NASA STTR 2016 Phase I Solicitation

Small Business Technology Transfer

Launch Propulsion Systems Topic T1
Launch Propulsion Systems reflects a staged development of critical technologies that include both “pull” technologies that are driven by known short- or long-term agency mission milestones, as well as “push” technologies that generate new performance or mission capabilities over the next 20 to 25 years. While solid and liquid propulsion systems are reaching the theoretical limits of efficiency, they have known operational and cost challenges while continuing to meet critical national needs. Improvements in these launch propulsion systems and their ancillary systems will help maintain the nation’s historic leadership role in space launch capability. Newer technologies like air-breathing launch propulsion, unconventional, and other propulsion technologies and systems, while low in TRL, can radically transform the nation’s space operations and mission capabilities and can keep the nation’s aerospace industrial base on the leading edge of launch technologies.

Sub Topics:

T1.01 Affordable Nano/Micro Launch Propulsion Stages

Lead Center: MSFC
Participating Center(s): AFRC, KSC

There has been recent significant growth in both the Quantity and Quality of Nano and Micro Satellite Missions:

- The number of missions has outpaced available ride share opportunities.
- Dedicated access to space increases small sat mission capability & allows new & emerging low-cost technologies to be flight qualified.

Stage concepts are sought that can be demonstrated within the scope & budget of a Phase II STTR project:

- MSFC is actively pursuing multiple technologies to significantly reduce orbital access cost.
- The scale of many Nano and Micro Launch vehicles allows stages to be completed within the scope and budget of a Phase II proposals.
- Accepted proposals will be limited to stages that “plug and play” into existing or proposed architectures for orbital launch vehicles with payload capabilities from 5-50 kg. A flight test is expected in Phase II.
- The university/small business partnership is ideal to provide the correct technology combination allowing for this affordable access to space.

State of the Art

Small launch vehicles are targeting a total launch cost of ~$1-2M. Proposed stages must demonstrate significant cost savings over state of the art.

What is the compelling need for this Subtopic?

- This subtopic is necessary because there are currently no available rides for experimental propulsive stages.
- Technological advancements like additive mfg. must be demonstrated to produce aerospace quality parts at low fixed cost. These technologies must be validated for use in propulsive stages.
• The correct combination of new technologies and approaches will enable affordable, dedicated, on-demand access to space.
• Technologies that are demonstrated and validated at the nano/micro scale can be robustly infused into large launch vehicles where loads and vibrations are not as severe.
• The success of Nano/Micro Launch vehicles benefit every NASA center by enabling unprecedented experimental access to space.
• Commercial development opportunities abound since the small satellite market is robust and growing.

STMD/NASA/NARP/National-Affordable access to space is a key objective for NASA. The Nano/Micro Launch scale is an affordable avenue that will enable the development and validation of key technologies and approaches to reduce fixed cost, recurring costs and range costs.

T1.02 Detailed Multiphysics Propulsion Modeling & Simulation Through Coordinated Massively Parallel Frameworks
Lead Center: MSFC
Participating Center(s): SSC
Detailed modeling and simulation to assess combustion instability of recent large combustors while successful to a degree showed the need for significant advances in two-phase flow, combustion, unsteady flow, and acoustics. Additionally, simulation of water spray systems for launch acoustic sound suppression and test stand rocket engine acoustic sound suppression showed the need for advances in two-phase flow, droplet formation, and particulate trajectory. In these cases, and others, the need for improved physics based models is accompanied by the requirement for high fidelity and computational speed.

Rocket combustion dynamic simulations are 3D, multiphase, reacting computations involving the mixing of hundreds of individual injection elements which require a long time history to be computed. Methods are sought (VOF, SPH, DNS/LES, PIC, etc.) to accurately capture the physics of the injection elements in a computationally efficient manner. Experimental validation of individual submodels are required.

NASA successfully leveraged advances/innovation in computer science technology to leapfrog the barriers to massive parallelism via the adoption of the Loci framework in the late 1990's. Computer science has evolved in the last two decades with respect to technology of massive parallelism. The intent of this subtopic is to infuse newest technologies, i.e., improved physics based models accompanied by the requirement for high fidelity and computational speed, into tools for propulsion related fluid dynamic simulation. This solicitation seeks simultaneously coordinated computer science (CS) technology advances, multi-physics (MP) simulation, and high fidelity (HF) models. The value and requirement for proposals is this coordinated CS-MP-HF framework. Ideally, technologies that are up to this point only Lower TRL demonstrations are strong candidates if they are developed to fit in a coordinated CS-MP-HF framework that can be applied to propulsion system fluid dynamics.

Tools developed in this framework are expected to enable propulsion system production & DDT&E cost reductions.

In-Space Propulsion Technologies Topic T2
Reserved for future Solicitations.
Sub Topics:
  Space Power and Energy Storage Topic T3
Space Power and Energy Storage is divided into four technology areas: power generation, energy storage, power management and distribution, and cross cutting technologies. NASA has many unique needs for space power and energy storage technologies that require special technology solutions due to extreme environmental conditions. These missions would all benefit from advanced technologies that provide more robust power systems with lower mass.
Sub Topics:

T3.01 Energy Transformation and Multifunctional Power Dissemination
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. As such, transforming and disseminating naturally occurring and artificially induced energy from multiple environments into usable power is critical toward supporting future power generation systems. This subtopic addresses the potential for deriving power from the environment for; local or remote consumption, inundating structures or environments with energy, transmission, distribution, regulation, and storage of said energies. Conversion and transformation technologies for gathering energy naturally occurring in conjunction with induced energies are being pursued, and novel technologies capable of artificially saturating an environment with energy for storage and power dissemination along with non-conventional transmission via the surrounding environments such as wireless power are also applicable. Energy gathering is limited by the quantity of energy available within a system’s immediate environment, and often the environment’s energy contains prolonged periods of lulls in harvestable energy. Technologically bridging power from a distance would fundamentally alleviate issues with low energy environments by allowing energy to be supplementally broadcast through preexisting structures and environments while simultaneously reducing docking and interfacing for power transfer. Technology development should support powering small remotely located equipment such as wireless instrumentation, or support power gathering for independently providing supplementary power to centralized equipment such as control consoles. Distributed Nano energy generating technologies are applicable for gathering scattered environmental energies into significant amounts of accumulated power along with supplementation for long-duration power utilization. This kind of distributed power should also be able to recover waste energy from rocket, nuclear, fission, and electrical propulsion devices while providing enhanced protection from energies contained within the work environment through transformation and consumption. Transforming harmful radiation, elevated temperatures, unwanted vibrations etc. into usable energy will support increased scope and duration of missions while enhancing protection from the waste energies (mitigation by transformation and consumption). Waste energies from warm soil, liquids (water, oils, hydraulic fluids), kinetic motion, piezoelectric materials, or various naturally occurring energy sources, etc. should also be transformable.

Areas of special focus for this subtopic include consideration of:

- Innovative technologies for the efficient broadcast, capture, regulation, storage and/or transformation of acoustic, kinetic, radiant (including radiation), electric, magnetic, radio frequencies and thermal energy types.
- Technologies which can work either under typical ambient environments for the above energy types and/or under high intensity energy environments for the above energy types as might be found in propulsion testing and launch facilities.
- As above, energy capture, transmission and transformation technologies that can work in very harsh environments such as those which are very hot and/or ablative (e.g., in the proximity of rocket exhaust) and/or very cold (e.g., temperatures associated cryogenic propellants) may be of interest.
- Innovations in miniaturization and suitability for manufacturing of energy capture, transmission and transformation systems so as to be used towards eventual powering of assorted sensors and IT systems on vehicles and infrastructures.
- High efficiency and reliability for use in environments that may be remote and/or hazardous and having low maintenance requirements.
- Employ green technology considerations to minimize impact on the environment and other resource usage.

Rocket propulsion test facilities within NASA provide excellent test beds for testing and using the innovative technologies discussed above because they offer a wide spectrum of energy types and energy intensities for capture and transformation. Additional Federal mandates require the optimization of current energy use and development of alternative energy sources to conserve on energy and to enhance the sustainability of these and other facilities. Specific emphasis is on technologies which can be demonstrated in a ground test environment and have the ability/intention to be extrapolated for in-space applications such as on space vehicles, platforms or habitats. Energy transformation technologies to generate higher power output than what is presently on the market are a highly desired to an expected outcome from this subtopic.

Phase I will develop feasibility studies and demonstrate through proof-of-concept demonstrations. Phase II will
develop prototypical hardware and demonstrate infusion readiness to be incorporated into other products.

T3.02 Self-Powered, Ultra-Miniature Devices

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

As the Human Exploration and Operations (HEOMD) Mission Directorate seeks technologies in support of NASA space operations related to human exploration in Space, development of technologies that address efficient energy usage and storage are considered to be of utmost importance. Development of a range of self-powered devices that maximize the safety and reliability of extended missions can only enhance human space flight capabilities in support of human and robotic exploration programs.

Suggested research appropriate for small colleges and universities, are development of Self-Powered Exploration Devices (SPED), and Miniature Ultra-power Storage Technologies (MUST). The SPED objective is to run a small self-powered mobile device around a small table-top, low-friction track using electrical energy generated by elements of the environment, with no stored power at the start. The energy source can be vibrational, acoustic, biological, chemical, thermal, solar, or any physical characteristic from the natural environment that can generate energy for storage or immediate use. The MUST objective is to run a small device continuously, from environmentally generated power, for an extended period of time, using a miniature capacitor, or battery, technology. A long running device is the objective.

These tasks are suitable for small academic institutions where probable long technology development time trajectories and low levels of focused technology development effort are ideally accommodating for students to mature to convergence with concurrently maturing respective technologies. The SPED and MUST technologies are designed to merge into a “Game Changing” Development (TRL 3-5) of Smart Dust Motes, partnering with a larger university already making advances in the field.

“Smart Dust Motes” are millimeter-scale self-contained micro-electromechanical devices (MEMS) that include sensors, computational ability, bi-directional wireless communications technology and a power supply. Size development as of about 2007, Hitachi, are tiny dust particle devices with dimensions of about 0.05 x 0.05 mm. This aggregate development, sensing/bi-directional wireless communication, hence “swarming”, is biomimetic. Potential future partnership possibilities are companies and institutions interested in low-bandwidth, low-power wireless mesh networks that transmit data using radio signals.

Finally, DARPA researchers pioneered the area of Dust Motes since the early ’90s. Top research universities such as Berkeley, MIT, Stanford, etc., have also been active in this field, involving MEMS and the most recent advances in digital circuitry and wireless communication since inception of the idea. The challenges for Smart Dust are to create a package that includes all the elements needed to perform sensory measurements, while also being able to communicate back to a base station to process the data. The “Smart Dust Mote”, which could contain micro-fabricated sensors, optical receivers, passive and active optical transmitters, signal-processing and control circuitry, and power sources, in a MEMS device, is very highly advanced already, relative to someone just getting started. SPED/MUST research is ideal for smaller colleges and universities to gain experience in these areas. This positions them to participate in ultimate Dust Mote development ideal for a partnership arrangement.

Interested NASA directorates are, e.g., HEOMD, and STMD.
enhancing or exceeding human performance in sensing, piloting, driving, manipulating, and rendezvous and
docking; development of cooperative and safe human interfaces to form human-robot teams; and improvements in
autonomy to make human crews independent from Earth and make robotic missions more capable.

Sub Topics:

T4.01 Dynamic Servoelastic (DSE) Network Control, Modeling and Optimization

Lead Center: AFRC

Participating Center(s): JPL, LaRC

This subtopic addresses advanced control-oriented techniques for dynamic servoelastic (DSE) terrestrial,
planetary, and space environment flight systems using distributed network sensor and control systems. Methods
include modeling, simulation, optimization and stabilization of DSE systems to actively and/or adaptively control
structural dynamic geometry/topology, vibration, atmospheric and intraspace disturbances, static/dynamic loads,
and other structural dynamic objectives for enhanced dynamic servoelastic performance and stability
characteristics.

- DSE control for performance enhancements while minimizing dynamic interaction.
- Flexible aircraft and spacecraft stabilization and performance optimization.
- Modeling and system identification of distributed DSE dynamics.
- Sensor/actuator developments and modeling for distributed DSE control.
- Uncertainty modeling of complex DSE system behavior and interactions.
- Distributed networked sensing and control for vehicle shape, vibration, and load control.

This subtopic also addresses capabilities enabling design solutions for performance and environmental challenges
of future air and space vehicles. Research in revolutionary aerospace configurations include lighter and more
flexible materials, improved propulsion systems, and advanced concepts for high lift/performance and drag/energy
reduction. This subtopic targets efficiency and environmental compatibilities requiring performance challenges and
novel control-oriented techniques for aero-servoelastic considerations which are gaining prevalence in advanced
aerospace flight vehicles, atmospheric and extra-terrestrial.

