NASA STTR 2018 Phase I Solicitation

Small Business Technology Transfer

T1.01 Affordable Nano/Micro Launch Propulsion Stages

Lead Center: HQ

Participating Center(s): AFRC

Technology Area: TA15 Aeronautics

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

This subtopic seeks to mature innovative ideas providing a pipeline of components, processes, technologies, propellants, and materials that enhance propulsive performance or that enable adequate propulsive performance at a significant cost savings. Innovations submitted under this subtopic must focus on meeting the affordability objectives. Each innovation must be linked to an existing or proposed launch architecture and operational paradigm. A develop path must be outlined that defines the current development state of the innovation(s) and outlines the improvements sought that will enable a launch system to meet the affordability objectives.

Proposed ideas must lead to a proof of concept test during Phase II. The test results should provide measurements of the propulsive performance required for the proposed launch architecture. Test article costs must be disclosed and linked to the affordability objectives.

The pipeline is meant to feed SBIR topic Z9.01, Small Launch Vehicle Technologies and Demonstrations.

Technology areas of specific interest from Z9.01 are as follow:

- Innovative Propulsion Technologies & Prototype Stages.
- Affordable Guidance, Navigation & Control.
- Manufacturing Innovations for Launch Vehicle Structures & Components.
- Reusability Innovations.
- Dual Use Hypersonic Flight Testbeds.
Proof of concept testing that mature technologies for inclusion in these areas of interest are specifically sought.

**T3.02 Intelligent/Autonomous Electrical Power Systems**

**Lead Center:** HQ  
**Participating Center(s):** JPL

**Technology Area: TA15 Aeronautics**

Missions to Mars and beyond experience communication delays with Earth of between 3 to 45 minutes. Due to this, it is impractical to rely on ground-based support and troubleshooting in the event of a power system fault or component failure. Intelligent/autonomous systems are required that can manage the power system in both normal mode and failure mode.

In normal mode, the system would predict energy availability, perform load scheduling, maintain system security and status on-board and ground based personnel. One aspect of overall system autonomy would be solar array characterization, for spacecraft utilizing this technology. One drawback of current satellite systems is the lack of adequate means of determining solar panel or cell status. Being able to automatically characterize solar panel status can enhance energy availability prediction. Similar technology to access that status of battery systems would further enhance these predictions.

In failure mode, the system must identify a fault or failure and perform contingency planning to react or reconfigure the system appropriately to move it back into normal mode of operation, without human involvement. The technologies to detect and identify specific failures in both the generation, distribution and storage systems are needed along with strategies to utilize the failure data to identify recovery strategies for the power system.

With the potential of future manned missions to Mars, this technology will become increasingly important for electrical power management and distribution. Specific areas of interest include:

- Autonomous/intelligent PMAD.
- Failure detection strategies.
- Recovery strategies.
- Generation and storage characterization.

**T3.03 Bio-inspired Concepts for the Development of Power, Energy and Storage Technologies for Air and Space**

**Lead Center:** HQ  
**Participating Center(s):** ARC, LaRC

**Technology Area: TA15 Aeronautics**

Biomimicry is the imitation of life and life's principles characterized by reduced use of energy, water and raw materials. Energy and material use is substituted by information and structure. The goal of this topic is to focus efforts on system driven technology development that draws from nature to solve technical challenges in aeronautics and space exploration. This subtopic is also looking for proposals that include data collection that would add to the Periodic Table of Life database. For example, if looking at building a solar concentrator based on plants, it would be valuable to collect and share information on a wide variety of applicable plants and related biological models. The data may be from literature, museums, or through measurements conducted as part of the STTR.

Proposals must demonstrate that the proposed technology complies with natural principles, patterns and
mechanisms. Refer to the following sources to understand biomimetic principles.

Some resources are provided here:

- V.I.N.E. (Virtual Interchange for Nature-inspired Exploration) - [https://www.grc.nasa.gov/vine](https://www.grc.nasa.gov/vine) [1].
- PeTaL - [https://www.grc.nasa.gov/vine/about/what-is-petal/](https://www.grc.nasa.gov/vine/about/what-is-petal/) [2].
- Taxonomy tool - [https://asknature.org/](https://asknature.org/) [3].

Technology is sought in the following areas:

**Bio-inspired resource utilization, power generation, energy storage, power management and distribution**

The NRC has identified a NASA Top Technical Challenge as the need to "Increase Available Power". Additionally, a NASA Grand Challenge is "Affordable and Abundant Power" for NASA mission activities. It is essential to be able to harness, store and distribute energy while maintaining minimal system mass and complexity. Biological models such as the oriental hornet or electric eel may be obvious candidates. Methods to improve solar cell efficiency or to create structural solar cells are of interest.

