



## NASA SBIR 2016 Phase I Solicitation

### Space Technology

#### Power & Energy Storage Topic Z1

The Advanced Space Power and Energy Storage Systems topic area will focus on technologies that generate power and/or store energy within the space environment. Functional areas, sub-topics, of interest include:

#### High Power/Voltage Electronics

NASA is seeking performance improvements to Power Management and Distribution (PMAD) systems through increases to the operating voltages and temperatures of these electrical components. Although many parts 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/high temperature components 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.

Sub Topics:

#### Z1.01 High Power/Voltage Electronics

Lead Center: GSFC

Participating Center(s): GRC, LaRC

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The premise of this solicitation is that there have been recent improvements to semi-conductor devices at the material level, e.g., SiC and GaN, which have enabled higher efficiency, voltage and temperature regimes for parts and systems working terrestrially. However the first generation devices have proven unsatisfactory for use in space applications due to radiation-induced early failures after exposure to heavy-ion fluences of concern to most space missions. Further research and development effort must be accomplished to fully understand the failure mechanisms within devices made of these advanced materials and iterative design cycles must then be conducted to develop components that have the performance characteristics required for future NASA missions.

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The types of components coming under this topic include:

- Semiconductor switches, e.g., the design of Wide Band Gap semiconductors such as switches and diodes using GaN or SiC, with minimum voltage and current ratings of 1200 V and 12 A.
- Switch driver diodes.
- High temperature capacitors.
- Interconnection wires for switchgears.
- Associated control electronics.

This solicitation topic seeks proposals that address each of the following points:

- Analysis and research into the failure modes related to heavy-ion radiation exposure, as well as high temperature operation of GaN and SiC devices.
- Design and development of “next-generation” components.

It is important to note that technologies of interest to NASA under this topic must not simply provide an incremental improvement as the solution but must have the potential to significantly improve upon device operating points, thermal range, heavy-ion single-event effect tolerance, and the mass and volume characteristics. Proposals submitted in response to this topic must state the initial component state of the art and justify the expected final performance metrics.

Target performance levels include:

- Radiation hardness:
  - 300 krad(Si) total ionizing dose tolerance, and
  - For vertical-field power devices: No heavy-ion induced permanent destructive effects upon irradiation with ions having a silicon-equivalent surface-incident linear energy transfer (LET) of 40 MeV-cm<sup>2</sup>/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 with ions having a silicon-equivalent surface-incident linear energy transfer (LET) of 75 MeV-cm<sup>2</sup>/mg and sufficient energy to fully penetrate the active volume prior to the ions reaching their maximum LET (Bragg peak).
- Thermal range: 150 °C or greater junction temperature.

#### Thermal Management Topic Z2

NASA is seeking unique solutions for mid-temperature thermal control technologies that will facilitate a low mass highly reliable thermal control system for an exploration vehicle. Future human spacecraft will require more sophisticated thermal control systems that can operate in severe environments ranging from full sun to deep space and can dissipate a wide range of heat loads. Planetary systems (both human and robotic) need to minimize mass and maximize performance to enable more science payloads, and face complications from dust and regolith in many locations, and from the Mars atmosphere. The systems must perform their function while using fewer of the limited spacecraft mass, volume and power resources while increasing the reliability of these components. Furthermore, as human missions require longer extravehicular activities, the need for a closed loop, mass efficient thermal control system is needed for the EVA Suit. NASA's Technology Roadmaps 6 and 14 cover many of the defined key performance parameters sought through this SBIR. The following technical areas seek to cover the gaps outlined through this solicitation:

- Variable Heat Rejection Technologies.
- Advanced-Closed Loop EVA Thermal Control.
- Highly Efficient, Low Pour Point Thermal Control Fluids.
- Advanced Heat Exchangers.