Technical elements for the Phase I proposals may also include:

- Mission/maneuver adaptivity with dissipative optimal energy-force distribution.
- Data-driven multi-objective DSE control with physics-based sensing.
- Robust sensing-control-communication networks for sensor-based distributed control.
- Compressive information-based sensing and information structures.
- Evolving systems as applied to self-assembling and robotic maneuvering.
- Scalable and evolvable information networks with layering architectures.
- Modular architectures for distributed autonomous aerospace systems.
- Multi-objective, multi-level control and estimation architectures.
- Distributed multi-vehicle dynamics analysis and visualization with complex simulations.
- Reduced order modeling capable of substructure coupling of nonlinear materials.

Development of distributed sensory-driven control-oriented DSE systems is solicited to enable future flight vehicle
concepts and designs that manage structural dynamic uncertainty on a vehicle's overall performance. Proposals
should assist in revolutionizing improvements in performance to empower a new generation of air and space
vehicles to meet the challenges of terrestrial and commercial space 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.

Advanced mission applicability in Phase II should show the ability of aerospace GN&C systems to achieve mission
objectives as a function of GN&C sensor performance, vehicle actuation/power/energy, and the ability to jointly
design them as onboard-capable, real-time computing platforms with applicable environmental effects and robust
guidance algorithms. Goals are to:
State of the Art

This subtopic will:

- Provide capabilities that would enable new projects and missions that are not currently feasible, using distributed sensing and controls for network processing.
- Impact multiple missions in NASA space operations and science, earth science, and aeronautics.
- Be influential across aerospace and non-aerospace disciplines with dynamic interactions.

Potential technical impacts are:

- Vehicle energy efficiency with passive/active dissipativity for control and dynamic stability with extreme power constraints.
- Weight minimization through dynamic servoelastic control.
- Mission adaptivity and robustness with real-time, consensus-coordinated control dealing with computation, communication, and dynamics.

New technologies proposed should have the potential to impact the following NASA missions:

- Data availability for science missions.
- Mission planning.
- Autonomous rendezvous/docking technology.
- Environmental monitoring for human habitation.

Apart from NASA missions, the aeronautics technology could be adapted for development and use in autonomous operation of wind/ocean energy and smart space power grid systems in dynamic environments. There are number of advantages to exploring this subtopic technology:

- Increase in autonomy and fuel efficiency of coordinated robotic vehicles and sub-components.
- Improved science, atmospheric, and reconnaissance data.
- Cost, risk and reliability of flight vehicles for a terrestrial, planetary, or space mission.
- Inter-networks with improved dynamic behavior.

Potential technical impacts are:

- Vehicle energy efficiency with passive/active dissipativity for control and dynamic stability with extreme power constraints.
- Weight minimization through dynamic servoelastic control.
- Mission adaptivity and robustness with real-time, consensus-coordinated control dealing with computation, communication, and dynamics.

T4.02 Regolith Resources Robotics - R3

Lead Center: KSC

Participating Center(s): ARC, LaRC

The use of robotics for In-Situ Resource Utilization (ISRU) in outer space on various planetary bodies is essential since it uses large quantities of regolith that must be acquired and processed. In some cases this will happen while
the crew is not there yet, or it will take place at a remote destination where the crew cannot spend much time due to radiation exposure limits (Asteroids, Mar’s Moons & NEO’s). Communications latencies of greater than 40 minutes at Asteroids mandate autonomous robotics applications. Proposals are sought which provide solutions for the following space resource related technology area:

**Asteroid Resource Prospecting and Characterization**

The first step towards using resources derived from small bodies in space, such as water, volatiles, metals and organic compounds is to visit the Near Earth Object (NEO) target body and prospect it with sample acquisition devices and subsequently do characterization of these samples. Proposals are sought for innovative resource prospecting mission concepts and associated technology demonstrations such as autonomous small marsupial free flier prospector spacecraft that can sample an asteroid, comet or Mars moon and transport the sample back to a locally orbiting spacecraft with an associated suite of characterization instruments for analysis.

Proposals are sought for innovative resource prospecting mission concepts, technology development, and demonstrations.

Technologies include sample acquisition methods and devices, regolith anchoring methods, autonomous conops, sub-surface access, excavation, specialized sensors, dust lofting mitigation, perception in dusty environments, mobility methods, surveying, remote sample characterization, geodetic mapping, replenishing and transferring robotic commodities such as propellants, electric power, data transfer, pneumatics and robust interfaces for commodity transfer.

Future prospecting missions include:

- Water/Ice on Mars, Mars moons or Earth’s Moon.
- Micro-gravity Near Earth Object (NEO) operations to prospect/sample surface resources.
- Lava tubes/shadowed crater cold traps on planetary surfaces to characterize volatiles accumulation.

**T4.03 Coordination and Control of Swarms of Space Vehicles**

**Lead Center: JPL**

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).
Communication and Navigation Topic T5

Communications and Navigation Systems, consists of six technology subareas: optical communication and navigation; radio frequency communication; internetworking; position, navigation and timing; integrated technologies; and revolutionary concepts. Communication links are the lifelines to spacecraft, providing commanding, telemetry, and science data transfers as well as navigation support. Therefore, the Communications and Navigation Systems Technology Area supports all NASA space missions. Advancement in communication and navigation technology will allow future missions to implement new and more capable science instruments, greatly enhance human missions beyond Earth orbit, and enable entirely new mission concepts.

Sub Topics:

T5.01 Autonomous Ka-band Spacecraft Terminals

Lead Center: GRC
Participating Center(s): GSFC

This subtopic focuses on the ability of small spacecraft to autonomously connect and communicate with other approved spacecraft, relays, and ground terminals in a manner that ensures compliance with NASA communications and software defined radio standards, access protocols, and frequency spectrum constraints. Innovations are sought to increase the autonomy, flexibility and performance of Ka-band spacecraft terminals while reducing their cost, size, mass, power consumption and thermal and vibrational impact on user spacecraft. Advances in compact directional antennas, flexible software defined radios (SDR) or software transceivers (SDT), and autonomous communications terminal operations will enable small spacecraft to establish communications with existing and emerging NASA space relays and ground terminals, as well as other approved spacecraft within the network. Automation embedded into the user terminals will help ensure efficient use of all available Ka-band communications capacity and mitigate potential for interference.

Background

Future missions will need higher data rates, more opportunities to transmit and receive data, lower communications burden on the spacecraft, and flexibility and automation where practicable to reduce human intervention. To reduce life-cycle development cost and schedule, NASA missions are trending toward smaller spacecraft and clusters of spacecraft to accomplish mission objectives. Autonomous communications operations in Ka-band frequencies will enable higher data rates, better utilization of existing and emerging NASA and commercial infrastructure, increase instantaneous use of available relay and ground network capacity, mitigate potential for interference.

Programmatic Relevance

NASA’s Space Communications and Navigation (SCaN) Program has been deploying Ka-band service capabilities into near Earth relays and near Earth and deep space ground terminal infrastructure to enable NASA missions to help reduce congestion in lower frequency bands. This migration also leverages significant commercial investments in Ka-band communications technologies over the past two decades. However, the lack of innovative, commercially sourcedlow-cost, autonomous user terminals has hindered mission movement into Ka-band with the exception of a few custom, one-of-a-kind, mission specific terminals. Compliance with SCaN’s Space Network (SN) and Near Earth Network (NEN) User Guides and NASA Space Telecommunications Radio Systems (STRS) standards will enable new missions based on small spacecraft and clusters of spacecraft to accomplish mission objectives. Autonomous communications operations in Ka-band frequencies will enable higher data rates, better utilization of existing and emerging NASA and commercial infrastructure, increase instantaneous use of available relay and ground network capacity, mitigate potential for interference.

Technology Advancement Goals

Proposed advancements are encouraged in, but are not limited to, any or several of the following capabilities. Autonomous integrated terminals: Agility across and compliance with NASA Ka-band space-space and space-ground frequency spectrum allocations autonomous pointing, tracking, and communications with known or discovered relay, ground and/or proximity assets; autonomous optimization of data throughput based on predicted or sensed link conditions; flexible use of antenna and transceiver gains to cover a range of operating conditions; minimal impact on user spacecraft; cost-effective implementation; clear path to space qualifiable implementation.
SDTs: NASA STRS compliant implementation; NASA space and ground infrastructure compliant; variable and/or adaptive coded modulation and data rates; autonomous link margin optimization; compact, low-mass, power efficient. Ka-band Antennas: electronically steered, scanned or switched directional beams; potential for multiple simultaneous beams; isoflux beams for space-ground links; hemispherical or omni coverage for proximity and nondirectional conditions; small size or compact deployable; low mass, low power consumption; low cost.

Research Institution (RI)/Small Business (SB) Collaboration Goals:

The goals of this collaborative effort are to:

- Select practical advancements from a range of autonomous operations technologies, SDT approaches, and innovative antenna concepts; and
- Refine, integrate and demonstrate the potential of those advancements in response to the unique needs and practical constraints of small spacecraft operating within NASA's Ka-band space and ground infrastructure.

Collaboration between the RI and SB should allow for rapid TRL advancement into practical autonomous communications terminals that are flexible and commercially realizable.

Human Health, Life Support and Habitation Systems Topic T6

Human Health, Life Support and Habitation Systems, includes technologies necessary for supporting human health and survival during space exploration missions and consists of five technology subareas: environmental control and life support systems and habitation systems; extravehicular activity systems; human health and performance; environmental monitoring, safety, and emergency response; and radiation. These missions can be short suborbital missions, extended microgravity missions, or missions to various destinations, and they experience what can generally be referred to as “extreme environments” including reduced gravity, high radiation and UV exposure, reduced pressures, and micrometeoroids and/or orbital debris.

Sub Topics:

T6.01 Space Suit Environmental Protection Garment Materials and Technologies

Lead Center: JSC

Pressure garments designed for long-duration exploration missions require new Environmental Protection Garments (EPGs) to address the environments and use conditions to which they will be subjected. The EPG on the Apollo A7LB spacesuit was required to only tolerate a few days of working in a dusty environment whereas the surface mission on Mars will last for up to 500 days with routine EVAs.

An EPG is a lay-up of materials that protect the inner layers (bladder and restraint) of the pressure garment. Environmental protection functions of the EPG include protection from: thermal extremes; secondary ejecta; cuts and punctures; abrasion and wear from dust; durability with respect to cycle fatigue and radiation exposure; and resistance to chemical corrosion. The layers of the EPG work together as a system to address all of these functions.

To date, very limited effort has been focused on developing the EPG. If new materials are required it is anticipated that a development effort of up to 10 years may be necessary to reach TRL 6, making EPG technology a schedule driver for exploration. Materials that are immediately applicable will be offered to the ISS space EMU subsystem manager for potential incorporation.

The challenges being addressed with this call include dust mitigation, cut and puncture resistance, and cycle life:

- **Dust Mitigation** - Dust mitigation can be addressed on one or both of two fronts: dust repellant (keep dust from penetrating) and dust resistance (dust doesn’t degrade performance). Protection from both lunar and Martian regolith and from the full range of particle sizes of the regolith is of interest. Materials that are resistant to the potentially corrosive chemical products resulting from Mars regolith combining with oxygen and/or water vapor. Unique methods of fabrication and of design to limit the intrusion of dust at breaks.
between sections of the EPG (such as between the lower arm and shoulder sections of the EPG) are included.

- **Cut and punctures** - Current ISS EMU materials have proven susceptible to cuts from sharp edges on hand rails. Exploration suits will be handling rocks, dirty tools, and other abrasive and rough surfaces.

- **Durability** - EPGs will see hundreds of thousands to millions of cycles as the joints of the space flex as crewmembers walk, grasp, and use tools. Materials need to be highly durable to withstand the cycles of joint flexion in the thermal, dust and radiation environments on planetary surfaces.

Additionally, the goal of the EPGs design is to improve performance on all fronts. When the ISS EMU glove design was changed to increase durability against sharp edges, its mobility was reduced. The EPG dust mitigation, for example, that protects the suit bladder from dust will also have minimal impact (less than 10%) on suit range of motion and torque.

This call seeks innovative materials and creative approaches for both individual layers of the EPG as well as full EPG lay-ups, as well as, EPG system level dust mitigation approaches.

Research done in Phase I of these efforts should focus on technical feasibility with an emphasis on hardware development that can be further expanded in a future Phase II award cycle. Phase II products must include a demonstration unit suitable for testing by NASA. Prototyping should be tailored to applications to ongoing HEO Mission Directorate missions and possible collaborative use in both the governmental and commercial manned spaceflight disciplines. Minimum deliverables at the end of Phase I are analysis and/or test reports, with priority given to functional hardware prototypes for further evaluation. Technical maturation plans should be submitted with Phase I submittals, as well as any expected commercial applications both internal and external to the manned spaceflight enterprise.