Power generation and management systems are also of interest to the growing Hybrid Gas Electric Propulsion Project under ARMD. There is specific interest in motor thermal management and low loss power distribution and storage. New concepts for electric motors and hybrid systems are desirable.

Topics include, but are not limited to:

- Solar electric propulsion concepts (packing strategies based on nature, cell orientation/stabilization)
- Thermal management for solar electric propulsion.
- In Situ Resource Utilization using nature-inspired principles (passive, feedback controls, using local resources and energy sources, water-based chemistry and processes).
- Life support systems and personal protective equipment including anti-microbial films, first aid, radiation protection. Examples of natural models include tardigrades, structural color in butterflies/peacocks, shark skin.
- Swarm topologies, communication strategies and system dynamics applied to CubeSats or rovers.

**Cross cutting technology making use of bio-inspired processes**

Specific areas of interest include:

- Tools to aid in discovery of bio-inspired materials or technology.
- Demonstrations of advantages in mass savings made possible through bioinspired topologies enabled by additive manufacturing methods.
- Controlled synthesis of lightweight engineering materials due to bioinspired synthesis methods.

**T4.01 Information Technologies for Intelligent and Adaptive Space Robotics**

Lead Center: HQ

Participating Center(s): JPL, JSC

**Technology Area: TA15 Aeronautics**

The objective of this subtopic is to develop information technologies (algorithms, avionics, and software) that enable robots to better support space exploration. Improving robot information technology is critical to improving the capability, flexibility, and performance of future NASA missions. In particular, the NASA "Robotics and
Autonomous Systems’ technology roadmap (T04) indicates that extensive and pervasive use of robots can significantly enhance future exploration missions that are progressively longer, complex, and operate with fewer ground control resources.

The performance of space robots is directly linked to the quality and capability of the information technologies that are used to build and operate them. Thus, proposals are sought that address the following technology needs:

- Advanced robot user interfaces that facilitate distributed collaboration, geospatial data visualization, summarization and notification, performance monitoring, and physics-based simulation. The primary objective is to enable more effective and efficient interaction with robots remotely operated with discrete commands or supervisory control. Note: proposals to develop user interfaces for direct teleoperation (manual control) are not being solicited and will be considered non-responsive.
- Navigation systems for mobile robot (free-flying and wheeled) operations in man-made (inside the International Space-Station) and unstructured, natural environments (Earth, Moon, Mars). Emphasis on multi-sensor data fusion, obstacle detection, and localization. The primary objective is to radically and significantly increase the performance of mobile robot autonomous navigation through new sensors, avionics (including COTS processors for use in space), perception algorithms and software. Proposals for small size, weight, and power (SWAP) systems are particularly encouraged.
- Robot software systems that support system-level autonomy, instrument/sensor targeting, downlink data triage, and activity planning. The primary objective is to facilitate the creation, extensibility and maintenance of complex robot systems for use in the real-world. Proposals that address autonomy for planetary rovers operating in rough terrain or performing non-traditional tasks (e.g., non-prehensile manipulation) are particularly encouraged.

Proposers are encouraged to target the demonstration of these technologies to existing NASA research robots or current projects in order to maximize relevance and potential for infusion.

Deliverables to NASA:

- Identify scenarios, use cases, and requirements.
- Define specifications based on design trades.
- Develop concepts and prototypes.
- Demonstrate and evaluate prototypes in real-world settings.
- Deliver prototypes (hardware and/or software) to NASA.

T4.03 Coordination and Control of Swarms of Space Vehicles

Lead Center: HQ

Technology Area: TA15 Aeronautics

This subtopic is focused on developing and demonstrating technologies for coordination and autonomous control of teams and swarms of space systems including but not limited to spacecraft and planetary rover teams in a dynamic environment.

Possible areas of interest include but are not limited to:

- Coordinated task planning, operation, and execution.
- Relative localization in space and on planet surface.
- Close proximity operations of spacecraft swarms including sensors required for collision detection and avoidance.
- Fast, real-time, coordinated motion planning in areas densely crowded by other agents.
- Human-Swarm interaction interfaces for controlling the multi-agent system as an ensemble.
- Distributed fault detection and mitigation due to hardware failures or compromised systems.
• Communication-less coordination by observing and estimating the actions of other agents in the multi-agent system.

Phase I awards will be expected to develop theoretical frameworks, algorithms, software simulation and demonstrate feasibility (TRL 2-3). Phase II awards will be expected to demonstrate capability on a hardware testbed (TRL 4-6).

T6.01 Innovative Solutions to Carbon Dioxide Removal for Spacecraft, Surface Systems, and EVA Systems

Lead Center: HQ

Participating Center(s): ARC, MSFC

Technology Area: TA15 Aeronautics

Technology advancements in Extra-Vehicular Activity (EVA) and spacecraft cabin life support systems are required to enable forecasted microgravity and planetary human exploration mission scenarios and to support potential extension of the International Space Station (ISS) mission beyond 2020.

