - Integrated Attitude Detection and Control Systems (ADCS) that can provide pointing for 3U and 6U CubeSat:
      - Knowledge 1.0 arc-second - 3 sigma.
      - Control 4.0 arcsec - 3 sigma.
      - Stability 0.05 arcsec over 1.0 sec - 3 sigma.
  - 10.0 Hz ctrl cycle.
- **Actuators:**
- Slew rate on the order of 1 deg/sec.
- Momentum capacity: 4 orbits.
- Handle tipoff rates on the order of 5.0 deg/sec per axis:
  - Ensure a stable platform can be achieved after separation.
- **Sensors:**
  - Small, low power (<1 W) star trackers and innovative baffle design.
  - Low Noise Gyro:
    - Can propagate on Gyro for 4 orbits.
To allow infusion into multiple smallsat architectures, it is highly desirable for ACS/GN&C components to provide options to support multiple onboard data busses (i.e., I2C, SPI, CAN).

For the above components, the environmental specifications are; operating temperature -40 to +85°C, radiation hard to at least 40 krad TID, latch up immune to an LET of at least 80, and a device SEE rate of not greater than 0.01 event/day in Adams 90% worst case GEO environment. Successful proposals for the above technologies will address reliability and radiation tolerance at the part level all the way up through their component/subsystem implementation. For descriptions of radiation effects in electronics, the proposer may visit http://radhome.gsfc.nasa.gov/radhome/background.htm [9].

Beyond the higher reliability technologies listed above, this subtopic also solicits technologies offering significant improvements in cubesat/smallsat capabilities. These technologies would not need to have sufficient reliability and radiation tolerance to be directly infused into long duration missions. However, there should be a viable path by which these technologies could be matured for such missions. Technologies solicited include:

- Low power, high throughput processors, SoC or MPSoC with an order of magnitude performance improvement over state-of-the-art.
- Radiation resistant, self-repairing technologies (both in hardware and software).
- Modular, reconfigurable flight software environments and architectures.
- Technologies that enable rapid software integration, test and validation.
- Radiation tolerant GN&C systems and components with an order of magnitude performance improvement over state-of-the-art.
- Small, low thrust RCS systems for smallsats with an order of magnitude performance improvement over state-of-the-art.
- Alternate technologies for attitude determination (i.e., navigation via x-ray sources, or planetary bodies).
- Technologies to isolate sources of spacecraft vibration from sensors or payloads.
- Advanced GN&C software programs and algorithms.
- Miniature rate gyros with an order of magnitude performance improvement over state-of-the-art MEMS gyros in drift and noise.
- Innovative miniature angular momentum exchange devices that are not susceptible to reliability issues associated with bearing wear.
- Miniature sensors and actuators for smallsat rendezvous, docking and spacecraft servicing, including include vision systems, miniature robotics, and docking actuators.

Z9.01 Small Launch Vehicle Technologies and Demonstrations

Lead Center: MSFC

Participating Center(s): KSC, LaRC

Technology Area: TA15 Aeronautics

As small spacecraft capabilities steadily expand the demand for low-cost dedicated launch capability is expected to grow and give rise to a viable small payload market segment. Servicing this market segment will likely require a variety of small launch vehicle capabilities to deliver payload masses ranging from 5-kg cubesats up to 180-kg ESPA-Class spacecraft. Orbital altitudes of interest range between 350 to 700 km with inclinations between 28 to 98.2 degrees to support CONUS operators and sun synchronous orbits at maximum altitude. Affordability objectives are focused on reducing launch costs below $60,000/kg with a goal of less than $20,000/kg.

NASA is interested in fostering the small spacecraft commercial launch sector by investing in new technologies and innovations that are poised for rapid maturation and subsequent commercialization. It is recognized that a combination of multiple technologies and production practices will likely be needed, and it is highly desirable that disparate but complementary technologies formulate and adopt standardized interfaces to better allow for transition and integration into small spacecraft launch systems.