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Sub Topics:

## **Z2.01 Active Thermal Control Systems for Space Exploration**

**Lead Center:** JSC

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

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### **Variable Heat Rejection Technologies**

As NASA moves beyond low earth orbit, exploration vehicles that must accommodate various mission scenarios find a need for variable heat rejection. A vehicle may need to operate in severe environments ranging from full sun to deep space while managing a wide range waste energy rejection including active and dormant phases. Heat rejection systems and/or radiators that can operate at low fractions of their design heat load in the cold environments that are required for deep space missions. Room temperature thermal control systems are sought that are sized for full sun yet are able to maintain set point control and operate stably at 25% of their design heat load in a deep space (0 K) environment. This variation in heat rejection is often described as a turn-down ratio. NASA Technology Roadmap Area 14 outlines a turn down goal of 6 to 1 by a thermal control system operating at the scale of kilowatts of waste energy removal. Solutions for variable heat rejection may include the use of novel thermal control fluids, advanced radiator technologies, and/or variable conductance.

### **Advanced-Closed Loop EVA Thermal Control**

NASA has evolved space suit technology beyond the Extravehicular Mobility Unit (EMU) state of the art for exploration missions. However, the latest iteration of the portable life support system includes the use of a Suit Water Membrane Evaporator to facilitate the rejection of waste energy produced by the suit, which still vents water vapor like the EMU sublimators. Longer duration extra vehicular activities and systems that do not impact the environment of Mars are needed, including a closed loop, non-venting EVA thermal control system capable of working in the Martian atmosphere. The solicitation seeks novel approaches to close the thermal control system of the Suit so that minimal to no consumables are used for rejection of waste energy. Approaches may include, but are not limited to, novel radiative approaches, desiccant systems to reclaim evaporants, etc. Examples of such technologies and goals are outlined in NASA's Technology Roadmap Area 06.

### **Highly Efficient, Low Pour Point Thermal Control Fluids**

Most if not all space vehicles have the need for a thermal control fluid that does not freeze at relatively low temperatures. These fluids with low pour points come with decreased thermal performance, causing an increase in system mass to the thermal control system. This scenario was apparent with JPL's Mars Science Laboratory as well as the Orion Vehicle. Vehicles subjected to the environments of deep space through transit scenarios to the Moon and Mars especially need a highly efficient thermal control fluid with low pour point. Ideally, this new thermal control fluid would have a pour point near -110°C with thermal physical properties near water. Furthermore, for use in human systems, this thermal control fluid would have low toxicity, flammability, and vapor pressures for use in a habitable volume.

### **Advanced Heat Exchangers**

Air/liquid, liquid/liquid, coldplates, and phase change material heat exchangers are at the core of any thermal control system for a vehicle. Advances in manufacturing may yield a considerable mass savings over the current state of the art heat exchangers. Furthermore, lightweight non-venting phase change heat exchangers are sought

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to ameliorate the environmental transients that would be seen in planetary (Martian or Lunar) orbit. Heat exchangers that have minimal structural mass and good thermal performance are sought. Furthermore, the use of phase change materials that have a transition temperature between 8°-12°C with heat of fusions above 200 kJ/kg are needed. The goal is a ratio exceeding 2/3 phase change material mass and 1/3 structural mass. Condensing heat exchangers (air/liquid heat exchangers) are deemed to be a critical component of a closed loop environmental control life support system. The need for highly reliable condensing heat exchangers that do not contaminate due to microbial growth and do not impact the water processing system of an ECLSS system due to coatings on the HX is of high need for future human systems. Finally, advances in the aforementioned heat exchangers are expected to utilize new materials and manufacturing techniques over conventional brazing processes used today. NASA's Technology Roadmap Area 14 details various points of interest for these heat exchangers.

### Advanced Manufacturing Topic Z3

NASA is using several manufacturing processes supporting the Space Launch System to create structures with superior mechanical properties and increased reliability. Advancing the state of the art for advanced metallic materials and processes will continue to be a critical technology to build more efficient space vehicles with less expensive materials.

This topic seeks to develop new and innovative materials and manufacturing processes (both additive and subtractive) for lightweight and/or multifunctional metallic components and structures for NASA and related applications. Technologies that can enable joining of new or dissimilar materials, as well as significantly reduce costs, increase production rates, and improve weld quality should be considered.