Providing cost effective, efficient and reliable carbon dioxide removal for human space applications has been a challenge. The state-of-the-art zeolite-based system currently in use in for closed-loop atmosphere revitalization on the ISS has suffered from the production of fines, resulting in the need for frequent maintenance. Vacuum-based swing bed systems for potential use in the Portable Life Support Systems (PLSS) used in EVA space suits will not be effective in the Mars surface environment due to the partial pressure of carbon dioxide in the Mars atmosphere. Both solutions become less efficient if the inlet partial pressure of CO$_2$ from the crew environment is reduced. Novel solutions are sought for applications including Spacecraft, Surface Systems, and EVA Systems.

Advanced Extravehicular Mobility Unit (EMU)

Technologies are sought for continuous CO$_2$ and relative humidity removal capability that can operate within space vacuum and Martian atmospheres (0.6 kPa, or 4.5 torr). Examples of advancements sought include:

• Improvements in sorbent CO$_2$ and H$_2$O uptake leading to smaller, more efficient beds.
• Providing for independent control and selectivity for CO$_2$ and water vapor.
• Consideration for alternative process technologies, including but not limited to metal organic frameworks, ionic liquids, other liquid sorbents and supported structures, or selective permeable membranes.
• Novel systems integration and enhancements, such as using efficient boost compressors that may enable pressure swing operation in the Martian atmosphere, or temperature swing cycles that do not place a large power burden on the EMU.

Systems for Spacecraft Cabin and Surface Systems

Currently state-of-the-art CO$_2$ removal systems are large and power intensive. Alternative systems have been proposed, including but not limited to, metal organic frameworks, ionic liquids and liquid sorbents, structured or other alternative solid sorbents, selective membranes, electrochemical separation, etc. Many of these novel alternative technologies are at a low TRL and require additional research and development to prove the concepts, especially at the low partial pressures required for use in the cabin environment. Improvements are sought in the following areas:

• Improvements in sorbent CO$_2$ capacity and selectivity leading to smaller, more efficient components, lower energy consumption and operation at lower CO$_2$ partial pressures.
• Increases in the robustness of sorbent materials to mechanical stresses, temperature and humidity changes, or poisoning.
• Advanced and novel methods to increase the efficiency of temperature and pressure swing adsorption processes.
Innovations and improvements in capillary structures and gravity insensitive frameworks for containment and management of ionic liquids and liquid sorbents.

NASA is especially interested in systems that can be incorporated into closed loop life support systems that recycle CO\textsubscript{2} and humidity, and could achieve the following performance targets. These parameters address the full system, including fans, valves, heat exchangers, etc.):

- Removal rate of 4.16 kg/day (a four-person load).
- Operate in an environment with 2.0 mmHg ppCO\textsubscript{2} for cabin applications (based on the daily average ppCO\textsubscript{2}).
- System size \(?0.3\) cubic meters for the 4-person load.
- System power use \(?2500\) watts of power for the 4-person load.
- System mass of \(?100\) kilograms for the 4-person load.
- Effectively separate out water vapor (less than 100 ppm water vapor in the CO\textsubscript{2} product is desired).
- Effectively separate out oxygen and nitrogen (less than 1\% O\textsubscript{2} and 2\% N\textsubscript{2} by volume in the CO\textsubscript{2} product is desired).

Phase I Deliverables - Detailed analysis, proof of concept test data, and predicted performance (mass, volume, thermal performance) addressing inlet partial pressures of CO\textsubscript{2} below and above 2 mmHg, with description of regeneration requirements, especially relationship to Mars atmosphere vacuum. Deliverables should clearly describe and predict performance over the state of the art.

Phase II Deliverables - Delivery of technologically mature components/subsystems that demonstrate functional performance with appropriate interfaces are required. Prototypes should be at least at a 1-crewmember scale.

**T7.01 Advanced Bioreactor Development for In Situ Microbial Manufacturing**

**Lead Center:** HQ

**Technology Area:** TA15 Aeronautics

NASA’s future long-duration missions require a high degree of materials recovery and recycling as well as the ability to manufacture required mission resources in situ. While physico-chemical methods offer potential advantages for the production of many products, biological systems are able to manufacture a wide range of materials that are not yet possible with abiotic systems. Microbial systems are currently being developed by academic institutions, industry, and government agencies to produce a wide array of products that are applicable to space missions. Relevant mission resources include, but are not limited to, food, nutrients, pharmaceuticals, polymers, fuels and various chemicals.

While current space-based research involves engineering of organisms to produce targeted compounds as well as the in-situ production of microbial media to support larger scale operations, additional enabling research is needed to develop specialized bioreactors that are highly efficient, reliable, low volume and mass, and that otherwise meet the unique rigors of space.