Technologies of specific interest under this subtopic are as follow:
• Innovative Propulsion Technologies.
• Affordable Guidance, Navigation & Control.
• Manufacturing Innovations for Launch Vehicle Structures & Components.

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 5 or 6 by the end of Phase II effort. Technologies that can be developed and readied for flight-testing by the end of Phase II effort are of particular interest. A brief descriptive summary of desired technical objectives and goals are provided below.

Innovative Propulsion Technologies

Innovative chemical propulsion technologies and system 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 solid, liquid, or hybrid propellants. Technical approaches that address the critical challenges associated with downward scaling of launch vehicles are 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.

**Z10.01 Cryogenic Fluid Management**

Lead Center: MSFC

Participating Center(s): JSC, MSFC

**Technology Area: TA15 Aeronautics**

This subtopic solicits technologies related to cryogenic propellant (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 and In-Situ Resource Utilization in cooperation with Mars Landers in support of the Evolvable Mars Campaign.

Specifically, listed in order of importance:

- Analysis of cryogenic systems for improved modeling of turbulence effects on heat and mass transfer across the liquid/gas interface. Of particular interest are improved models for turbulent heat transfer and mass transfer across the liquid/gas interface that can be applied to Unsteady Reynolds Averaged Navier-Stokes (URANS) simulations using Eulerian-based two-phase models, such as Volume of Fluid. Data to guide modeling efforts such as NASA-TM-2003-212926 or NASA-TM-105411.
- Mars surface cryogenic storage requires a vacuum jacket in order to reduce heat leak and power requirements. A lightweight vacuum jacketed system may be possible, where the vacuum jacket is designed for Mars atmospheric pressure (5-7 torr). The vacuum jacket may be launched purged, evacuated upon reaching orbit, and then sealed prior to Mars entry. The vacuum jacketed system would then have to retain a vacuum for several years while on the surface of Mars.
- 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.
- Analysis of cryogenic systems sometimes requires computational fluid dynamics, especially when significant deformation or breakup of the liquid/gas interface occurs. For many components, or for settled conditions, a simpler fluid and thermal network approach may be sufficient. Of interest is the capability to tightly couple CFD and fluid/thermal network approaches, such as a fluid-thermal network analysis of an active pressure control system coupled to a CFD simulation of the fluid and thermodynamics occurring in a cryogenic storage tank.
**Z10.02 Methane In-Space Propulsion**

Lead Center: MSFC  
Participating Center(s): JSC, MSFC

**Technology Area: TA15 Aeronautics**

NASA is developing high thrust in-space chemical propulsion capabilities to enable human and robotic missions into the proving ground (Mars and beyond). Successful proposals are sought for focused investments on key technologies and design concepts that may transform the path for future exploration of Mars or beyond, while providing component and system-level cost and mass savings. In-space propulsion is defined as the development and demonstration of technologies for ascent, orbit transfer, pulsing attitude/reaction control (RCS), and descent engines.

Technologies of interest for operation with liquid oxygen and liquid methane specifically are sought:

- Components for integrated RCS (~100-lb class) and Main Propulsion System (MPS) (25,000-lb class) feed systems (utilizing common propulsion tanks), including:
  - Lower power (~100 - 30 W) electric-pump systems (28-100 Vdc) at desired flowrates (~8-10 lbm/s max).
  - Vacuum capable (<10 torr) compact exciters with high spark rates (>200 sps) and 30-50 mJ minimum delivered spark energy.
  - Improved materials/manufacturing capabilities for high temperature (>800 K), high pressure (>1000 psia) applications.

- Technologies to improve throttling in pressure-fed engines (5000-lb class), to minimize performance losses, such as:
  - Improved injector concepts that provide at least 98% c* (c-star) efficiency at full throttle conditions and maintain stability at 20% throttle ratios.
  - Fast-acting (<80 ms response time), low-leakage (<3 SCCS to 0.1 SCCS gaseous propellants) throttle valves, which meet the following performance considerations: maintain consistent mixture ratio (MR) over the throttle range, 50% (minimum) force margin, cold and warm operations, easily chilled in.