Technologies should result in components with minimal or no machining; Technologies should provide novel techniques for producing high-strength components and joints that are highly free of defects. Emphasis on reduced structural mass, improves processing lead-time, and minimizes touch labor and final assembly steps, resulting in increased capability, reliability and reduced cost.

Sub Topics:

#### **Z3.01 Advanced Metallic Materials and Processes Innovation**

**Lead Center: MSFC**

**Participating Center(s): JPL, LaRC**

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This subtopic seeks innovative processes and development of metallic material systems. The emphasis is on solid state welding practices including but not limited to: ultrasonic, thermal, and friction stir welding; new concepts for built-up structure approaches for lightweight structural panel applications, advanced near-net shaping, additive manufacturing processes; advanced coating technologies for wear and environmental resistance; functionally-graded (gradient alloy) materials that exhibit superior performance exceeding that of the individual constituent alloys. Technologies should result in components with minimal or no machining.

Proposals are sought in the following areas:

- Joining new materials: technologies that enable welding on a wide range of alloys and a wide range of

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thicknesses, including high-strength, temperature-resistant materials (such as titanium alloys, Inconel/Nickel-Based alloys, steels, and copper), metal-matrix composites, and other materials previously considered unweldable.

- Joining of complex geometries: technologies that enable welding of complex curvature joints or other types of structure variations that increase manufacturing possibilities.
- Development and prototyping technologies for fabricating gradient alloy (functionally graded) or amorphous (bulk metallic glass) materials for solid state welding processes, near- net shape, and additive manufacturing processes.

Responses should identify key performance parameters and TRL advancement in terms of quantifiable benefits to address specific areas including but not limited to the following: reduced structural mass, increased structural efficiency, improved processing lead-time, minimized touch labor and final assembly steps, increased reliability and reduced cost. Scale-up and transition to aerospace hardware and products should also be addressed.

#### Lightweight Structures and Materials Topic Z4

The Lightweight Materials, Structures, and Advanced Manufacturing/Assembly SBIR topic area will focus on technologies that will enable mass reduction, improved performance, lower cost and scalability of the material and structural systems that will be critical to NASA's space exploration and science missions. As NASA strives to explore deeper into space than ever before, improvements in all of these areas will be critical. For example, mass reduction is an ever-present goal in the development of space-exploration systems. Reductions in structural mass can either enable additional payload to be launched to orbit or reduce the mass of the payload that must be returned to Earth or landed on another planetary surface. Application areas for the material, structural, and manufacturing/assembly technologies developed under this SBIR topic include launch and crew vehicles, in-space transportation elements, habitation and crew-transfer systems, surface systems, and other systems used for space exploration.

Since this topic area has a broad range of interest, subtopics are selected by the Space Technology Mission Directorate to enhance and/or fill gaps in the exploration technology development programs and to complement other mission directorate topic areas. Advances in composite, metallic, and ceramic material systems are of interest in this topic, as are advances in the associated manufacturing methods for these various material systems. Significant advances can be realized by improvements in material formulation through improvements in the capabilities to manufacture and assemble large-scale structural components. Therefore, subtopics of interest will include but will not be limited to nanomaterial and nanostructures development, advanced metallic materials and processes development, and large-scale polymer matrix composite structures, materials, and manufacturing technologies. Other sub-topic areas may be added as required to address specific agency needs.

The subtopic of interest for FY16 addresses joining techniques and designs for large segmented polymer matrix composite (PMC) structures. The intent of this specific focus is to address needs for large composite hardware applications for programs such as SLS as well as future composite structure applications for exploration such as habitat, transit vehicles and surface systems. Joining technologies (bonded or mechanical) to enable 5 – 9 m diameter composite structures will be of interest, as will new concepts for lightweight separation joints. The specific needs and metrics of this focus area is described in the subtopic description.

Research awarded under this topic should be conducted to demonstrate technical feasibility (proof of concept) during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a full-scale demonstration unit for functional and environmental testing at the completion of the Phase II contract.

#### References:

- (<http://www.nasa.gov/directorates/spacetech/home/index.html> [1]).