Advanced bioreactor research and development has been primarily focused on terrestrial applications, particularly pharmaceutical, food and chemical production systems. Some space bioreactor work regarding flight experiments and life support applications has been conducted, such as algal reactors for CO\textsubscript{2}/O\textsubscript{2} management. However, little to no effort has been conducted on the bioreactor design and operations that are required to enable in-situ microbial manufacturing. Therefore, innovations are sought to provide:

- Bioreactors that minimize mass, power and volume, maintenance, process inputs and waste production.
- Bioreactors that are capable of operating on the surface of Mars or potentially in-flight scenarios.
- Bioreactors that incorporate novel microbial biomass separation/harvesting/purification methods, materials recycling/recovery and ease of cleaning.
- High-density bioreactors that are capable of producing extremely high levels of microbial biomass and/or
• Advanced bioreactor monitoring and control systems, including oxygen, temperature, pH, nutrients.
• Experimental bioreactors that exhibit the ability to scale upwards.
• Bioreactors that maximize reliability, component miniaturization, materials handling ability, gas management and overall performance.

Overall, proposals should focus on advancing bioreactor development for space applications, rather than the production of a particular product or microorganism. The Phase I STTR deliverable should include a Final Report that captures any scientific results and processes as well as details on the technology identified. The Final Report should also include a Feasibility Study which defines the current technology readiness level and proposes the maturation path for further evolution of the system. Opportunities for commercial and government infusion should be addressed. Other potential deliverables include bioreactor system designs, hardware components and prototypes, and system control approaches and software.

T7.02 Space Exploration Plant Growth

Lead Center: HQ

Participating Center(s): JSC

Technology Area: TA15 Aeronautics

Producing food for crew consumption is an important goal for achieving Earth independence and reducing the logistics associated with future exploration missions. NASA seeks innovative technologies to enable plant growth systems for food production for in-space and planetary exploration missions.

• Regolith to Soil - Cultivation of crops for a Mars surface mission could be done hydroponically, or in combination with solid media generated from mineral regolith found near the landing site. NASA is interested in testing and developing concepts for generating "soil" media from Mars-like regolith to support food crop growth and allow uptake of essential minerals. Consideration should be given to improving water and nutrient retention characteristics, and remediation of potentially toxic perchlorate compounds common to Mars regolith.
• CO₂ Control for Plant Chambers - More advanced plant chambers for space typically manage their internal atmosphere separately, which allows recycling of transpired humidity. But this requires the use of consumable, compressed CO₂ sources for controlling the plant chamber. Cabin air typically has high CO₂ levels and technologies are sought to scavenge or adsorb cabin CO₂ from cabin air and allow careful, controlled additions of the CO₂ to the plant chamber.
• Cultivation and Growth Systems - Spacecraft systems are constrained to utilize minimal volume and require minimal crew time for management and operation. Future systems may even require autonomous start-up and operation prior to crew arrival. NASA seeks innovative systems for plant growth and cultivation that are volume efficient, flexible for a range of plant types and sizes (examples: tomatoes, wheat, beans, and potatoes).

Technologies should be adaptive for the entire life cycle (from seeding, to managing plant growth and spacing, through harvest), and reusable across multiple harvests. Concepts need to address integration with watering and nutrient/fertilizer systems (whether soil/media based, hydroponic, or aeroponic). Systems should address whether they are microgravity compatible, surface gravity compatible, or both.

T8.02 Photonic Integrated Circuits

Lead Center: HQ

Participating Center(s): GRC, JSC
Technology Area: TA15 Aeronautics

Integrated photonics generally is the integration of multiple lithographically defined photonic and electronic components and devices (e.g., lasers, detectors, waveguides/passive structures, modulators, electronic control and optical interconnects) on a single platform with nanometer-scale feature sizes. The development of photonic integrated circuits permits size, weight, power and cost reductions for spacecraft microprocessors, communication buses, processor buses, advanced data processing, free space communications and integrated optic science instrument optical systems, subsystems and components. This is particularly critical for small spacecraft platforms. This topic solicits methods, technology and systems for development and incorporation of active and passive circuit elements for integrated photonic circuits for:

- **Integrated photonic sensors (physical, chemical and/or biological) circuits:** NASA applications examples include (but are not limited to): Lab-on-a-chip systems for landers, Astronaut health monitoring, Front-end and back-end for remote sensing instruments including trace gas lidars Large telescope spectrometers for exoplanets using photonic lanterns and narrow band filters. On chip generation and detection of light of appropriate wavelength may not be practical, requiring compact hybrid packaging for providing broadband optical input-output and also, as means to provide coupling of light between the sensor-chip waveguides and samples, unique optical components (e.g., Plasmonic waveguides, microfluidic channel) may be beneficial. Examples: Terahertz spectrometer, Optical spectrometer, gyroscope, magnetometer, urine/breath/blood analysis.