### T6.02 Space Radiation Storms: Monitoring, Forecasting and Impact Analysis

**Lead Center:** GSFC

Radiation hazards constitute one of the most serious risks to future human and robotic missions beyond Low-Earth Orbit, and particularly to long-duration, long-distance space missions. The main contributors to space radiation are Galactic Cosmic Rays (GCRs) and Solar Particle Events (SPEs). The latter is the more unpredictable of the two and is associated with most energetic solar eruptions: flares and coronal mass ejections; at the same time, SPEs are capable of inducing acute and profound effects on humans and on spacecraft components. The goal of the current opportunity is to help address the challenges by focusing on investigations that can potentially lead to longer-range (2-3 days) forecasting of SPEs (or at least an improved all-clear SPE forecasting capability), as well as those which couple radiation environment models with engineering models of radiation effects so that single-event effects on specific hardware and instruments can be predicted.

**State of the Art**

Many questions regarding space radiation have yet to be answered, and numerous challenges remain, such as improving the forecasting capability of the dynamic radiation environment (particularly SPEs), coupling the radiation environment models with engineering models of radiation effects on specific instruments or spacecraft hardware, and achieving a quantitative measure of human or space assets’ response to radiation storms.

**What is the compelling need for this Subtopic?**

Penetrating particle radiation from SPEs adversely affect aircraft avionics, communication and navigation, and potentially the health of airline crews and passengers on polar flights. SPEs also constitute major hazards for astronauts performing EVAs (Extra-Vehicular Activities) on board the International Space Station (ISS). Characterizing and predicting the dynamic variation of the radiation environment is a crucial capability, enabling personnel to take preventive measures to mitigate the potential risks, and facilitating adoption of the proper mitigation strategy.

STMD/NASA/NARP/National: Identified as an NRC High Priority Technology Area.
T6.03 Sustainability in Space

Lead Center: JSC

Survival in remote locations such as another planet requires conservation, smart utilization and reuse of resources and resilience, especially in the event of a failed resupply ship. Closed loop living systems such as this are also important for Earth as world population grows and natural resources decrease. This STTR subtopic seeks to advance the state-of-the-art for spacecraft habitats by “closing the loop” on materials needed to sustain life and provide energy on exploration missions, while simultaneously reducing the environmental impact of aerospace processes. Air, water and waste all need to be regenerated with highly reliable systems to reduce or eliminate the need to launch more materials into space as missions become longer. Energy for life support and other systems can also be obtained from renewable energy sources or waste streams. Many current cleaning, manufacturing and testing processes for spacecraft also create an environmental burden that could be mitigated by new technologies. All these “green” technologies will improve sustainability in space and on Earth.

Technical innovation and unique approaches are solicited for the development of new technologies that will lower mission cost and environmental impact by conserving resources and closing the materials loop. This will enable self-sufficiency and thus longer space exploration missions. Also, technologies that conserve resources or reduce negative impact during spacecraft development are solicited to improve sustainability at NASA. Real world demonstration of the technologies should be emphasized, even in Phase I. Many areas of research are possible, but preference will be given to those that address gaps in the following areas and lead to early applications and dual use partnerships:

- **Waste Water Treatment and Reuse** - Reuse/recycling of waste water from gray and black water sources with minimal mass, power, volume and expendables is needed. A particular challenge is treatment of urine to prevent odor and fouling of systems without the use of hazardous chemicals. NASA would like to extract nearly 100% of the water from any brine that may be created by a primary processor. Easy regeneration of filter and resin elements is desirable to reduce expendables.
- **Waste Processing** – Technologies for stabilization, safening, recycling or creation of energy or useful products from feces or trash are sought. Proposed technologies must take into account relevant factors for space exploration such as resource scarcity, planetary protection and human factors.
- **Renewable Energy and use of Waste Heat** – Solar and other renewable energy technologies that apply to “closing the loop” in space and on Earth are sought. This could include high efficiency and regenerative fuel cell technologies and technologies that combine waste and water treatment with energy production. Also included are technologies that make use of waste heat from one process for another purpose.
- **Greener Ground Processing** – Many aerospace processes require chemicals that are not environmentally friendly or result in lots of waste. NASA seeks technologies that will significantly reduce environmental impacts for NASA as well as others who use similar processes. Technologies are sought that: reduce or eliminate solvent waste from precision cleaning and validation processes; improve particle removal efficiency when cleaning with supercritical fluids; combine multi step processes (such as metal cleaning and passivation) into one step with reduction of waste.

T6.04 Closed-Loop Living System for Deep-Space ECLSS with Immediate Applications for a Sustainable Planet

Lead Center: ARC

NASA’s plans to explore space beyond Low Earth Orbit will push the performance of life support systems toward closed loop living systems. Deep space missions will require life support systems that will be self-sustaining since we cannot expect to carry enough spares and consumables for year-long missions. Achieving the development of such systems will provide the understanding for managing limited availability of resources. The parallel with earth planetary resources management is ideal as the world population grows and resources and infrastructure availability decreases. We expect that technologies developed for closed loop living systems will be immediately available and applicable to provide planetary sustainability as well.

State of the Art
An immediate example of such endeavors exists in the form of the NASA Ames Sustainability Base where technologies for deep space exploration have been used to create one of the greenest buildings in the federal building inventory. These technologies include power generation with fuel cells, water recovery systems, advanced HVAC, environmental control, recyclable materials and use of local resources. Even though these technologies are readily available for deep space travel, each has its own set of challenges for adaption to earth application along with integration challenges.

Closed-loop living systems are mostly based on the thermodynamics laws of the conservation of mass and energy. We expect to maximize the conservation so that only a minimal amount of resources needs to be taken on a deep space mission.

Innovations are sought to enable:

- Transfer of deep space exploration technologies to earth applications.
- Development of integrated self-sustainable systems.
- Development of the most effective processes to allow for closed loop living applications.
- Application to so-called “off-the-grid” habitation in remote areas where infrastructure is inexistent.

Potential deliverables may include a demo of ECLSS concept(s) with clear applications to earth, enhanced control techniques of multiple life support subsystems (e.g., environment, water recovery, power usage, etc.), or prototype hardware and/or software to enable sustainability.

Human Exploration Destination Systems Topic T7

Human Exploration Destination Systems, includes six technology subareas: in-situ resource utilization, sustainability and supportability, advanced human mobility systems, advanced habitat systems, missions operations and safety, and cross cutting technologies. The technologies included here are necessary for supporting human operations and scientific research during space exploration missions, both in transit and on surfaces.

Technology areas in this topic should be considered enabling systems, rather than competing discrete technologies, all of which are required for mission success.

Sub Topics:

**T7.01 Synthetic/Engineering Biology for NASA Applications**

**Lead Center: ARC**

Synthetic Biology (SB) provides a unique opportunity to engineer organisms that reliably perform necessary functions for future exploration activities. NASA is interested in harnessing this emerging field to create technological advances that will benefit both future spaceflight and surface missions in a variety of enabling areas. Proposals must use a biologically-based approach, such as synthetic biology, to engineer novel biologically-based (or inspired) functions that significantly exceed current biological capabilities. Proposed projects should focus on using microorganisms in novel ways that enable ISRU, with a particular focus on resource acquisition and/or utilization or feedstock production to enable ISM. NASA’s ISM program has the desire to be able to manufacture materials, parts and/or structures utilizing feedstock generated from renewable biology-based resources. Available in-situ resources may include crew and spacecraft by-products or resources found on planetary surfaces. Products of interest might include, but are not limited to, various metals, bioplastics, biocements, and other biomaterials. Applications that concurrently support more reliable and efficient life support systems during the acquisition and utilization of in-situ resources or the production of feedstock are highly desirable. Proposals should address how systems and technologies will reduce the required launch-mass and dependence on consumables, resupply, and energy and should identify how such technologies provide advantages over physico-chemical systems. 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. There is strong potential for the Phase I effort continuing to a Phase II STTR demonstration to compare ground to microgravity data (obtained via parabolic and/or ISS flight demonstration).
Science Instruments, Observatories and Sensor Systems Topic T8

Science Instruments, Observatories, and Sensor Systems addresses technologies that are primarily of interest for missions sponsored by NASA’s Science Mission Directorate and are primarily relevant to space research in Earth science, heliophysics, planetary science, and astrophysics. This topic consists of three Level 2 technology subareas:

- Remote sensing instruments/sensors.
- Observatories.
- In-situ instruments/sensors.

Sub Topics:

**T8.01 Technologies for Planetary Compositional Analysis and Mapping**

*Lead Center: JPL*

This subtopic is focused on developing and demonstrating technologies for both orbital and in-situ compositional analysis and mapping that can be proposed to future planetary missions. Technologies that can increase instrument resolution, precision and sensitivity or achieve new and innovative scientific measurements are solicited. For example missions, see [http://science.hq.nasa.gov/missions](http://science.hq.nasa.gov/missions). For details of the specific requirements see the National Research Council’s, Vision and Voyages for Planetary Science in the Decade 2013-2022 [http://solarsystem.nasa.gov/2013decadal](http://solarsystem.nasa.gov/2013decadal).

Possible areas of interest include:

- Improved sources such as lasers, LEDs, X-ray tubes, etc. for imaging and spectroscopy instruments (including Laser Induced Breakdown Spectroscopy, Raman Spectroscopy, Deep UV Raman and Fluorescence spectroscopy, Hyperspectral Imaging Spectroscopy, and X-ray Fluorescence Spectroscopy).
- Improved detectors for imaging and spectroscopy instruments (e.g., flight-compatible iCCDS and other time-gated detectors that provide gain, robot arm compatible PMT arrays and other detectors requiring high voltage operation, detectors with improved UV and near-to-mid IR performance, near-to-mid IR detectors with reduced cooling requirements).
- Technologies for 1-D and 2-D raster scanning from a robot arm.
- Novel approaches that could help enable in-situ organic compound analysis from a robot arm (e.g., ultra-miniaturized Matrix Assisted Laser Desorption-Ionization Mass Spectrometry).
- "Smart software" for evaluating imaging spectroscopy data sets in real-time on a planetary surface to guide rover targeting, sample selection (for missions involving sample return), and science optimization of data returned to earth.
- Other technologies and approaches (e.g., improved cooling methods) that could lead to lower mass, lower power, and/or improved science return from instruments used to study the elemental, chemical, and mineralogical composition of planetary materials.
- Projects selected under this subtopic should address at least one of the above areas of interest. Multiple-area proposals are encouraged. Proposers should specifically address:
  - The suitability of the technology for flight applications, e.g., mass, power, compatibility with expected shock and vibration loads, radiation environment, interplanetary vacuum, etc.
  - Relevance of the technology to NASA’s planetary exploration science goals.

Phase I contracts will be expected to demonstrate feasibility, and Phase II contracts will be expected to fabricate and complete laboratory testing on an actual instrument/test article.

**T8.02 Photonic Integrated Circuits**

*Lead Center: GSFC*

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, and integrated optic science instrument optical systems, subsystems and components. This is particularly critical for small spacecraft platforms. On July 27, 2015 - Vice President Joe Biden, at an event in Rochester, NY, announced the New York consortium has been selected to lead the Integrated Photonics Institute for Manufacturing Innovation. For details see (http://manufacturing.gov/ip-imi.html [3]). Proposed as part of President Obama’s National Network for Manufacturing Innovation (NNMI), the IP-IMI was established to bring government, industry and academia together to advance state-of-the-art photonics technology and better position the United States relative to global competition in this critical field. The use of the IP-IMI for work proposed under this topic is highly encouraged. 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.

- 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 microresonantors 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.

- Integrated photonic circuits for very high speed computing: Advanced computing engines that approach TeraFLOP per second computing power for spacecraft in a fully integrated combined photonic and electronic package.

T8.03 Detection technologies for extant or extinct life for use on robotic missions

Lead Center: ARC

One of the biggest questions that NASA is chartered to address, is "Are we alone?" NASA desires to extend the search for existing or past life on non-terrestrial bodies. Leveraging work done on extreme environment ecologies and related fields, technologies are sought that can detect and/or quantify pre-biotic compounds (amino acids, polymers) or unique molecules (organic biomarkers including certain chiral compounds, polypeptides/proteins, lipids, nucleic acid polymers) that may be evidence of living processes. These sensors or instruments should eventually be compatible with small spacecraft, rovers, or small penetrator platforms.

Efforts within this initial STTR activity are to identify potential detection approaches and system architectures that demonstrate a pathway forward for inclusion on future robotic missions. A number of research institutions have capabilities in the supporting technologies that will be critical to detecting life, including research systems deployed in extreme environments, in addition to a large number of laboratory bench techniques that may be adapted to robotic platforms. The industrial partner will be crucial not only in commercializing the technology, but developing it and maturing it towards application on robotic missions. These robotic missions may employ in-situ measurements, or may also use remote sensing methods.