#### Sub Topics:

#### **Z4.01 Joining for Large-Scale Polymer Matrix Composite (PMC) Structures**

**Lead Center: MSFC**

**Participating Center(s): GSFC, LaRC**

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The subtopic area for Large-Scale Polymer Matrix Composite (PMC) Structures and Materials concentrates on developing lightweight structures, using advanced materials technologies and new manufacturing processes. The objective of the subtopic is to advance technology readiness levels of PMC materials and manufacturing for launch vehicles and in-space applications resulting in structures having affordable, reliable, and predictable performance. A key to better understanding predictable performance and faster qualification of components includes integrating the analytical tools between the materials and manufacturing process.

This subtopic will focus efforts on innovative low cost, light weight, high reliability composite joint concepts/techniques to enable the fabrication of complex geometry and/or large composite structures (5 to 9 meter diameter by 10 meters long). The specific area of interest is focused on:

- Novel concepts for joining (mechanical or bonded) large and/or complex segmented PMC structures together are of interest. Useful concepts can consider metallic-to-composite and composite-to-composite material interfaces. Examples of joints of interest include, but are not limited to, longitudinal and circumferential joint configurations for launch vehicle structures. In addition, cylinder to cylinder, and cylinder to frustum/conical ("Y" shaped) designs are of interest.
- Innovative joint designs with integrated sensing for the purposes of assisting with qualification of the joint design and interrogation of the joint during use to assess its performance and capability are also of interest.
- For bonded structure, novel, reproducible, and scalable surface treatments, bonding methods and techniques for very large structure, and novel adhesives are of interest as well as techniques to verify bond quality and predict/validate strength. Useful concepts can consider metallic-to-composite and composite-to-composite bond interfaces.
- New concepts for lightweight separation joints, both longitudinal and circumferential designs.

Concepts must consider end-to-end process evaluation with considerations to modeling of the joint/joining process and to full-size scale-up factors which will limit autoclave and oven access for joint cures (if needed). Concepts that are amenable to in-situ and/or on-orbit implementation are also of interest. Research should be conducted to demonstrate novel approaches, technical feasibility, and basic performance characterization for large-scale PMC structures and joint concepts during Phase I, and show a path toward a Phase II design allowables and prototype demonstration. Emphasis should be on demonstrable manufacturing technology that can be scaled up for very large structures.

#### References:

- Kirsch, M. T., "Composite Crew Module: Primary Structure," (<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110020665.pdf> [2]).
- Tenney, D. R. et al., "NASA Composite Materials Development: Lessons Learned and Future Challenges," (<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090037429.pdf> [3]).

#### Robotics and Autonomous Systems Topic Z5

One of NASA's strategic goals is to extend and sustain human activities across the solar system. With time delays and potentially sparse communications back to earth, astronauts will face the daunting task of operating and maintaining numerous systems that might unexpectedly break or may even be required to perform life-saving surgery without support from the earth based operators. The augmented reality (AR) technology holds the promise to reduce crew reliance of ground and paper procedure support in a deep-space human spaceflight missions.

NASA invests in the development of autonomous systems, advanced avionics, augmented reality and robotics technology capabilities for the purpose of enabling complex missions and technology demonstrations supporting the Science, Technology Mission Directorate (STMD). The software, avionics, and robotics elements requested within this topic are critical to enhancing human spaceflight system functionality. These elements increase autonomy and system reliability; reduce system vulnerability to extreme radiation and thermal environments; and support human exploration missions with robotic assistants, precursors and caretaker robots. As key and enabling technology areas, autonomous systems, avionics, augmented reality and robotics are applicable to broad areas of technology use, including heavy lift launch vehicle technologies, robotic precursor platforms, utilization of the International Space Station, and spacecraft technology demonstrations performed to enable complex or long

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duration space missions. All of these flight applications will require unique advances in autonomy, software, augmented reality, robotic technologies and avionics. The exploration of space requires the best of the nation's technical community to provide the technologies, engineering, and systems to enable human exploration beyond LEO, to visit Asteroids and the Moon, and to extend our reach to Mars.