- **Integrated Photonic Circuits for Analog RF applications:** NASA applications include new methods due to Size, Weight and Power improvements, passive and active microwave signal processing, radio astronomy and Terahertz spectroscopy. As an example, integrated photonic circuits having very low insertion loss (e.g., ~1dB) and high spur free dynamic range for analog and RF signal processing and transmission which incorporate, for example, monolithic high-Q waveguide microresonators or Fabry-Perot filters with multi-GHz RF pass bands. These components should be suitable for designing chip-scale tunable opto-electronic RF oscillator and high precision optical clock modules. Examples: Ka, W, V band radar/receivers.

- **Integrated photonic circuits for very high-speed computing and free space communications:** Advanced computing engines that approach Teraflop per second computing power for spacecraft in a fully integrated combined photonic and electronic package. Free space communications downlink modems at the > 1 Terabit per second level for Near-Earth (Low-Earth Orbit to ground) and > 100 Mbls for > 1 AU distances. Examples: Transmitters, receivers, microprocessors.

T9.01 Lander Systems Technology

Lead Center: HQ

Participating Center(s): GRC, JSC, LaRC

Technology Area: TA15 Aeronautics

**Lander Components and Affordable/Sustainable Development**

Lander systems require many components that will need to advance beyond their current capability to meet the needs of lander missions. A lander is essentially a system of components and each must be developed to enable mission success. Several components for lander systems have been identified as weak points or long lead development and/or qualification concerns that necessitate advancement. These include the following:

- Additive manufacturing for LOX/Methane and other propulsion components. Additional development in the area of additive manufacturing for propulsion components will continue to open up the trade space for lander systems.
- Testbed and hardware-in-the-loop testing systems that allow rapid hardware development and permit parallel design and test efforts.
- Less expensive methods for qualifying Commercial Off the Shelf (COTS) components as well as flight developed components.
- Developments to improve mission design and simulation tools. With advancing Technology Readiness
Level (TRL) components, better mission design and simulation tools will be needed to capture and model the changing lander systems in order to leverage improvements.

- Avionics and flight software development is needed for proper lander systems control, navigation, propulsion operation.
- Lander systems scalability studies to facilitate larger payloads.
- Deep Space Engine capability; particularly in Monomethylhydrazine (MMH) and Mixed Oxides of Nitrogen (MON-25) development which allow lower propellant temperatures.

**LOX/Methane Propulsion Technology** (see also Z10.02)

LOX/Methane propulsion remains attractive to lander systems and will require further advancements to leverage its full potential. LOX/Methane Propulsion Technology is focused on propulsion systems and engine components development that increase durability, reliability, and capability, while reducing the mass of the component or the overall system. These technologies include the following:

- Integrated propulsions systems that reduce duplication of systems to support main engines and Reaction Control Systems (RCS).
- 25lbf to 100 lbf thrust Reaction Control Systems (RCS) to enable higher payloads and manned missions.
- Engine components designed for 1000 lbf to 4000 lbf thrust LOX/Methane systems.
- Low leakage valves that minimize propellant loss over long duration missions. With missions to Mars taking years, low leakage valves are essential to conserve propellant that will be needed for ascent and maneuvers.
- Reliable, low actuator load valves designed to operate and be compatible with cryogenic propellants (such as Methane). Low actuator loads keep power and mass requirements to a minimum which is of particular importance for long duration lander missions.
- LOX/Methane Engine components compatible with In-Situ Resource Utilization capabilities that reduce launch mass.
- Design and test demonstration of Integrated Main Propulsion System (MPS) Reaction Control with LOX/Methane.
- Large scale nozzle and nozzle extension technology (>40” dia) using novel processing techniques that reduce fabrication costs and schedule.
- High temperature (>2600° F) nozzle material development to support in-space, ultra-light weight applications in a methane environment. This includes but is not limited to Carbon-Carbon (C-C) and refractory metal nozzles that are regeneratively or radiatively-cooled.

**In-Situ Resource Utilization (ISRU) Compatible Propulsion**

ISRU compatible propulsion systems will be essential to make long-term manned missions possible with landers. ISRU compatible propulsion technologies include the following:

- Liquefaction system design and testing.
- Liquefaction subsystem development that demonstrates the performance required for a Mars ISRU plant.
- Integrated liquefaction and propulsion system concepts.
- Tanking and Cryogenic Fluid Management (CFM) capabilities for ISRU applications.
- Insulation systems for ISRU propulsion.