Proposers MUST clearly articulate the metrics of their technology, and must show a clear understanding of the current state of the art (SOA), and explicitly describe how their technology advances the state of the art. A clearly defined description of the following, at a minimum, is desired:

- Assessment of SOA with the key performance parameters (KPP) of their choosing (such as performance, mass, response time, etc.), including specifics which may be referenced in backup material - provide SOA for each major technology element in the proposal.
- Address the outstanding technology performance being promised and the degree to which the concept is new, different, and important. Particularly, explicitly define how the technology and/or fabrication technique proposed saves cost, schedule and/or mass. If a new manufacturing technique is proposed, clearly define how the technique provides a unique technology not feasible through other manufacturing methods.
- Provide quantitative rather than qualitative assertions (e.g., x% improvement of y, z kg of mass savings, xx% in cost savings, etc.) to the advancement over the SOA.
- Identify specific deliverables being offered. Clearly and explicitly specify what items are being delivered as part of contract performance, and clearly identify if hardware is being offered. Explicitly identify if any commitment has been made for post-development testing.

Phase I Deliverables - Research to identify and evaluate candidate technology applications to demonstrate the technical feasibility and show a path towards a demonstration. Bench or lab-level demonstrations are desirable.
The technology concept at the end of Phase I should be at a TRL of 4 to 5.

Phase II Deliverables - Emphasis should be placed on developing and demonstrating the technology under simulated mission conditions. The proposal shall outline a path showing how the technology could be developed into mission-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a TRL of 5 to 6.

Note: Technologies for cryogenic applications must be demonstrated in relevant environment by end of Phase II. Water demonstration is not sufficient for demonstrating TRL 5 capability.

Z10.03 Nuclear Thermal Propulsion (NTP)

Lead Center: MSFC

Participating Center(s): GRC, SSC

Technology Area: TA15 Aeronautics

Nuclear Thermal Propulsion (NTP)

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. The current NASA Strategic Space Technology Investment Plan states NTP is a high priority technology needed for future human exploration of Mars. 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 \(\sim 15,000-35,000\ \text{lbf}\) 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 (\(\sim 4\)) 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 \(\sim 50\) minutes.

Technologies being sought include:

- Reactor fuel element designs with high temperature (\(>2600\)K), high power density (\(>5\) MW/L) to optimize hydrogen propellant heating.

- New additive 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. Fuel can made of Ceramic-metallic (cermet) or composite/carbide 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.
  - Insulator design (one application is for tie tubes) 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. Also needed are radiation shielding technologies that minimize exposure to other stage components and reduce total crew radiation dose. 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.
  - Concept for quick restart of reactor (2-6 hours) after 30-40 minute burns and accounting for Xe135 buildup.
- Radiation shielding concepts that protect the crew and minimize heating of store propellant and the stage. Strategies that minimize radiation shielding system mass, such as utilization of the payload and consumables for shielding (when practical) that may provide an additional bonus of shielding galactic cosmic radiation as well as radiation from the NTP engines.

**Ground Test Technologies**

Environmental regulations require NTP engine exhaust filtering of radioactive noble gases and particulates to maintain safe environmental levels. NTP engine ground testing will require the development of large scale engine exhaust scrubber technologies and options for integrating it to the NTP engine for ground tests (reference 51st AIAA/SAE/ASEE Joint Propulsion Conference paper AIAA 2015-3773, ‘Review of Nuclear Thermal Propulsion Ground Test Options’, D. Coote, et al). 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:

- Advanced high-temperature and hydrogen embrittlement resistant materials for use in a hot hydrogen environment (<5500°F) and possibly exposed to neutrons and gamma rays.
- 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.
- Effluent scrubber technologies for efficient filtering and management of high temperature, high flow hydrogen exhausts. Specific interests include:
  - Filtering of radioactive particles and debris from exhaust stream having an efficiency rating greater than 99.5%.
  - Removal of radioactive halogens, noble gases and vapor phase contaminants from a high flow exhaust stream with an efficiency rating greater than 99.5%.
- Applicable Integrated System Health Monitoring and autonomous test operations control systems.
- Modern robotics which can be used to inspect the ground test system exposed to a radiation environment.