Sub Topics:

## **Z5.01 Augmented Reality**

**Lead Center:** JSC

**Participating Center(s):** JPL, KSC

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

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

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

Proposal are sought to address the following Technology Areas:

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

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

### Wireless Technology Topic Z6

Wireless sensor networks can effectively support an array of sensors able to measure structural properties, the heat profile for thermal protection, impact detection for orbital debris and other functions requiring distributed sensors. Moreover, embeddable passive wireless sensors can greatly increase the capabilities of the sensing and telemetry portion of a spacecraft. This would be relevant to any of the ascent and landing systems needed for planetary exploration as part of the spacecraft or mission support systems. Of particular interest is the capability of adding sensors at a low cost - enabling better Integrated Health Management and Spacecraft Autonomy functions, which depend upon better sensing of spacecraft state and environment. If developed under STMD, the resulting

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technology has high potential for infusion into SMD and HEOMD Programs leading to more effective ascent vehicles, better spacecraft management, new entry, descent and landing systems and future planetary exploration systems.

Sub Topics:

## **Z6.01 Wireless Technology**

**Lead Center: ARC**

**Participating Center(s): GRC, JSC, MSFC, SSC**

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While wireless sensors have been slowly improved, tested and deployed on earth, their extension to aerospace has not occurred. The technology itself does not limit such extension, but rather traditional methods using wired interconnects have proven adequate for most vehicles and missions. However, there are major advantages conferred by wireless technology for aerospace avionics that make adoption favorable.

### **Wireless technology**

- Reduces the mass and volume of spacecraft by eliminating large heavy cable runs. This is particularly useful for small satellites, where internal volume is often highly constrained particularly for subsystem cables and connectors. This would enable smaller and lighter spacecraft.
- Can transfer data across pressure interfaces, into remote locations where it is difficult to run cables and onto movable structures where cables are at risk of failure.
- Provides less intrusive measurement and health monitoring capability by enabling sensors within fuel tanks and pipes and across pressure interfaces without breaching the structure.
- Supports late additions or mission enhancements by significantly limiting changes to vehicle structure and data paths.
- Functions despite structural failures that can break physical wires such as those caused by micrometeorite impacts or connector contamination, thereby creating heterogeneous redundancy for critical systems that improve reliability and safety.
- Supports dynamic reconfiguration of networks and components, enabling robust response to faults or changes in operating mode.

In time, wireless interconnects and interaction methods could largely supplant (or perhaps more importantly, complement) wired methods. Consider the adoption of mobile computing devices, which rely on purely wireless interfaces for communication, printing and even peripheral connection. Such advantages can apply to spacecraft, distributed sensor networks and even distributed instruments and planetary surface exploration systems.

Specifically, this subtopic solicits the following technologies:

- Low power, low mass, and small volume components, where sensor/actuator modules are less than 20 grams in mass and less than 1 cc in volume. Of particular interest are highly scalable systems for measurement and data acquisition where total subsystem mass would be under 1 Kg and would operate under 3 W of power.
- Components capable of surviving and operating in aerospace environments requiring tolerance to extreme temperatures, shock and vibration, and radiation effects that exist for satellites, launch vehicles, planetary and space habitats, deep space exploration systems and landing/re-entry systems.
- Techniques that decrease reliance upon batteries or eliminate the need for charging and battery

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replacement, including novel approaches for electromagnetic energy harvesting, generating and storage methods; including capacitive, hybrid and acoustic power harvesting technologies.

- Wireless technology, protocols, architectures and software systems that support redundant networks that can dynamically reconfigure to reestablish connectivity and function after temporary interruptions or component failures, including internal fault detection capability.

The major NASA and commercialization thrust for wireless technology would be its maturation for use in aviation and space. The end product of this SBIR subtopic is likely to be a series of demonstrations of capability of interest to NASA Programs for Phase III maturation. Significant commercial opportunities for these products are available in the existing aerospace market, particularly for aviation.