**Lander Systems of Interest**

Additional lander systems are needed to develop capabilities and open trade spaces for further concepts. Other lander systems of interest include the following:

- Reduced toxicity hypergolic thrusters and components.
- Multi-engine architecture with distributed avionics.
- Long duration wetted seals for MON-25 propulsion.
- Engine cooling technologies.
- Variable Conductance Heat Pipes (active and/or passive).
The use of thin-ply composites is one area of composites technology that has not yet been fully explored or exploited. Thin-ply composites are those with cured ply thicknesses below 0.0025 in. and commercially available prepregs are now available with ply thicknesses as thin as 0.00075 in. By comparison, a standard-ply-thickness composite would have a cured ply thickness of approximately 0.0055 in. or greater. Thin-ply composites hold the potential for reducing structural mass and increasing performance due to their unique structural characteristics, which include (when compared to standard-ply-thickness composites):

- Improved damage tolerance.
- Resistance to microcracking (including cryogenic-effects).
- Improved aging and fatigue resistance.
- Reduced minimum-gage thickness.
- Thinner sections capable of sustaining large deformations without damage.
- Increased scalability.

These characteristics can make thin-ply composites attractive for a number of applications in both aeronautics and space. For example, preliminary analyses show that the notched strength of a hybrid of thin and standard ply layers can increase the notched tensile strength of composite laminates by 30%. Thus, selective incorporation of thin plies into composite aircraft structures may significantly reduce their mass. There are numerous possibilities for space applications. The resistance to microcracking and fatigue makes thin-ply composites an excellent candidate for a deep-space habitation structure where hermeticity is critical. Since the designs of these types of pressurized structures are typically constrained by minimum gage considerations, the ability to reduce that minimum gage thickness also offers the potential for significant mass reductions. For other space applications, the reduction in thickness enables: thin-walled, deployable structural concepts only a few plies thick that can be folded/rolled under high strains for launch (and thus have high packaging efficiencies) and deployed in orbit; and greater freedom in designing lightweight structures for satellite buses, landers, rovers, solar arrays, and antennas. For these reasons, NASA is interested in exploring the use of thin-ply composites for aeronautics applications requiring very high structural efficiency, for pressurized structures (such as habitation systems and tanks), for lightweight deep-space exploration systems, and for low-mass high stiffness deployable space structures (such as rollable booms or foldable panels, hinges or reflectors). There are many needs in development, qualification and deployment of composite structures incorporating thin-ply materials – either alone or as a hybrid system with standard ply composite materials.

The particular capabilities requested for in a Phase I proposal in this subtopic are:

- New processing methods for making repeatable, consistent, high quality thin-ply carbon-fiber prepreg materials, (i.e., greater than 55% fiber density with low degree of fiber twisting, misalignment and damage, low thickness non-uniformity and minimal gaps in the material across the width). Prepreg product forms of interest have areal weights below 60 g/m² for unidirectional tape with tape widths between 6 and 100 mm wide, and below 130 g/m² for woven/braided prepreg materials. Matrices of interest include both toughened epoxy resins for aeronautics applications, and resins qualified for use in space.
- Initial process development in using thin-ply prepregs for component fabrication using automated tape layup or other robotic technologies.
• Contributing to the development of the design and qualification database through testing and interrogation of the structural response and damage initiation/progression at multiple scales including evaluation of environmental durability and ageing.
• Analysis and design tool validation and calibration to ensure that the technology to appropriately design, identify any application-specific shortcomings with suggested improvements, and certify thin-ply composite components is matured sufficiently to be used for NASA applications.
• Micromechanics models for spread-tow woven/braided laminates, including viscoelastic response.
• Development of testing methods adapted for thin-ply high-strain composite materials and structures, with particular interest to dedicated large deformation bending and creep tests.
• Engineering viscoelastic behavior of thin-ply laminates for controlled deployment of space structures.

The intention of a Phase II follow-on effort would be to develop or to further mature the necessary design/analysis codes, and to validate the approach through design, build, and test of an article representative of the component/application of interest to NASA.

T12.02 Extensible Modeling of Metallurgical Additive Manufacturing Processes

Lead Center: HQ

Technology Area: TA15 Aeronautics

The subtopic of modeling of additive processes is highly relevant to NASA as NASA is currently on a path to implement additive processes in space flight systems with little or no ability to model the process and thereby predict the results. In order to reliably use this process with a variety of materials for space flight applications, NASA has to have a much deeper understanding of the process. NASA is currently considering these processes for MOXIE, SHERLOC, ion engines and other spacecraft structural and multifunctional applications.

Additive manufacturing of development and flight hardware with metallic alloys is being developed by NASA and its various partners for a variety of spacecraft applications. These components are expected to see extreme environments coupled with a need for high-reliability (e.g., manned spaceflight), which requires a deeper understanding of the manufacturing processes. Modeling of the additive processes to provide accurate dimensional designs, preferred microstructures and defect-free is a significant challenge that would dramatically benefit from a joint academic-industry approach. The objective would be to create process models that are compatible with current alloys systems and additive manufacturing equipment which will provide accurate prediction of outcomes from a variety of additive manufacturing process parameters and materials combinations. The primary alloys of interest to NASA at this time include: Inconel 625 & 718, stainless steels, such as 304 and 316, Al10SiMg, Ti-6Al-4V, and copper alloys (GrCop-84). It is desired that the modeling approach address a focused material system, but be readily adaptable to eventually accommodate all of these materials. Therefore, the model should incorporate modest parameter changes coupled with being easily extensible for future alloys of interest to NASA. NASA is interested in modeling of the Selective Laser Melting (SLM), Electron Beam Melting (EBM) and Laser Engineered Net Shaping (LENS) processes.