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, GRC, GSFC, JPL, JSC, KSC, LaRC, MSFC

**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 NASA's current sensor capability. It 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 I's 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 interested in the simulation and analysis of NDE data, please see Subtopic Z11.02 - NDE Simulation and Analysis.*

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

**Z11.02 NDE Simulation and Analysis**

Lead Center: LaRC

Participating Center(s): ARC, JSC

**Technology Area: TA15 Aeronautics**

Technologies sought under this subtopic include near real-time large scale nondestructive evaluation (NDE) and
structural health monitoring (SHM) simulations and automated data reduction/analysis methods for large data sets. Simulations techniques will seek to expand NASA’s use of physics based models to predict inspection coverage for complex aerospace components and structures. Analysis techniques should include optimized automated reduction of NDE/SHM data for enhanced interpretation appropriate for detection/characterization of critical flaws in space flight structures and components. Space flight structures will include light weight structural materials such as composites and thin metals. Future purposes will include application to long duration space vehicles, as well as validation of SHM systems. It is also considered highly desirable to develop tools for automating detection of material Foreign Object Debris (FOD) and/or defects and evaluation of bondline and in-depth integrity for light-weight rigid and/or flexible ablative materials are sought. Typical internal void volume detection requirements for ablative materials are on the order of less than 6mm and bondline defect detection requirements are less than 25mm.

Techniques sought include advanced material-energy interaction (i.e., NDE) simulations for high-strength lightweight material systems and include energy interaction with realistic damage types in complex 3D component geometries (such as bonded/built-up structures). Primary material systems can include metals but it is highly desirable to target composite structures and/or thermal protection systems. NDE/SHM techniques for simulation can include ultrasonic, laser, Micro-wave, Terahertz, Infra-red, X-ray, X-ray Computed Tomography, Fiber Optic, backscatter X-Ray and eddy current. It is assumed that any data analysis methods will be focused on NDE techniques with high resolution high volume data. Modeling efforts should be physics based and it is desired they can account for material aging characteristics and induced damage, such as micrometeoroid impact. Examples of damage states of interest include delamination, microcracking, porosity, fiber breakage. Techniques sought for data reduction/interpretation will yield automated and accurate results to improve quantitative data interpretation to reduce large amounts of NDE/SHM data into a meaningful characterization of the structure. Realistic computational methods for validating SHM systems are also desirable. It is advantageous to use co-processor configurations for simulation and data reduction. Co-Processor configurations can include graphics processing units (GPU), system on a chip (SOC), field-programmable gate array (FPGA) and Intel’s Many Integrated Core (MIC) Architecture. Combined simulation and data reduction/interpretation techniques should demonstrate ability to guide the development of optimized NDE/SHM techniques, lead to improved inspection coverage predictions, and yield quantitative data interpretation for damage characterization.

Phase I Deliverables - Feasibility study, including demonstration simulations and data interpretation algorithms, proving the proposed approach to develop a given product (TRL 2-4). Plan for Phase II including proposed verification methods.

Phase II Deliverables - Software of proposed product, along with full report of development and test results, including verification methods (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.

Potential NASA Customers include:

- Space exploration missions such as missions to Asteroids, Mars or various Earth-Moon Liberation Waypoints.
- International Space Station.

For proposers with an interest in the sensors used in NDE, please see Subtopic Z11.01 - NDE Sensors.