#### High Power/Voltage Electronics Topic Z1.01

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Target performance levels include:

- Radiation hardness:
  - 300 krad(Si) total ionizing dose tolerance, and
  - For vertical-field power devices: No heavy-ion induced permanent destructive effects upon irradiation with ions having a silicon-equivalent surface-incident linear energy transfer (LET) of 40 MeV-cm<sup>2</sup>/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 with ions having a silicon-equivalent surface-incident linear energy transfer (LET) of 75 MeV-cm<sup>2</sup>/mg and sufficient energy to fully penetrate the active volume prior to the ions reaching their maximum LET (Bragg peak).
- Thermal range: 150 °C or greater junction temperature.

Sub Topics:

Active Thermal Control Systems for Space Exploration Topic Z2.01

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### **Highly Efficient, Low Pour Point Thermal Control Fluids**

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Most if not all space vehicles have the need for a thermal control fluid that does not freeze at relatively low temperatures. These fluids with low pour points come with decreased thermal performance, causing an increase in system mass to the thermal control system. This scenario was apparent with JPL's Mars Science Laboratory as well as the Orion Vehicle. Vehicles subjected to the environments of deep space through transit scenarios to the Moon and Mars especially need a highly efficient thermal control fluid with low pour point. Ideally, this new thermal control fluid would have a pour point near  $-110^{\circ}\text{C}$  with thermal physical properties near water. Furthermore, for use in human systems, this thermal control fluid would have low toxicity, flammability, and vapor pressures for use in a habitable volume.

### **Advanced Heat Exchangers**

Air/liquid, liquid/liquid, coldplates, and phase change material heat exchangers are at the core of any thermal control system for a vehicle. Advances in manufacturing may yield a considerable mass savings over the current state of the art heat exchangers. Furthermore, lightweight non-venting phase change heat exchangers are sought to ameliorate the environmental transients that would be seen in planetary (Martian or Lunar) orbit. Heat exchangers that have minimal structural mass and good thermal performance are sought. Furthermore, the use of phase change materials that have a transition temperature between  $8^{\circ}\text{C}$ - $12^{\circ}\text{C}$  with heat of fusions above  $200\text{ kJ/kg}$  are needed. The goal is a ratio exceeding  $2/3$  phase change material mass and  $1/3$  structural mass. Condensing heat exchangers (air/liquid heat exchangers) are deemed to be a critical component of a closed loop environmental control life support system. The need for highly reliable condensing heat exchangers that do not contaminate due to microbial growth and do not impact the water processing system of an ECLSS system due to coatings on the HX is of high need for future human systems. Finally, advances in the aforementioned heat exchangers are expected to utilize new materials and manufacturing techniques over conventional brazing processes used today. NASA's Technology Roadmap Area 14 details various points of interest for these heat exchangers.

Sub Topics:

Advanced Metallic Materials and Processes Innovation Topic Z3.01

NASA is using several manufacturing processes supporting the Space Launch System to create structures with superior mechanical properties and increased reliability. Advancing the state of the art for advanced metallic materials and processes will continue to be a critical technology to build more efficient space vehicles with less expensive materials.

This topic seeks to develop new and innovative materials and manufacturing processes (both additive and subtractive) for lightweight and/or multifunctional metallic components and structures for NASA and related applications. Technologies that can enable joining of new or dissimilar materials, as well as significantly reduce costs, increase production rates, and improve weld quality should be considered.

Technologies should result in components with minimal or no machining; Technologies should provide novel techniques for producing high-strength components and joints that are highly free of defects. Emphasis on reducing structural mass, improving processing lead-time, and minimizing touch labor and final assembly steps, resulting in increased capability, reliability and reduced cost.

This subtopic seeks innovative processes and development of metallic material systems. The emphasis is on solid state welding practices including but not limited to: ultrasonic, thermal, and friction stir welding; new concepts for built-up structure approaches for lightweight structural panel applications, advanced near-net shaping, additive manufacturing processes; advanced coating technologies for wear and environmental resistance; functionally-graded (gradient alloy) materials that exhibit superior performance exceeding that of the individual constituent alloys. Technologies should result in components with minimal or no machining.