Entry, Descent and Landing Systems Topic T9
Entry, Descent, and Landing, consists of four sub-technology areas:
Entry, Descent and Landing (EDL) is a critical technology that enables many of NASA’s landmark missions, including Earth reentry, Moon landings, and robotic landings on Mars. The EDL topic defines entry as the phase from arrival through hypersonic flight, with descent being defined as hypersonic flight to the terminal phase of landing, and landing being from terminal descent to the final touchdown. EDL technologies can involve all three of these mission phases, or just one or two of them.

Sub Topics:

**T9.01 Navigation and Hazard Avoidance Sensor Technologies**

**Lead Center:** LaRC

**Participating Center(s):** JSC

Missions to solar systems bodies must meet increasingly ambitious objectives requiring new or improved capabilities such as: “precision surface-relative navigation”, “automatic rendezvous and capture”, “well-controlled soft landing”, “precision landing”, and “hazard avoidance”. Robotic missions to the Moon and Mars demand landing at pre-designated sites of high scientific value near hazardous terrain features, such as craters, slopes, and rocks. Missions aimed at paving the path for colonization of the Moon and human landing on Mars need to execute onboard hazard detection and precision maneuvering to ensure safe landing near previously deployed assets. Asteroid missions require precision rendezvous, identification of the landing or sampling site location, and navigation to the highly dynamic object that may be tumbling at a fast rate. NASA seeks sensor technologies enabling these missions to solar system bodies. The same sensor or sensor component technologies can also benefit space operations such as satellite servicing and optical communication.

Sensor and sensor component technologies are sought for providing measurement of vehicle relative proximity and velocity, bearings, and high resolution 3-dimensional images during the approach to the targeted body. Also of interest are sensors capable of measuring atmospheric winds and density for aiding navigation and guidance of landing vehicles in general and large hypersonic decelerators in particular. The proposals should target advanced sensor technologies for eventual space utilization. Phase I research should demonstrate the technical feasibility and show a path toward a Phase II prototype unit. Phase II prototypes should be capable of laboratory demonstration and preferably suitable for operation in the field from an aircraft platform or rocket-power terrestrial test vehicles. The component and sensor system technologies being sought include but limited to the following list:

- Highly sensitive Flash lidar camera including 2-D detector array, associated readout integrated circuit (ROIC), and drive/control electronics. Operational wavelength range 1.06-1.54 micron, the camera shall be capable of providing image frames greater than 60k pixels at 20 Hz with better than 3 cm range precision.
- Very compact and rugged laser transmitter operating in the 1.0 µm – 1.6 µm wavelength range with an output pulse energy of 30 mJ to 60 mJ, pulse width of about 6 nsec, and repetition rate of 20 Hz to 50 Hz suitable for flash lidars. The proposed laser must show path in maturing for operation in space environment.
- Non-mechanical laser beam steering devices capable of 2-axis pointing over +/- 25 degrees angle.
- Novel lightweight transmit and receive optical systems for 3-D flash lidar, Doppler lidar, or laser altimeter with aperture size from 5 cm to 10 cm suitable for operation in space environment.
- Space-qualifiable compact and rugged single-frequency CW laser systems operating at 1.55 micron wavelength region. Proposed lasers must be able to generate at least 5 W of power with less than 5 KHz linewidth over a tunable range of about 50 nm. Systems must be highly wavelength stable and come with full supporting electronic systems for thermal and power control. The lasers must be developed with space environment considerations and demonstrate a clear path to space.
Modeling, Simulation, Information Technology and Processing Topic T11

Modeling, Simulation, Information Technology and Processing consists of four technology subareas, including computing, modeling, simulation, and information processing. NASA’s ability to make engineering breakthroughs and scientific discoveries is limited not only by human, robotic, and remotely sensed observation, but also by the ability to transport data and transform the data into scientific and engineering knowledge through sophisticated needs. With data volumes exponentially increasing into the petabyte and exabyte ranges, modeling, simulation, and information technology and processing requirements demand advanced supercomputing capabilities.

Sub Topics:

**T11.01 Information Technologies for Intelligent and Adaptive Space Robotics**

**Lead Center: ARC**

The objective of this subtopic is to develop information technologies that enable robots to better support space exploration. Improving robot information technology (algorithms, avionics, software) is critical to improving the capability, flexibility, and performance of future NASA missions. In particular, the NASA "Robotics, Tele-Robotics, and Autonomous Systems" roadmap (TA04) indicates that extensive and pervasive use of robots can significantly enhance 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 proximity ops. The primary objective is to radically and significantly increase the performance of mobile robot 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 appropriate for quad-copters, Astrobot/SPHERES free-flying robots, and Spirit/Opportunity scale rovers are particularly encouraged.
- Robot software systems that support adaptive autonomy, automated instrument/sensor targeting, payload data triage, and 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.

**Deliverables to NASA:**

- Identify scenarios and use cases.
- Define specifications based on design trades.
- Develop concepts to address use cases.
- Build, test, and demonstrate prototype sub-systems or systems.
- Deliver prototypes to NASA.

**T11.02 Distributed Spacecraft Missions (DSM) Technology Framework**

**Lead Center: GSFC**

A Distributed Spacecraft Mission (DSM) is a mission that involves multiple spacecraft to achieve one or more common goals; some DSM Instances include Constellations, Formation Flying missions, or Fractionated missions. Apart from Science goals that can only be attained with DSM, distributed missions are usually motivated by several goals, among which: increasing data resolution in one or several dimensions (e.g., temporal, spatial, spectral or...
angular), decreasing launch costs, increasing data bandwiths, as well as ensuring data continuity and inter-
mission validation and complementarity. Constellations have been proposed in several NASA Decadal Surveys and
recent studies; in Earth Science (e.g., a multi-spacecraft Landsat for increasing temporal resolution), in
Heliophysics (e.g., the Geospace Dynamics Constellation) or in Planetary Science (e.g., the Lunar Geophysical
Network). Many constellations and Formation Flying missions have also been proposed more recently in cubesat-
related research projects. For the purpose of this subtopic, we do not assume the spacecraft to be of any specific
sizes, i.e., we do not restrict this study to cubesats or smallsats.

The goal of this subtopic is to mature NASA capabilities to formulate and implement novel science missions based
on distributed platforms. Technologies solicited in this call are the following:

- **Novel DSM-enabling technologies such as:**
  - Technologies for high-bandwidth and efficient inter-satellite communication;
  - Metrology systems capable of sensing and controlling relative position and/or orientation of multi-
    element DSMs to sub-milli-arcsecond angular resolution and sub-micro-meter positional accuracy;
  - Autonomous and scalable ground-based constellation operations approaches including science
    operations and data management, and compatible with the Goddard Mission Services Evolution
    Center (GMSEC) (open source software developed at NASA Goddard).

- **Scalable DSM flight software systems such as:**
  - Software components compatible with the Core Flight System (CFS) (open source software
    developed at NASA Goddard), enabling to control and navigate DSM formations and constellations;
    for example, discrete event supervisors offering a means to autonomously control systems based
    on selected mission metrics (e.g., spacecraft separation distance, number of active spacecraft, etc.);
  - Technologies for onboard collaborative processing and intelligence, including but not limited to, inter-
    spacecraft collaboration for collecting, storing and downloading data as well as multi-platform
    Science observation coordination and event targeting.

Research proposed to this subtopic should demonstrate technical feasibility and should discuss how it relates to
NASA programs and projects. Proposed work is expected to be at an entry Technology Readiness Level (TRL)
between 2 and 5, and to demonstrate a TRL increase of at least one level during each phase of the project.
Proposals will be evaluated based on their degree of innovation and their potential for future infusion.

Materials, Structures, Mechanical Systems and Manufacturing Topic T12
Materials, Structures, Mechanical Systems, and Manufacturing This topic is extremely broad, covering five
technology areas: materials, structures, mechanical systems, manufacturing, and cross-cutting technologies. The
topic consists of enabling core disciplines and encompasses fundamental new capabilities that directly impact the
increasingly stringent demands of NASA science and exploration missions.

Sub Topics:

**T12.01 Advanced Structural Health Monitoring**

*Lead Center: LaRC*

*Participating Center(s): ARC, GSFC, JSC, KSC*

Future manned space missions will require spacecraft and launch vehicles that are capable of monitoring the
structural health of the vehicle and diagnosing and reporting any degradation in vehicle capability. This subtopic
seeks new and innovative technologies in structural health monitoring (SHM) and integrated vehicle health
management (IVHM) automated systems and analysis tools. Techniques sought include modular/low mass-
volume systems, low power, low maintenance systems, and complete systems that reduce or eliminate wiring, as
well as smart-sensor systems that provide processed data as close to the sensor and systems that are flexible in
their applicability. Examples of possible automated sensor systems are: Surface Acoustic Wave (SAW)-based
sensors, passive wireless sensor-tags, flexible sensors for highly curved surfaces, flexible strain and load sensors
for softgoods products (broadcloth, webbing or cordage), direct-write film sensors, and others. Damage detection
modes include leak detection, ammonia detection, micrometeoroid impact and others. Reduction in the complexity
of standard wires and connectors and enabling sensing functions in locations not normally accessible is also
desirable. Proposed techniques should be capable of long term service with little or no intervention. Sensor
systems should be capable of identifying material state awareness and distinguish aging related phenomena and
damage conditions in complex composite and metallic materials. Techniques and analysis methods related to quantifying material properties, density, microcrack formation, fiber buckling and breakage, etc. in complex composite, metallic and softgoods material systems, adhesively bonded/built-up and/or polymer-matrix composite sandwich structures are of particular interest. Some consideration will be given to the IVHM /SHM ability to survive in on-orbit and deep space conditions, allow for changes late in the development process and enable on orbit modifications. System should allow NASA to gain insight into performance and safety of NASA vehicles as well as commercial launchers, vehicles, inflatable structures and payloads supporting NASA missions. Inclusion of a plan for detailed technical operation and deployment is highly favored.

State of the Art

Current tools for SHM are rudimentary and or need development for future space missions. Current data analysis methods are frequently non-ideal for the large scales of data needed for SHM analysis and/or require expert involvement in interpretation of data.

This technology enables:

- Monitoring of advanced structures/vehicles.
- Cost-effective methods for optimizing SHM techniques.
- Feasible methods for validating structural health monitoring systems.

Once developed this technology can be infused in any program requiring advanced structures/vehicles Aerospace companies are very interested in this enabling technology.

STMD/NASA/NARP/National - Directly aligns with NASA space technology roadmaps and Strategic Space Technology Investment plan.

T12.02 Technologies to Enable Novel Composite Repair Methods

Lead Center: KSC
Participating Center(s): JSC

As composite structures become more prevalent on launch vehicles, it will become necessary to have the capability to inspect and repair these structures during ground processing prior to launch. Current composite repair methods developed for the aviation industry are time consuming and require complex infrastructure in order to restore the structural strength. Aerospace structures have structural and thermal profiles which are different than aircraft and require different considerations; for example, unlike a commercial aircraft, a launch vehicle sees high loading but is only a one time use vehicle. Advancements are needed to repair materials and methods which allow for a structural repair to be performed in locations with minimal access and in a short time frame. Small damages may be accepted by analysis with no repair. Large damages may require extensive repair or component replacement. This subtopic focuses on developing novel composite repair methods for damages that fall in between these two categories. These novel materials and methods should consider the following:

- Use of out of autoclave composite materials and processes, which are being investigated for large launch vehicle components, such as fairings, skirts and tanks on the Space Launch System vehicle.
- Advancements in these material systems has begun to approach properties of autoclave materials but allow for larger structures to be fabricated.
- Simplified preparation of the damaged structure. Current methods require very precise methods, which is time consuming and can be a risk for further damage.
- Material systems and methods which reduce or eliminate the need for external heat and/or vacuum. These require complex infrastructure, which can be difficult to accommodate at the launch pad, and can be time consuming, which could cause a launch delay.
- Ability to acquire data on the state of the repair, during repair and/or during the launch. This may include data such as temperature at the bondline during cure, strain across the repair patch, etc.
Development of a material system and repair method which increases the performance of the repair and reduces the complexity and time required to perform a repair increases the launch capability and success rate. Improvements or modifications to current materials and processes can be made to meet NASA requirements. This technology can also be expanded to develop methods for in-situ repairs to spacecraft on long missions.

T12.03 Increasing Predictability of Softgoods Material Behavior for Inflatable Space Structures

Lead Center: LaRC
Participating Center(s): JSC

This subtopic is seeking innovative design and fabrication methodologies that increase the predictability and repeatability of the mechanical behavior of softgoods material architectures, including broadcloth, webbing and cordage that are used in expandable space habitats. To date, high-strength softgoods materials used in deployable habitats have been manufactured to industrial or Mil-Spec standards that only require meeting a minimum strength requirement for acceptance. NASA is seeking high-strength softgoods material architectures and processes that significantly improve pristine repeatability on strength and stiffness, and provide improved predictability of mechanical properties when loaded over time. In addition, these materials may be packaged in an unloaded state for long periods of time prior to deployment, thus methods for maintaining predictability after a period of relaxation are being sought.