T13.01 Intelligent Sensor Systems

Lead Center: HQ

Participating Center(s): KSC, MSFC

Technology Area: TA15 Aeronautics

This subtopic area seeks to develop advanced instrumentation technologies which can be embedded in systems and subsystems. Embedded sensor systems have the potential for substantial reduction in time and cost of propulsion systems development, with substantially reduced operational costs and evolutionary improvements in ground, launch and flight system operational robustness. The technologies developed would be capable of addressing multiple mission requirements for remote monitoring such as vehicle health monitoring. The goal is to
provide a highly flexible instrumentation solution capable of monitoring remote or inaccessible measurement locations. All this while reducing substantially or eliminating cabling. Highly desirable to be integrated into process control for highly autonomous system operation including the ability to detect present conditions and apply appropriate control system reactions.

Rocket propulsion development is enabled by rigorous ground testing in order to mitigate the propulsion system risks that are inherent in spaceflight. Test articles and facilities are highly instrumented to enable a comprehensive analysis of propulsion system performance. This subtopic seeks to develop advanced instrumentation technologies which can be embedded in systems and subsystems. The goal is to provide a highly flexible instrumentation solution capable of monitoring remote, hazardous or inaccessible measurement locations. All this while reducing or completely eliminating cabling and auxiliary power. It is focused on near-term products that augment and enhance proven, state-of-the-art propulsion test facilities and new ones to be developed. Rocket propulsion test facilities within NASA provide excellent test beds for testing and using the innovative technologies discussed above. The technologies developed would be capable of addressing multiple mission requirements for remote monitoring such as vehicle health monitoring.

Intelligent sensor systems have the potential for substantial reduction in time and cost of propulsion systems development, with substantially reduced operational costs and evolutionary improvements in ground, launch and flight system operational robustness. Sensor systems should provide an advanced diagnostics capability to monitor test facility parameters including simultaneous heat flux, temperature, pressure, strain and near-field acoustics. Applications encompass remote monitoring of vacuum lines, gas leaks and fire; where the use of wireless/self-powered sensors to eliminate power and data wires would be beneficial.

Sensor technologies should be capable of being embedded in structures and systems that are smaller, more energy efficient, and allow for more complete and accurate health assessments including structural health monitoring for long-duration missions. Structural health monitoring is one of the top technical challenges. Nanotechnology enhanced sensors are desired where applicable to provide a reduction in scale, increase in performance, and reduction of power requirements. Specific technology needs include the following:

- Sensor systems should have the ability to provide the following functionality:
  - Measurement.
  - Measure of the quality of the measurement.
  - Measure of the health of the sensor.
- Sensors are needed with capability to function reliably in extreme environments, including rapidly changing ranges of environmental conditions, such as those experienced in ground test, launch environment and space. These ranges may be from extremely cold temperatures, such as cryogenic temperatures, to extremely high temperatures, such as those experienced near a rocket engine plume. Collected data must be time stamped to facilitate analysis with other collected data sets.
- Sensor systems should be self-contained to collect information and relay measurements through various means by a sensor-web approach to provide a self-healing, auto-configuring method of collecting data from multiple sensors, and relaying for integration with other acquired data sets.
- Sensor technologies shall be capable of measuring pressure and temperature with cryogenic and gaseous fluid flow within metal piping.
- Sensor systems should enable the ability to detect anomalies, determine causes and effects, predict future anomalies, and provides an integrated awareness of the health of the system to users (operators, customers, management, etc.).
- The proposed innovative systems must lead to improved safety, reduced test, and space flight costs by allowing for the real-time analysis of data, information, and knowledge through efficient interfaces to enable integrated awareness of the system condition by users.
- The system provided must interface with existing data acquisition systems and the software used by such systems.
- The system must provide NIST traceable measurements.
- The system design should consider an ultimate use of space flight sensor systems, which could be used for multi-vehicle use.
This subtopic addresses an advanced aeroelastic design concept for dynamic elastic flight systems. Methods include prototype design and optimization and scaled model design, optimization, manufacturing, and ground and flight (or wind tunnel) tests. Both a baseline configuration (using traditional approach) and a new (or state-of-art) design concept aircraft should be studied to demonstrate the innovation. The followings are recommended as candidate flight systems to be designed, optimized, and tested:

- Demonstration of new design concept:
  - Test articles designed using advanced design concept.
- Or application of state-of-art design concept:
  - NASA X-plane: such as hybrid wing body aircraft, low-boom supersonic commercial transport aircraft, etc.: [https://www.nasa.gov/aero/nasa-moves-to-begin-historic-new-era-of-x-plane-research](https://www.nasa.gov/aero/nasa-moves-to-begin-historic-new-era-of-x-plane-research) [5].
  - Mars plane, & etc.: [https://www.nasa.gov/centers/armstrong/features/mars_airplane.html](https://www.nasa.gov/centers/armstrong/features/mars_airplane.html) [8].