Proposals are sought in the following areas:

- Joining new materials: technologies that enable welding on a wide range of alloys and a wide range of thicknesses, including high-strength, temperature-resistant materials (such as titanium alloys, Inconel/Nickel-Based alloys, steels, and copper), metal-matrix composites, and other materials previously considered unweldable.
- Joining of complex geometries: technologies that enable welding of complex curvature joints or other types of structure variations that increase manufacturing possibilities.
- Development and prototyping technologies for fabricating gradient alloy (functionally graded) or amorphous

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(bulk metallic glass) materials for solid state welding processes, near-net shape, and additive manufacturing processes.

Responses should identify key performance parameters and TRL advancement in terms of quantifiable benefits to address specific areas including but not limited to the following: reduced structural mass, increased structural efficiency, improved processing lead-time, minimized touch labor and final assembly steps, increased reliability and reduced cost. Scale-up and transition to aerospace hardware and products should also be addressed.

Sub Topics:

Joining for Large-Scale Polymer Matrix Composite (PMC) Structures Topic Z4.01

The subtopic area for Large-Scale Polymer Matrix Composite (PMC) Structures and Materials concentrates on developing lightweight structures, using advanced materials technologies and new manufacturing processes. The objective of the subtopic is to advance technology readiness levels of PMC materials and manufacturing for launch vehicles and in-space applications resulting in structures having affordable, reliable, and predictable performance. A key to better understanding predictable performance and faster qualification of components includes integrating the analytical tools between the materials and manufacturing process.

This subtopic will focus efforts on innovative low cost, light weight, high reliability composite joint concepts/techniques to enable the fabrication of complex geometry and/or large composite structures (5 to 9 meter diameter by 10 meters long). The specific area of interest is focused on:

- Novel concepts for joining (mechanical or bonded) large and/or complex segmented PMC structures together are of interest. Useful concepts can consider metallic-to-composite and composite-to-composite material interfaces. Examples of joints of interest include, but are not limited to, longitudinal and circumferential joint configurations for launch vehicle structures. In addition, cylinder to cylinder, and cylinder to frustum/conical ("Y" shaped) designs are of interest.
- Innovative joint designs with integrated sensing for the purposes of assisting with qualification of the joint design and interrogation of the joint during use to assess its performance and capability are also of interest.
- For bonded structure, novel, reproducible, and scalable surface treatments, bonding methods and techniques for very large structure, and novel adhesives are of interest as well as techniques to verify bond quality and predict/validate strength. Useful concepts can consider metallic-to-composite and composite-to-composite bond interfaces.
- New concepts for lightweight separation joints, both longitudinal and circumferential designs.

Concepts must consider end-to-end process evaluation with considerations to modeling of the joint/joining process and to full-size scale-up factors which will limit autoclave and oven access for joint cures (if needed). Concepts that are amenable to in-situ and/or on-orbit implementation are also of interest. Research should be conducted to demonstrate novel approaches, technical feasibility, and basic performance characterization for large-scale PMC structures and joint concepts during Phase I, and show a path toward a Phase II design allowables and prototype demonstration. Emphasis should be on demonstrable manufacturing technology that can be scaled up for very large structures.

References:

- Kirsch, M. T., "Composite Crew Module: Primary Structure," (<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110020665.pdf> [2]).
- Tenney, D. R. et al., "NASA Composite Materials Development: Lessons Learned and Future Challenges," (<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090037429.pdf> [3]).

Sub Topics:

Augmented Reality Topic Z5.01

One of NASA's strategic goals is to extend and sustain human activities across the solar system. With time delays and potentially sparse communications back to earth, astronauts will face the daunting task of operating and maintaining numerous systems that might unexpectedly break or may even be required to perform life-saving surgery without support from the earth based operators. The augmented reality (AR) technology holds the promise to reduce crew reliance of ground and paper procedure support in a deep-space human spaceflight missions.