Integration of indicator fibers or yarns into these materials during manufacture is also of interest, to identify damaged or stressed areas of the softgoods during and after fabrication, and to provide a measure of the softgoods structural integrity over time. Post-fabrication integration of advanced health monitoring sensors, such as for strain and load, are covered under a separate subtopic.

NASA is also interested in modeling and simulation approaches that can model the effects and impact of the space environment (thermal, radiation, vacuum) on these materials over time to maintain structural margins. These modeling techniques in combination with materials built for higher predictability and integrated health monitoring should allow prediction of residual strength and remaining safe life for missions of several years.

In summary NASA seeks innovations in:

- Designing and fabricating high-strength softgoods material architectures with highly predictable strength and stiffness in the pristine state, with improved predictability of long-term behavior after extended packaged or inflated conditions in a space environment.
- Integrating specialized indicator fibers or yarns into these materials during fabrication, to enable evaluation of structural integrity.
- Advanced modeling and simulation methodologies to predict mechanical behavior of these materials after long-term exposure to the space environment.

Contractors should prove the feasibility of proposed innovations using suitable analyses and small scale tests in Phase I. In Phase II, significant testing / fabrication or software capabilities should be developed and demonstrated. A Technology Readiness Level (TRL) at the end of Phase II of 4 is desired.

T12.04 Experimental and Analytical Technologies for Additive Manufacturing

Lead Center: MSFC
Participating Center(s): GSFC

Additive manufacturing is becoming a leading method for reducing costs, increasing quality, and shortening schedules for production of innovative parts and component that were previously not possible using more traditional methods of manufacturing. In the past decade, methods such as selective laser melting (SLM) have emerged as the leading paradigm for additive manufacturing (AM) of metallic components, promising very rapid, cost-effective, and on-demand production of monolithic, lightweight, and arbitrarily intricate parts directly from a
CAD file. In the push to commercialize the SLM technology, however, the modeling of the AM process and physical properties of the resulting artifact were paid little attention. As a result, commercially available systems are based largely on hand-tuned parameters determined by trial and error for a limited set of metal powders. The system operation is far from optimal or efficient, and the uncertainty in the performance of the produced component is too large. This, in turn, necessitates a long and costly certification process, especially in a highly risk-aware community such as aerospace. Modeling and real time process control of selective laser melting is needed coupled with statistically significant correlations and understanding of the important process parameters and the resultant microstructural and mechanical properties, validated with detailed metallurgical investigations of the as-fabricated structures.

State of the Art

This topic seeks technologies that close critical gaps between SOA and needed technology in both experimental and analytical areas in materials design, process modeling and material behavior prediction to reduce time and cost for materials development and process qualification for SLM.

Technological advancements are needed in the areas of:

- Real-time additive manufacturing process monitoring for real-time material quality assurance prediction.
- Reduced-order physics models for individual phases of additive manufacturing technique.
- Analytical tools to understand effects of process variables on materials evolution.
- Digital models to standardize the use of structured light scanning or equivalent within manufacturing processes.
- Software for high-fidelity simulation of various SLM phases for guiding the development, and enabling the subsequent verification.

Ground and Launch Systems Processing Topic T13

Ground and Launch Systems Processing. The goal of this topic is to provide a flexible and sustainable US capability for ground processing as well as launch, mission, and recovery operations to significantly increase safe access to space. The Ground and Launch Systems Processing topic consists of four technology subareas, including: technologies to optimize the operational life-cycle, environmental and green technologies, technologies to increase reliability and mission availability, and technologies to improve mission safety/mission risk. The primary benefit derived from advances in this technology area is reduced cost, freeing funds for other investments.

Sub Topics:

T13.01 Embedded Intelligent Sensor Systems

Lead Center: SSC

Participating Center(s): KSC, MSFC

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 eliminating cabling and auxiliary power.

Rocket propulsion test facilities within NASA provide excellent test beds for testing and using the innovative technologies discussed above. Rocket propulsion development is enabled by rigorous ground testing 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 primary emphasis is to develop near-term products that augment and enhance proven, state-of-the-art propulsion test facilities. But the ultimate goal is develop sensor technologies capable of being embedded in structures and systems that are smaller, more energy efficient allowing for more complete and accurate vehicle health assessments. Development of a range of self-powered devices that maximize the safety and reliability of
extended missions will enhance human space flight capabilities in support of human and robotic exploration missions. It is anticipated these sensor system will achieve orders of magnitude reduction in mass and size in the future.

Specific technology needs include the following:

- 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 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.

- 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.).
- Sensors are needed with capability to function reliably in extreme environments. 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.
- The proposed innovative systems must lead to improved safety and reduced test costs by allowing real-time analysis of data, information, and knowledge through efficient interfaces to enable integrated awareness of the system condition by users.

Thermal Management Systems Topic T14
Reserved for future Solicitations.
Sub Topics:
  Aeronautics Topic T15
A strong national program of research and development (R&D) for aeronautics technology forms the foundation of the U.S. aeronautics and aviation enterprise. Aeronautics R&D is critical for national security and homeland defense, an efficient national air transportation system, and the economic well-being and quality of life of our citizens. The National Aeronautics Research and Development Plan (Plan) lays out high-priority national aeronautics R&D challenges, goals, and supporting objectives to guide the conduct of U.S. The Plan includes an important new goal regarding the integration of unmanned aircraft systems into the National Airspace System. In addition, this R&D Plan:

- Supports the coordinated efforts of the Federal departments and agencies in the pursuit of stable and long-term foundational research.
- Ensures U.S. technological leadership in aeronautics for national security and homeland defense capabilities.
- Advances aeronautics research to improve aviation safety, air transportation, and reduce the environmental impacts of aviation.
- Promotes the advancement of fuel efficiency and energy independence in the aviation sector; and
- Spurs the development of innovative technologies that enable new products and services.

Most of the R&D goals and objectives will require stable and long-term foundational research across a breadth of aeronautics disciplines to provide the underlying basis for new technological advances and breakthroughs. Such foundational research is often cross-cutting, resulting in technology advances that have applications across several Principles. Moreover, new ideas and technologies that are generated by foundational research will help inform future updates to the National Aeronautics Research and Development Plan.
Sub Topics:
T15.01 Power Systems for Hybrid Electric Propulsion

Lead Center: GRC

Proposals are sought which support the technology development of power systems for aircraft hybrid electric propulsion. Hybrid electric propulsion systems, involving distributed propulsion provided by an electric power system, requires the integration of propulsion, electric power, and aerodynamics.

Distributed propulsion systems using electric motor driven fans, with power electronics used for voltage and frequency control, and having peak load equal to the total power generation provides unique challenges associated with the power system control and protection methods. The nonlinear, constant power propulsor loads also complicate the stable operation of the power control, and the limited capacity of the generators complicates the protection system and recovery control following faulted operation. Proposals addressing the power management and stability issues inherent in these kinds of power systems, and the power control methods that can be exploited to enable the power system for distributed hybrid electric propulsion are needed.

The inclusion of electric power for distributed propulsion, with much faster dynamics, also requires innovative methods for simulation of the integrated system. Advanced hybrid (algebraic and dynamic) power system simulations using load flows methods in conjunction with dynamics as needed to allow for an integrated simulation capability are also of interest.

New approaches for advanced power electronic switching devices that go beyond wide band gap semiconductors and utilize graphene or carbon nanotubes, and added manufacturing methods that can be utilized to manufacture an integrated electro-magnetic and electrical structure for electric machines are also of interest.

T15.02 Aeronautical Communications, Navigation, Surveillance and Information (CNSI) Systems for UAS

Lead Center: GRC

Under the Aeronautics Research Mission Directorate, work will be performed to conduct fundamental, cutting-edge research into new aircraft technologies as well as the integration of new operations concepts and technologies into the Next Generation Air Transportation System (NextGen). Communications, Navigation, Surveillance and Information (CNSI) technology development supports the goals of these research programs in such areas as increasing airspace system capacity and efficiency, improving aviation system safety, and advancing the integration of unmanned aircraft into the national airspace system (NAS). Aviation nationally and globally is being developed upon a new paradigm of digital information transaction, supporting coordination and collaboration between airspace users and service providers based on collection and sharing of information on a much greater scale than ever before. NASA has contributed to this technological advance through the testing of control communications for unmanned aircraft, development of aircraft antennas for high frequency satellite communications, testing and demonstration of secure, high-rate wireless communications for airports, ground and flight testing of air-ground communications channels, and simulation, modeling and analysis of digital air traffic communications. Future research and technology development supports such initiatives as autonomous NAS operations and vehicles, mobile components of system-wide information management, beyond-line-of-sight control communications for unmanned aircraft, and national airspace system-wide performance assessments.

This solicitation seeks innovative approaches to Unmanned Aircraft Systems (UAS) communications for civil aviation in the current and future NAS, including for small UAS (< 55 lbs).

Desired focus areas include:

- CNSI operations technologies supporting unmanned vehicle integration into the national and global airspace systems, including advanced civil aviation air traffic control systems (including UAV traffic management), air traffic management, and airspace operations.
- CNSI system concepts, architectures and networks.
- Aeronautical CNSI components and subsystems for operation in civil aviation bands. These designs must account for all applicable aircraft certification and airworthiness requirements.
- Beyond line of sight communications technologies for UAS.
Affordable Nano/Micro Launch Propulsion Stages Topic T1.01
There has been recent significant growth in both the Quantity and Quality of Nano and Micro Satellite Missions:

- The number of missions has outpaced available ride share opportunities.
- Dedicated access to space increases small sat mission capability & allows new & emerging low-cost technologies to be flight qualified.

Stage concepts are sought that can be demonstrated within the scope & budget of a Phase II STTR project:

- MSFC is actively pursuing multiple technologies to significantly reduce orbital access cost.
- The scale of many Nano and Micro Launch vehicles allows stages to be completed within the scope and budget of a Phase II proposals.
- Accepted proposals will be limited to stages that “plug and play” into existing or proposed architectures for orbital launch vehicles with payload capabilities from 5-50 kg. A flight test is expected in Phase II.
- The university/small business partnership is ideal to provide the correct technology combination allowing for this affordable access to space.

State of the Art

Small launch vehicles are targeting a total launch cost of ~$1-2M. Proposed stages must demonstrate significant cost savings over state of the art.

What is the compelling need for this Subtopic?

- This subtopic is necessary because there are currently no available rides for experimental propulsive stages.
- Technological advancements like additive mfg. must be demonstrated to produce aerospace quality parts at low fixed cost. These technologies must be validated for use in propulsive stages.
- The correct combination of new technologies and approaches will enable affordable, dedicated, on-demand access to space.
- Technologies that are demonstrated and validated at the nano/micro scale can be robustly infused into large launch vehicles where loads and vibrations are not as severe.
- The success of Nano/Micro Launch vehicles benefit every NASA center by enabling unprecedented experimental access to space.
- Commercial development opportunities abound since the small satellite market is robust and growing.

STMD/NASA/NARP/National-Affordable access to space is a key objective for NASA. The Nano/Micro Launch scale is an affordable avenue that will enable the development and validation of key technologies and approaches to reduce fixed cost, recurring costs and range costs.

Sub Topics:
- Detailed Multiphysics Propulsion Modeling & Simulation Through Coordinated Massively Parallel Frameworks Topic T1.02
  Detailed modeling and simulation to assess combustion instability of recent large combustors while successful to a degree showed the need for significant advances in two-phase flow, combustion, unsteady flow, and acoustics. Additionally, simulation of water spray systems for launch acoustic sound suppression and test stand rocket engine acoustic sound suppression showed the need for advances in two-phase flow, droplet formation, and particulate trajectory. In these cases, and others, the need for improved physics based models is accompanied by the requirement for high fidelity and computational speed.

Rocket combustion dynamic simulations are 3D, multiphase, reacting computations involving the mixing of hundreds of individual injection elements which require a long time history to be computed. Methods are sought (VOF, SPH, DNS/LES, PIC, etc.) to accurately capture the physics of the injection elements in a computationally efficient manner. Experimental validation of individual submodels are required.
NASA successfully leveraged advances/innovation in computer science technology to leapfrog the barriers to massive parallelism via the adoption of the Loci framework in the late 1990's. Computer science has evolved in the last two decades with respect to technology of massive parallelism. The intent of this subtopic is to infuse newest technologies, i.e., improved physics-based models accompanied by the requirement for high fidelity and computational speed, into tools for propulsion related fluid dynamic simulation. This solicitation seeks simultaneously coordinated computer science (CS) technology advances, multi-physics (MP) simulation, and high fidelity (HF) models. The value and requirement for proposals is this coordinated CS-MP-HF framework. Ideally, technologies that are up to this point only Lower TRL demonstrations are strong candidates if they are developed to fit in a coordinated CS-MP-HF framework that can be applied to propulsion system fluid dynamics.