This subtopic also addresses capabilities enabling design solutions for performance and environmental challenges of future air vehicles. Research in revolutionary aerospace configurations include lighter and more flexible materials, improved sonic boom performance on the ground, and improved propulsion systems. This subtopic targets efficiency and environmental compatibilities requiring performance challenges and novel structural optimization for aeroelastic considerations which are gaining prevalence in advanced flight vehicles.

Technical elements for the Phase I proposals may also include:

- Introduction of new innovative or state-of-art design concept for higher performance flight systems.
- Initial conceptual design (mainly for application of state-of-art design concept):
  - Define own design requirement.
  - Outer-mold-line shape.
  - Target flight envelope for prototype.
  - Range.
  - Number of passenger (if needed).
  - Aircraft configuration, etc.

Proposals should assist in revolutionizing improvements in performance to empower a new generation of air vehicles to meet the challenges of subsonic and supersonic flight concerns with novel concepts and technology developments in systems analysis, integration and evaluation. Higher performance measures include energy efficiency to reduce fuel burn and operability technologies that enable information network decompositions that have different characteristics in efficiency, robustness, and asymmetry of information and control with tradeoff between computation and communication.

Technical elements for the Phase I results and deliverables should be as follows:

- Structural finite element models of the prototype should be delivered (at least preliminary design quality):
  - Baseline shape (use classical approach).
  - New (or state-of-art) design shape (use innovative approach).

- Show performance improvement between the baseline configuration and the new (or state-of-art) design concept configuration with structural optimization:
  - Stress/strain distribution under the critical design load condition with margin of safety information.
- Primary buckling characteristics and buckling shape.
- Natural frequencies and mode shapes of prototype models.
- Flutter boundary information with proposed flight envelope.
- Sonic boom noise level information on the ground (if used); & etc.

- Computer programs developed during Phase I:
  - Source codes.
  - Executable codes.
  - Quick user guide; & etc.

Technical elements for the Phase I listed above can be performed by small business and research institution as follows:

**A sample recommendation**

Small business:

- Develop tools or modeling methodology that can be used in initial design of baseline shape and new design shape.
- Develop tools (if needed) that incorporate stress/strain and modal analyses of initial design.
- Design and build test articles.

Research institution:

- Design tools (if needed) that allow optimization of baseline shape and new design shape.
- Perform optimization of baseline shape and new design shape.
- Design tools or a way to model buckling, flutter, and sonic boom (if needed) analyses of initial design to support small business.
- Perform ground based testing.

Technical elements for the Phase II proposals should include followings:

- Scaled model development plan:
  - Detailed description about scaling technique.
  - Finite element model development plan.
  - Manufacturing plan about scaled model hardware.
- Ground test plan:
  - Static test.
  - Ground vibration test.
- Flight (or wind-tunnel) test plan:
  - Detailed description about flight (or wind-tunnel) test plan.
  - Flight (or wind-tunnel) test will be performed if awarded for Phase III.

Technical elements for the Phase II results and deliverables should be as follows:

- Test articles (scaled models) developed under Phase II (baseline configuration and new (or state-of-art) design concept configuration).
- Ground test data should be delivered.
- CAD model of the test articles should be delivered.
- Validated (with respect to ground test data) structural finite element model of the test articles should be delivered.
- Stress/strain distribution under the critical design load condition with margin of safety information;
  - Primary buckling characteristics and buckling shape.
- Natural frequencies and mode shapes of the scaled model.
- Flutter boundary information with proposed flight envelope.
- Sonic boom noise level information on the ground (if used).
Comparisons and discussions of results between prototype vs. scaled model are needed.
Computer programs developed during Phase II: source codes; executable codes; quick user guide; & etc.

Links to program/project websites:

- ARMD's Advanced Air Vehicles Program (AAVP): [https://www.nasa.gov/aeroresearch/programs/aavp](https://www.nasa.gov/aeroresearch/programs/aavp) [9].
- ARMD's Flight Demonstrations and Capabilities (FDC) project under the Integrated Aviation Systems Program (IASP): [https://www.nasa.gov/aeroresearch/programs/iasp/fdc](https://www.nasa.gov/aeroresearch/programs/iasp/fdc) [10].