Within the ISS Program, maintenance requires well trained crew members and is labor intensive, expensive and

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inefficient. NASA use paper and electronic procedures to direct crew through complex maintenance procedures for all on-board systems. Developing and executing procedures are still time consuming and tedious tasks, and substantial training is needed to understand the technical details for troubleshooting defective components, and the performance of critical maintenance and repairs. Augmented Reality based systems could significantly support future human exploration missions by providing the type of guidance normally associated with an expert human trainer. The capabilities of envisioned future AR based system will augment the abilities of the crew while being simple and highly intuitive to use.

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

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

Proposal are sought to address the following Technology Areas:

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

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

Sub Topics:

Wireless Technology Topic Z6.01

Wireless sensor networks can effectively support an array of sensors able to measure structural properties, the heat profile for thermal protection, impact detection for orbital debris and other functions requiring distributed sensors. Moreover, embeddable passive wireless sensors can greatly increase the capabilities of the sensing and telemetry portion of a spacecraft. This would be relevant to any of the ascent and landing systems needed for planetary exploration as part of the spacecraft or mission support systems. Of particular interest is the capability of adding sensors at a low cost - enabling better Integrated Health Management and Spacecraft Autonomy functions, which depend upon better sensing of spacecraft state and environment. If developed under STMD, the resulting technology has high potential for infusion into SMD and HEOMD Programs leading to more effective ascent vehicles, better spacecraft management, new entry, descent and landing systems and future planetary exploration systems.

While wireless sensors have been slowly improved, tested and deployed on earth, their extension to aerospace has not occurred. The technology itself does not limit such extension, but rather traditional methods using wired interconnects have proven adequate for most vehicles and missions. However, there are major advantages conferred by wireless technology for aerospace avionics that make adoption favorable.

### **Wireless technology**

- Reduces the mass and volume of spacecraft by eliminating large heavy cable runs. This is particularly useful for small satellites, where internal volume is often highly constrained particularly for subsystem cables and connectors. This would enable smaller and lighter spacecraft.
- Can transfer data across pressure interfaces, into remote locations where it is difficult to run cables and onto movable structures where cables are at risk of failure.
- Provides less intrusive measurement and health monitoring capability by enabling sensors within fuel tanks

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- and pipes and across pressure interfaces without breaching the structure.
  - Supports late additions or mission enhancements by significantly limiting changes to vehicle structure and data paths.
  - Functions despite structural failures that can break physical wires such as those caused by micrometeorite impacts or connector contamination, thereby creating heterogeneous redundancy for critical systems that improve reliability and safety.
  - Supports dynamic reconfiguration of networks and components, enabling robust response to faults or changes in operating mode.

In time, wireless interconnects and interaction methods could largely supplant (or perhaps more importantly, complement) wired methods. Consider the adoption of mobile computing devices, which rely on purely wireless interfaces for communication, printing and even peripheral connection. Such advantages can apply to spacecraft, distributed sensor networks and even distributed instruments and planetary surface exploration systems.

Specifically, this subtopic solicits the following technologies:

- Low power, low mass, and small volume components, where sensor/actuator modules are less than 20 grams in mass and less than 1 cc in volume. Of particular interest are highly scalable systems for measurement and data acquisition where total subsystem mass would be under 1 Kg and would operate under 3 W of power.
- Components capable of surviving and operating in aerospace environments requiring tolerance to extreme temperatures, shock and vibration, and radiation effects that exist for satellites, launch vehicles, planetary and space habitats, deep space exploration systems and landing/re-entry systems.
- Techniques that decrease reliance upon batteries or eliminate the need for charging and battery replacement, including novel approaches for electromagnetic energy harvesting, generating and storage methods; including capacitive, hybrid and acoustic power harvesting technologies.
- Wireless technology, protocols, architectures and software systems that support redundant networks that can dynamically reconfigure to reestablish connectivity and function after temporary interruptions or component failures, including internal fault detection capability.

The major NASA and commercialization thrust for wireless technology would be its maturation for use in aviation and space. The end product of this SBIR subtopic is likely to be a series of demonstrations of capability of interest to NASA Programs for Phase III maturation. Significant commercial opportunities for these products are available in the existing aerospace market, particularly for aviation.

Sub Topics:

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