Tools developed in this framework are expected to enable propulsion system production & DDT&E cost reductions.

Sub Topics:

Energy Transformation and Multifunctional Power Dissemination Topic T3.01
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. As such, transforming and disseminating naturally occurring and artificially induced energy from multiple environments into usable power is critical toward supporting future power generation systems. This subtopic addresses the potential for deriving power from the environment for; local or remote consumption, inundating structures or environments with energy, transmission, distribution, regulation, and storage of said energies. Conversion and transformation technologies for gathering energy naturally occurring in conjunction with induced energies are being pursued, and novel technologies capable of artificially saturating an environment with energy for storage and power dissemination along with non-conventional transmission via the surrounding environments such as wireless power are also applicable. Energy gathering is limited by the quantity of energy available within a system's immediate environment, and often the environment's energy contains prolonged periods of lulls in harvestable energy.

Technologically bridging power from a distance would fundamentally alleviate issues with low energy environments by allowing energy to be supplementally broadcast through preexisting structures and environments while simultaneously reducing docking and interfacing for power transfer. Technology development should support powering small remotely located equipment such as wireless instrumentation, or support power gathering for independently providing supplementary power to centralized equipment such as control consoles. Distributed Nano energy generating technologies are applicable for gathering scattered environmental energies into significant amounts of accumulated power along with supplementation for long-duration power utilization. This kind of distributed power should also be able to recover waste energy from rocket, nuclear, fission, and electrical propulsion devices while providing enhanced protection from energies contained within the work environment through transformation and consumption. Transforming harmful radiation, elevated temperatures, unwanted vibrations etc. into usable energy will support increased scope and duration of missions while enhancing protection from the waste energies (mitigation by transformation and consumption). Waste energies from warm soil, liquids (water, oils, hydraulic fluids), kinetic motion, piezoelectric materials, or various naturally occurring energy sources, etc. should also be transformable.

Areas of special focus for this subtopic include consideration of:

- Innovative technologies for the efficient broadcast, capture, regulation, storage and/or transformation of acoustic, kinetic, radiant (including radiation), electric, magnetic, radio frequencies and thermal energy types.
- Technologies which can work either under typical ambient environments for the above energy types and/or under high intensity energy environments for the above energy types as might be found in propulsion testing and launch facilities.
- As above, energy capture, transmission and transformation technologies that can work in very harsh environments such as those which are very hot and/or ablative (e.g., in the proximity of rocket exhaust) and/or very cold (e.g., temperatures associated cryogenic propellants) may be of interest.
- Innovations in miniaturization and suitability for manufacturing of energy capture, transmission and transformation systems so as to be used towards eventual powering of assorted sensors and IT systems on vehicles and infrastructures.
- High efficiency and reliability for use in environments that may be remote and/or hazardous and having low maintenance requirements.
- Employ green technology considerations to minimize impact on the environment and other resource usage.
Rocket propulsion test facilities within NASA provide excellent test beds for testing and using the innovative technologies discussed above because they offer a wide spectrum of energy types and energy intensities for capture and transformation. Additional Federal mandates require the optimization of current energy use and development of alternative energy sources to conserve on energy and to enhance the sustainability of these and other facilities. Specific emphasis is on technologies which can be demonstrated in a ground test environment and have the ability/intention to be extrapolated for in-space applications such as on space vehicles, platforms or habitats. Energy transformation technologies to generate higher power output than what is presently on the market are a highly desired to an expected outcome from this subtopic.

Phase I will develop feasibility studies and demonstrate through proof-of-concept demonstrations. Phase II will develop prototypical hardware and demonstrate infusion readiness to be incorporated into other products.

Sub Topics:

**Self-Powered, Ultra-Minimum Devices Topic T3.02**

As the Human Exploration and Operations (HEOMD) Mission Directorate seeks technologies in support of NASA space operations related to human exploration in Space, development of technologies that address efficient energy usage and storage are considered to be of utmost importance. Development of a range of self-powered devices that maximize the safety and reliability of extended missions can only enhance human space flight capabilities in support of human and robotic exploration programs.

Suggested research appropriate for small colleges and universities, are development of Self-Powered Exploration Devices (SPED), and Miniature Ultra-power Storage Technologies (MUST). The SPED objective is to run a small self-powered mobile device around a small table-top, low-friction track using electrical energy generated by elements of the environment, with no stored power at the start. The energy source can be vibrational, acoustic, biological, chemical, thermal, solar, or any physical characteristic from the natural environment that can generate energy for storage or immediate use. The MUST objective is to run a small device continuously, from environmentally generated power, for an extended period of time, using a miniature capacitor, or battery, technology. A long running device is the objective.

These tasks are suitable for small academic institutions where probable long technology development time trajectories and low levels of focused technology development effort are ideally accommodating for students to mature to convergence with concurrently maturing respective technologies. The SPED and MUST technologies are designed to merge into a “Game Changing” Development (TRL 3-5) of Smart Dust Motes, partnering with a larger university already making advances in the field.

“Smart Dust Motes” are millimeter-scale self-contained micro-electromechanical devices (MEMS) that include sensors, computational ability, bi-directional wireless communications technology and a power supply. Size development as of about 2007, Hitachi, are tiny dust particle devices with dimensions of about 0.05 x 0.05 mm. This aggregate development, sensing/bi-directional wireless communication, hence “swarming”, is biomimetic. Potential future partnership possibilities are companies and institutions interested in low-bandwidth, low-power wireless mesh networks that transmit data using radio signals.

Finally, DARPA researchers pioneered the area of Dust Motes since the early ‘90s. Top research universities such as Berkeley, MIT, Stanford, etc., have also been active in this field, involving MEMS and the most recent advances in digital circuitry and wireless communication since inception of the idea. The challenges for Smart Dust are to create a package that includes all the elements needed to perform sensory measurements, while also being able to communicate back to a base station to process the data. The “Smart Dust Mote”, which could contain micro-fabricated sensors, optical receivers, passive and active optical transmitters, signal-processing and control circuitry, and power sources, in a MEMS device, is very highly advanced already, relative to someone just getting started. SPED/MUST research is ideal for smaller colleges and universities to gain experience in these areas. This positions them to participate in ultimate Dust Mote development ideal for a partnership arrangement.

Interested NASA directorates are, e.g., HEOMD, and STMD.

Sub Topics:

**Dynamic Servoelastic (DSE) Network Control, Modeling and Optimization Topic T4.01**

This subtopic addresses advanced control-oriented techniques for dynamic servoelastic (DSE) terrestrial, planetary, and space environment flight systems using distributed network sensor and control systems. Methods include modeling, simulation, optimization and stabilization of DSE systems to actively and/or adaptively control structural dynamic geometry/topology, vibration, atmospheric and intraspace disturbances, static/dynamic loads,
and other structural dynamic objectives for enhanced dynamic servoeelastic performance and stability characteristics.

- DSE control for performance enhancements while minimizing dynamic interaction.
- Flexible aircraft and spacecraft stabilization and performance optimization.
- Modeling and system identification of distributed DSE dynamics.
- Sensor/actuator developments and modeling for distributed DSE control.
- Uncertainty modeling of complex DSE system behavior and interactions.
- Distributed networked sensing and control for vehicle shape, vibration, and load control.

This subtopic also addresses capabilities enabling design solutions for performance and environmental challenges of future air and space vehicles. Research in revolutionary aerospace configurations include lighter and more flexible materials, improved propulsion systems, and advanced concepts for high lift/performance and drag/energy reduction. This subtopic targets efficiency and environmental compatibilities requiring performance challenges and novel control-oriented techniques for aero-servoeelastic considerations which are gaining prevalence in advanced aerospace flight vehicles, atmospheric and extra-terrestrial.

Technical elements for the Phase I proposals may also include:

- Mission/maneuver adaptivity with dissipative optimal energy-force distribution.
- Data-driven multi-objective DSE control with physics-based sensing.
- Robust sensing-control-communication networks for sensor-based distributed control.
- Compressive information-based sensing and information structures.
- Evolving systems as applied to self-assembling and robotic maneuvering.
- Scalable and evolvable information networks with layering architectures.
- Modular architectures for distributed autonomous aerospace systems.
- Multi-objective, multi-level control and estimation architectures.
- Distributed multi-vehicle dynamics analysis and visualization with complex simulations.
- Reduced order modeling capable of substructure coupling of nonlinear materials.

Development of distributed sensory-driven control-oriented DSE systems is solicited to enable future flight vehicle concepts and designs that manage structural dynamic uncertainty on a vehicle's overall performance. Proposals should assist in revolutionizing improvements in performance to empower a new generation of air and space vehicles to meet the challenges of terrestrial and commercial space 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.

Advanced mission applicability in Phase II should show the ability of aerospace GN&C systems to achieve mission objectives as a function of GN&C sensor performance, vehicle actuation/power/energy, and the ability to jointly design them as onboard-capable, real-time computing platforms with applicable environmental effects and robust guidance algorithms. Goals are to:

- Provide capabilities that would enable new projects/missions that are not currently feasible.
- Impact multiple missions in NASA space operations and science, earth science, and aeronautics.
- Be influential across aerospace and non-aerospace disciplines with dynamic interactions.

State of the Art

This subtopic will:

- Provide capabilities that would enable new projects and missions that are not currently feasible, using distributed sensing and controls for network processing.
- Impact multiple missions in NASA space operations and science, earth science, and aeronautics.
• Be influential across aerospace and non-aerospace disciplines with dynamic interactions.

Potential technical impacts are:

• Vehicle energy efficiency with passive/active dissipativity for control and dynamic stability with extreme power constraints.
• Weight minimization through dynamic servoelastic control.
• Mission adaptivity and robustness with real-time, consensus-coordinated control dealing with computation, communication, and dynamics.

New technologies proposed should have the potential to impact the following NASA missions:

• Data availability for science missions.
• Mission planning.
• Autonomous rendezvous/docking technology.
• Environmental monitoring for human habitation.

Apart from NASA missions, the aeronautics technology could be adapted for development and use in autonomous operation of wind/ocean energy and smart space power grid systems in dynamic environments. There are number of advantages to exploring this subtopic technology:

• Increase in autonomy and fuel efficiency of coordinated robotic vehicles and sub-components.
• Improved science, atmospheric, and reconnaissance data.
• Cost, risk and reliability of flight vehicles for a terrestrial, planetary, or space mission.
• Inter-networks with improved dynamic behavior.

Potential technical impacts are:

• Vehicle energy efficiency with passive/active dissipativity for control and dynamic stability with extreme power constraints.
• Weight minimization through dynamic servoelastic control.
• Mission adaptivity and robustness with real-time, consensus-coordinated control dealing with computation, communication, and dynamics.

Sub Topics:
Regolith Resources Robotics - R3 Topic T4.02
The use of robotics for In-Situ Resource Utilization (ISRU) in outer space on various planetary bodies is essential since it uses large quantities of regolith that must be acquired and processed. In some cases this will happen while the crew is not there yet, or it will take place at a remote destination where the crew cannot spend much time due to radiation exposure limits (Asteroids, Mar’s Moons & NEO’s). Communications latencies of greater than 40 minutes at Asteroids mandate autonomous robotics applications. Proposals are sought which provide solutions for the following space resource related technology area:

Asteroid Resource Prospecting and Characterization

The first step towards using resources derived from small bodies in space, such as water, volatiles, metals and organic compounds is to visit the Near Earth Object (NEO) target body and prospect it with sample acquisition devices and subsequently do characterization of these samples. Proposals are sought for innovative resource prospecting mission concepts and associated technology demonstrations such as autonomous small marsupial free flier prospector spacecraft that can sample an asteroid, comet or Mars moon and transport the sample back to a locally orbiting spacecraft with an associated suite of characterization instruments for analysis.

Proposals are sought for innovative resource prospecting mission concepts, technology development, and demonstrations.
Technologies include sample acquisition methods and devices, regolith anchoring methods, autonomous conops, sub-surface access, excavation, specialized sensors, dust lofting mitigation, perception in dusty environments, mobility methods, surveying, remote sample characterization, geodetic mapping, replenishing and transferring robotic commodities such as propellants, electric power, data transfer, pneumatics and robust interfaces for commodity transfer.

Future prospecting missions include:

- Water/Ice on Mars, Mars moons or Earth’s Moon.
- Micro-gravity Near Earth Object (NEO) operations to prospect/sample surface resources.
- Lava tubes/shadowed crater cold traps on planetary surfaces to characterize volatiles accumulation.

Sub Topics:
Coordination and Control of Swarms of Space Vehicles Topic T4.03
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).

Sub Topics:
Autonomous Ka-band Spacecraft Terminals Topic T5.01
This subtopic focuses on the ability of small spacecraft to autonomously connect and communicate with other approved spacecraft, relays, and ground terminals in a manner that ensures compliance with NASA communications and software defined radio standards, access protocols, and frequency spectrum constraints. Innovations are sought to increase the autonomy, flexibility and performance of Ka-band spacecraft terminals while reducing their cost, size, mass, power consumption and thermal and vibrational impact on user spacecraft. Advances in compact directional antennas, flexible software defined radios (SDR) or software transceivers (SDT), and autonomous communications terminal operations will enable small spacecraft to establish communications with existing and emerging NASA space relays and ground terminals, as well as other approved spacecraft within the network. Automation embedded into the user terminals will help ensure efficient use of all available Ka-band communications capacity and mitigate potential for interference.

Background

Future missions will need higher data rates, more opportunities to transmit and receive data, lower communications burden on the spacecraft, and flexibility and automation where practicable to reduce human intervention. To reduce life-cycle development cost and schedule, NASA missions are trending toward smaller spacecraft and clusters of spacecraft to accomplish mission objectives. Autonomous communications operations in Ka-band frequencies will enable higher data rates, better utilization of existing and emerging NASA and commercial infrastructure, increase instantaneous use of available relay and ground network capacity, mitigate potential for interference.

Programmatic Relevance
NASA’s Space Communications and Navigation (SCaN) Program has been deploying Ka-band service capabilities into near Earth relays and near Earth and deep space ground terminal infrastructure to enable NASA missions to help reduce congestion in lower frequency bands. This migration also leverages significant commercial investments in Ka-band communications technologies over the past two decades. However, the lack of innovative, commercially sourced low-cost, autonomous user terminals has hindered mission movement into Ka-band with the exception of a few custom, one-of-a-kind, mission specific terminals. Compliance with SCaN's Space Network (SN) and Near Earth Network (NEN) User Guides and NASA Space Telecommunications Radio Systems (STRS) standards will enable new missions based on small spacecraft and clusters of spacecraft to operate with high performance and lower cost than one-of-a-kind solutions. Compact, agile Ka-band antennas will enable uplinks, crosslinks and downlinks with a wide range of space and ground assets. Enabling cost-effective operations especially for small spacecraft in NASA's Ka-band frequency spectrum allocations will help ease congestion in current bands (e.g., UHF/VHF, S-band, X-bands and unregulated spectrum), and enable higher data rates and a higher return on NASA and commercial investments in Ka-band geostationary relays and ground terminals.

Technology Advancement Goals

Proposed advancements are encouraged in, but are not limited to, any or several of the following capabilities. Autonomous integrated terminals: Agility across and compliance with NASA Ka-band space-space and space-ground frequency spectrum allocations autonomous pointing, tracking, and communications with known or discovered relay, ground and/or proximity assets; autonomous optimization of data throughput based on predicted or sensed link conditions; flexible use of antenna and transceiver gains to cover a range of operating conditions; minimal impact on user spacecraft; cost-effective implementation; clear path to space qualifiable implementation. SDTs: NASA STRS compliant implementation; NASA space and ground infrastructure compliant; variable and/or adaptive coded modulation and data rates; autonomous link margin optimization; compact, low-mass, power efficient. Ka-band Antennas: electronically steered, scanned or switched directional beams; potential for multiple simultaneous beams; isoflux beams for space-ground links; hemispherical or omni coverage for proximity and non-directional conditions; small size or compact deployable; low mass, low power consumption; low cost.

Research Institution (RI)/Small Business (SB) Collaboration Goals:

The goals of this collaborative effort are to:

- Select practical advancements from a range of autonomous operations technologies, SDT approaches, and innovative antenna concepts; and
- Refine, integrate and demonstrate the potential of those advancements in response to the unique needs and practical constraints of small spacecraft operating within NASA’s Ka-band space and ground infrastructure.

Collaboration between the RI and SB should allow for rapid TRL advancement into practical autonomous communications terminals that are flexible and commercially realizable.

Sub Topics:

Space Suit Environmental Protection Garment Materials and Technologies Topic T6.01
Pressure garments designed for long-duration exploration missions require new Environmental Protection Garments (EPGs) to address the environments and use conditions to which they will be subjected. The EPG on the Apollo A7LB spacesuit was required to only tolerate a few days of working in a dusty environment whereas the surface mission on Mars will last for up to 500 days with routine EVAs.

An EPG is a lay-up of materials that protect the inner layers (bladder and restraint) of the pressure garment. Environmental protection functions of the EPG include protection from: thermal extremes; secondary ejecta; cuts and punctures; abrasion and wear from dust; durability with respect to cycle fatigue and radiation exposure; and resistance to chemical corrosion. The layers of the EPG work together as a system to address all of these functions.

To date, very limited effort has been focused on developing the EPG. If new materials are required it is anticipated that a development effort of up to 10 years may be necessary to reach TRL 6, making EPG technology a schedule driver for exploration. Materials that are immediately applicable will be offered to the ISS space EMU subsystem manager for potential incorporation.
The challenges being addressed with this call include dust mitigation, cut and puncture resistance, and cycle life:

- **Dust Mitigation** - Dust mitigation can be addressed on one or both of two fronts: dust repellant (keep dust from penetrating) and dust resistance (dust doesn't degrade performance). Protection from both lunar and Martian regolith and from the full range of particle sizes of the regolith is of interest. Materials that are resistant to the potentially corrosive chemical products resulting from Mars regolith combining with oxygen and/or water vapor. Unique methods of fabrication and of design to limit the intrusion of dust at breaks between sections of the EPG (such as between the lower arm and shoulder sections of the EPG) are included.

- **Cut and punctures** - Current ISS EMU materials have proven susceptible to cuts from sharp edges on hand rails. Exploration suits will be handling rocks, dirty tools, and other abrasive and rough surfaces.

- **Durability** - EPGs will see hundreds of thousands to millions of cycles as the joints of the space flex as crewmembers walk, grasp, and use tools. Materials need to be highly durable to withstand the cycles of joint flexion in the thermal, dust and radiation environments on planetary surfaces.

Additionally, the goal of the EPGs design is to improve performance on all fronts. When the ISS EMU glove design was changed to increase durability against sharp edges, its mobility was reduced. The EPG dust mitigation, for example, that protects the suit bladder from dust will also have minimal impact (less than 10%) on suit range of motion and torque.

This call seeks innovative materials and creative approaches for both individual layers of the EPG as well as full EPG lay-ups, as well as, EPG system level dust mitigation approaches.

Research done in Phase I of these efforts should focus on technical feasibility with an emphasis on hardware development that can be further expanded in a future Phase II award cycle. Phase II products must include a demonstration unit suitable for testing by NASA. Prototyping should be tailored to applications to ongoing HEO Mission Directorate missions and possible collaborative use in both the governmental and commercial manned spaceflight disciplines. Minimum deliverables at the end of Phase I are analysis and/or test reports, with priority given to functional hardware prototypes for further evaluation. Technical maturation plans should be submitted with Phase I submittals, as well as any expected commercial applications both internal and external to the manned spaceflight enterprise.

**Sub Topics:**
- Space Radiation Storms: Monitoring, Forecasting and Impact Analysis Topic T6.02

Radiation hazards constitute one of the most serious risks to future human and robotic missions beyond Low-Earth Orbit, and particularly to long-duration, long-distance space missions. The main contributors to space radiation are Galactic Cosmic Rays (GCRs) and Solar Particle Events (SPEs). The latter is the more unpredictable of the two and is associated with most energetic solar eruptions: flares and coronal mass ejections; at the same time, SPEs are capable of inducing acute and profound effects on humans and on spacecraft components. The goal of the current opportunity is to help address the challenges by focusing on investigations that can potentially lead to longer-range (2-3 days) forecasting of SPEs (or at least an improved all-clear SPE forecasting capability), as well as those which couple radiation environment models with engineering models of radiation effects so that single-event effects on specific hardware and instruments can be predicted.

**State of the Art**

Many questions regarding space radiation have yet to be answered, and numerous challenges remain, such as improving the forecasting capability of the dynamic radiation environment (particularly SPEs), coupling the radiation environment models with engineering models of radiation effects on specific instruments or spacecraft hardware, and achieving a quantitative measure of human or space assets' response to radiation storms.

What is the compelling need for this Subtopic?

Penetrating particle radiation from SPEs adversely affect aircraft avionics, communication and navigation, and potentially the health of airline crews and passengers on polar flights. SPEs also constitute major hazards for astronauts performing EVAs (Extra-Vehicular Activities) on board the International Space Station (ISS). Characterizing and predicting the dynamic variation of the radiation environment is a crucial capability, enabling personnel to take preventive measures to mitigate the potential risks, and facilitating adoption of the proper
mitigation strategy.  
STMD/NASA/NARP/National: Identified as an NRC High Priority Technology Area.  
SubTopics:  
  Sustainability in Space Topic T6.03  
Survival in remote locations such as another planet requires conservation, smart utilization and reuse of resources and resilience, especially in the event of a failed resupply ship. Closed loop living systems such as this are also important for Earth as world population grows and natural resources decrease. This STTR subtopic seeks to advance the state-of-the-art for spacecraft habitats by “closing the loop” on materials needed to sustain life and provide energy on exploration missions, while simultaneously reducing the environmental impact of aerospace processes. Air, water and waste all need to be regenerated with highly reliable systems to reduce or eliminate the need to launch more materials into space as missions become longer. Energy for life support and other systems can also be obtained from renewable energy sources or waste streams. Many current cleaning, manufacturing and testing processes for spacecraft also create an environmental burden that could be mitigated by new technologies. All these “green” technologies will improve sustainability in space and on Earth.

Technical innovation and unique approaches are solicited for the development of new technologies that will lower mission cost and environmental impact by conserving resources and closing the materials loop. This will enable self-sufficiency and thus longer space exploration missions. Also, technologies that conserve resources or reduce negative impact during spacecraft development are solicited to improve sustainability at NASA. Real world demonstration of the technologies should be emphasized, even in Phase I. Many areas of research are possible, but preference will be given to those that address gaps in the following areas and lead to early applications and dual use partnerships:

- **Waste Water Treatment and Reuse** - Reuse/recycling of waste water from gray and black water sources with minimal mass, power, volume and expendables is needed. A particular challenge is treatment of urine to prevent odor and fouling of systems without the use of hazardous chemicals. NASA would like to extract nearly 100% of the water from any brine that may be created by a primary processor. Easy regeneration of filter and resin elements is desirable to reduce expendables.

- **Waste Processing** – Technologies for stabilization, safening, recycling or creation of energy or useful products from feces or trash are sought. Proposed technologies must take into account relevant factors for space exploration such as resource scarcity, planetary protection and human factors.

- **Renewable Energy and use of Waste Heat** – Solar and other renewable energy technologies that apply to “closing the loop” in space and on Earth are sought. This could include high efficiency and regenerative fuel cell technologies and technologies that combine waste and water treatment with energy production. Also included are technologies that make use of waste heat from one process for another purpose.

- **Greener Ground Processing** – Many aerospace processes require chemicals that are not environmentally friendly or result in lots of waste. NASA seeks technologies that will significantly reduce environmental impacts for NASA as well as others who use similar processes. Technologies are sought that: reduce or eliminate solvent waste from precision cleaning and validation processes; improve particle removal efficiency when cleaning with supercritical fluids; combine multi step processes (such as metal cleaning and passivation) into one step with reduction of waste.

SubTopics:  
  Closed-Loop Living System for Deep-Space ECLSS with Immediate Applications for a Sustainable Planet Topic T6.04  
NASA’s plans to explore space beyond Low Earth Orbit will push the performance of life support systems toward closed loop living systems. Deep space missions will require life support systems that will be self-sustaining since we cannot expect to carry enough spares and consumables for year-long missions. Achieving the development of such systems will provide the understanding for managing limited availability of resources. The parallel with earth planetary resources management is ideal as the world population grows and resources and infrastructure availability decreases. We expect that technologies developed for closed loop living systems will be immediately available and applicable to provide planetary sustainability as well.

State of the Art  
An immediate example of such endeavors exists in the form of the NASA Ames Sustainability Base where technologies for deep space exploration have been used to create one of the greenest buildings in the federal building inventory. These technologies include power generation with fuel cells, water recovery systems, advanced
HVAC, environmental control, recyclable materials and use of local resources. Even though these technologies are readily available for deep space travel, each has its own set of challenges for adaption to earth application along with integration challenges.

Closed-loop living systems are mostly based on the thermodynamics laws of the conservation of mass and energy. We expect to maximize the conservation so that only a minimal amount of resources needs to be taken on a deep space mission.

Innovations are sought to enable:

- Transfer of deep space exploration technologies to earth applications.
- Development of integrated self-sustainable systems.
- Development of the most effective processes to allow for closed loop living applications.
- Application to so-called “off-the-grid” habitation in remote areas where infrastructure is inexistent.

Potential deliverables may include a demo of ECLSS concept(s) with clear applications to earth, enhanced control techniques of multiple life support subsystems (e.g., environment, water recovery, power usage, etc.), or prototype hardware and/or software to enable sustainability.

Sub Topics:

Synthetic/Engineering Biology for NASA Applications Topic T7.01

Synthetic Biology (SB) provides a unique opportunity to engineer organisms that reliably perform necessary functions for future exploration activities. NASA is interested in harnessing this emerging field to create technological advances that will benefit both future spaceflight and surface missions in a variety of enabling areas. Proposals must use a biologically-based approach, such as synthetic biology, to engineer novel biologically-based (or inspired) functions that significantly exceed current biological capabilities. Proposed projects should focus on using microorganisms in novel ways that enable ISRU, with a particular focus on resource acquisition and/or utilization or feedstock production to enable ISM. NASA's ISM program has the desire to be able to manufacture materials, parts and/or structures utilizing feedstock generated from renewable biology-based resources. Available in-situ resources may include crew and spacecraft by-products or resources found on planetary surfaces. Products of interest might include, but are not limited to, various metals, bioplastics, biocements, and other biomaterials. Applications that concurrently support more reliable and efficient life support systems during the acquisition and utilization of in-situ resources or the production of feedstock are highly desirable. Proposals should address how systems and technologies will reduce the required launch-mass and dependence on consumables, resupply, and energy and should identify how such technologies provide advantages over physico-chemical systems. 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. There is strong potential for the Phase I effort continuing to a Phase II STTR demonstration to compare ground to microgravity data (obtained via parabolic and/or ISS flight demonstration).

Sub Topics:

Technologies for Planetary Compositional Analysis and Mapping Topic T8.01

This subtopic is focused on developing and demonstrating technologies for both orbital and in-situ compositional analysis and mapping that can be proposed to future planetary missions. Technologies that can increase instrument resolution, precision and sensitivity or achieve new and innovative scientific measurements are solicited. For example missions, see (http://science.hq.nasa.gov/missions [1]). For details of the specific requirements see the National Research Council's, Vision and Voyages for Planetary Science in the Decade 2013-2022 (http://solarsystem.nasa.gov/2013decadal/ [2]).

Possible areas of interest include:

- Improved sources such as lasers, LEDs, X-ray tubes, etc. for imaging and spectroscopy instruments (including Laser Induced Breakdown Spectroscopy, Raman Spectroscopy, Deep UV Raman and Fluorescence spectroscopy, Hyperspectral Imaging Spectroscopy, and X-ray Fluorescence Spectroscopy).
- Improved detectors for imaging and spectroscopy instruments (e.g., flight-compatible iCCDS and other time-gated detectors that provide gain, robot arm compatible PMT arrays and other detectors requiring high voltage operation, detectors with improved UV and near-to-mid IR performance, near-to-mid IR detectors
with reduced cooling requirements).

- Technologies for 1-D and 2-D raster scanning from a robot arm.
- Novel approaches that could help enable in-situ organic compound analysis from a robot arm (e.g., ultra-miniaturized Matrix Assisted Laser Desorption-Ionization Mass Spectrometry).
- "Smart software" for evaluating imaging spectroscopy data sets in real-time on a planetary surface to guide rover targeting, sample selection (for missions involving sample return), and science optimization of data returned to earth.
- Other technologies and approaches (e.g., improved cooling methods) that could lead to lower mass, lower power, and/or improved science return from instruments used to study the elemental, chemical, and mineralogical composition of planetary materials.
- Projects selected under this subtopic should address at least one of the above areas of interest. Multiple-area proposals are encouraged. Proposers should specifically address:
  - The suitability of the technology for flight applications, e.g., mass, power, compatibility with expected shock and vibration loads, radiation environment, interplanetary vacuum, etc.
  - Relevance of the technology to NASA's planetary exploration science goals.

Phase I contracts will be expected to demonstrate feasibility, and Phase II contracts will be expected to fabricate and complete laboratory testing on an actual instrument/test article.

Sub Topics:

Photonic Integrated Circuits Topic T8.02
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, and integrated optic science instrument optical systems, subsystems and components. This is particularly critical for small spacecraft platforms. On July 27, 2015 - Vice President Joe Biden, at an event in Rochester, NY, announced the New York consortium has been selected to lead the Integrated Photonics Institute for Manufacturing Innovation. For details see (http://manufacturing.gov/ip-imi.html[3]). Proposed as part of President Obama’s National Network for Manufacturing Innovation (NNMI), the IP-IMI was established to bring government, industry and academia together to advance state-of-the-art photonics technology and better position the United States relative to global competition in this critical field. The use of the IP-IMI for work proposed under this topic is highly encouraged. 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.

- 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 microresonantors 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.

- Integrated photonic circuits for very high speed computing: Advanced computing engines that approach TeraFLOP per second computing power for spacecraft in a fully integrated combined photonic and electronic package.

Sub Topics:

Detection technologies for extant or extinct life for use on robotic missions Topic T8.03
One of the biggest questions that NASA is chartered to address, is "Are we alone?" NASA desires to extend the search for existing or past life on non-terrestrial bodies. Leveraging work done on extreme environment ecologies
and related fields, technologies are sought that can detect and/or quantify pre-biotic compounds (amino acids, polymers) or unique molecules (organic biomarkers including certain chiral compounds, polypeptides/proteins, lipids, nucleic acid polymers) that may be evidence of living processes. These sensors or instruments should eventually be compatible with small spacecraft, rovers, or small penetrator platforms.

Efforts within this initial STTR activity are to identify potential detection approaches and system architectures that demonstrate a pathway forward for inclusion on future robotic missions. A number of research institutions have capabilities in the supporting technologies that will be critical to detecting life, including research systems deployed in extreme environments, in addition to a large number of laboratory bench techniques that may be adapted to robotic platforms. The industrial partner will be crucial not only in commercializing the technology, but developing it and maturing it towards application on robotic missions. These robotic missions may employ in-situ measurements, or may also use remote sensing methods.

Sub Topics:

- **Navigation and Hazard Avoidance Sensor Technologies Topic T9.01**
  Missions to solar systems bodies must meet increasingly ambitious objectives requiring new or improved capabilities such as: "precision surface-relative navigation", "automatic rendezvous and capture", "well-controlled soft landing", "precision landing", and "hazard avoidance". Robotic missions to the Moon and Mars demand landing at pre-designated sites of high scientific value near hazardous terrain features, such as craters, slopes, and rocks. Missions aimed at paving the path for colonization of the Moon and human landing on Mars need to execute onboard hazard detection and precision maneuvering to ensure safe landing near previously deployed assets. Asteroid missions require precision rendezvous, identification of the landing or sampling site location, and navigation to the highly dynamic object that may be tumbling at a fast rate. NASA seeks sensor technologies enabling these missions to solar system bodies. The same sensor or sensor component technologies can also benefit space operations such as satellite servicing and optical communication.

Sensor and sensor component technologies are sought for providing measurement of vehicle relative proximity and velocity, bearings, and high resolution 3-dimensional images during the approach to the targeted body. Also of interest are sensors capable of measuring atmospheric winds and density for aiding navigation and guidance of landing vehicles in general and large hypersonic decelerators in particular. The proposals should target advanced sensor technologies for eventual space utilization. Phase I research should demonstrate the technical feasibility and show a path toward a Phase II prototype unit. Phase II prototypes should be capable of laboratory demonstration and preferably suitable for operation in the field from an aircraft platform or rocket-power terrestrial test vehicles. The component and sensor system technologies being sought include but limited to the following list:

- Highly sensitive Flash lidar camera including 2-D detector array, associated readout integrated circuit (ROIC), and drive/control electronics. Operational wavelength range 1.06-1.54 micron, the camera shall be capable of providing image frames greater than 60k pixels at 20 Hz with better than 3 cm range precision.
- Very compact and rugged laser transmitter operating in the 1.0 µm – 1.6 µm wavelength range with an output pulse energy of 30 mJ to 60 mJ, pulse width of about 6 nsec, and repetition rate of 20 Hz to 50 Hz suitable for flash lidars. The proposed laser must show path in maturing for operation in space environment.
- Non-mechanical laser beam steering devices capable of 2-axis pointing over +/- 25 degrees angle.
- Novel lightweight transmit and receive optical systems for 3-D flash lidar, Doppler lidar, or laser altimeter with aperture size from 5 cm to 10 cm suitable for operation in space environment.
- Space-qualifiable compact and rugged single-frequency CW laser systems operating at 1.55 micron wavelength region. Proposed lasers must be able to generate at least 5 W of power with less than 5 KHz linewidth over a tunable range of about 50 nm. Systems must be highly wavelength stable and come with full supporting electronic systems for thermal and power control. The lasers must be developed with space environment considerations and demonstrate a clear path to space.

Sub Topics:

- **Information Technologies for Intelligent and Adaptive Space Robotics Topic T11.01**
  The objective of this subtopic is to develop information technologies that enable robots to better support space exploration. Improving robot information technology (algorithms, avionics, software) is critical to improving the capability, flexibility, and performance of future NASA missions. In particular, the NASA "Robotics, Tele-Robotics, and Autonomous Systems" roadmap (TA04) indicates that extensive and pervasive use of robots can significantly enhance 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 teloperation (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 proximity ops. The primary objective is to radically and significantly increase the performance of mobile robot 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 appropriate for quad-copters, Astrobot/SPHERES free-flying robots, and Spirit/Opportunity scale rovers are particularly encouraged.

- **Robot software systems** that support adaptive autonomy, automated instrument/sensor targeting, payload data triage, and 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.

Deliverables to NASA:

- Identify scenarios and use cases.
- Define specifications based on design trades.
- Develop concepts to address use cases.
- Build, test, and demonstrate prototype sub-systems or systems.
- Deliver prototypes to NASA.

Sub Topics:

**Distributed Spacecraft Missions (DSM) Technology Framework Topic T11.02**

A Distributed Spacecraft Mission (DSM) is a mission that involves multiple spacecraft to achieve one or more common goals; some DSM Instances include Constellations, Formation Flying missions, or Fractionated missions. Apart from Science goals that can only be attained with DSM, distributed missions are usually motivated by several goals, among which: increasing data resolution in one or several dimensions (e.g., temporal, spatial, spectral or angular), decreasing launch costs, increasing data bandwidths, as well as ensuring data continuity and inter-mission validation and complementarity. Constellations have been proposed in several NASA Decadal Surveys and recent studies; in Earth Science (e.g., a multi-spacecraft Landsat for increasing temporal resolution), in Heliophysics (e.g., the Geospace Dynamics Constellation) or in Planetary Science (e.g., the Lunar Geophysical Network). Many constellations and Formation Flying missions have also been proposed more recently in cubesat-related research projects. For the purpose of this subtopic, we do not assume the spacecraft to be of any specific sizes, i.e., we do not restrict this study to cubesats or smallsats.

The goal of this subtopic is to mature NASA capabilities to formulate and implement novel science missions based on distributed platforms. Technologies solicited in this call are the following:

- **Novel DSM-enabling technologies** such as:
  - Technologies for high-bandwidth and efficient inter-satellite communication;
  - Metrology systems capable of sensing and controlling relative position and/or orientation of multi-element DSMs to sub-milli-arcsecond angular resolution and sub-micro-meter positional accuracy;
  - Autonomous and scalable ground-based constellation operations approaches including science operations and data management, and compatible with the Goddard Mission Services Evolution Center (GMSEC) (open source software developed at NASA Goddard).

- **Scalable DSM flight software systems** such as:
  - Software components compatible with the Core Flight System (CFS) (open source software developed at NASA Goddard), enabling to control and navigate DSM formations and constellations;
for example, discrete event supervisors offering a means to autonomously control systems based
on selected mission metrics (e.g., spacecraft separation distance, number of active spacecraft, etc.);
- Technologies for onboard collaborative processing and intelligence, including but not limited to, inter-
  spacecraft collaboration for collecting, storing and downloading data as well as multi-platform
  Science observation coordination and event targeting.

Research proposed to this subtopic should demonstrate technical feasibility and should discuss how it relates to
NASA programs and projects. Proposed work is expected to be at an entry Technology Readiness Level (TRL)
between 2 and 5, and to demonstrate a TRL increase of at least one level during each phase of the project.
Proposals will be evaluated based on their degree of innovation and their potential for future infusion.

Sub Topics:

Advanced Structural Health Monitoring Topic T12.01
Future manned space missions will require spacecraft and launch vehicles that are capable of monitoring the
structural health of the vehicle and diagnosing and reporting any degradation in vehicle capability. This subtopic
seeks new and innovative technologies in structural health monitoring (SHM) and integrated vehicle health
management (IVHM) automated systems and analysis tools. Techniques sought include modular/low mass-
volume systems, low power, low maintenance systems, and complete systems that reduce or eliminate wiring, as
well as smart-sensor systems that provide processed data as close to the sensor and systems that are flexible in
their applicability. Examples of possible automated sensor systems are: Surface Acoustic Wave (SAW)-based
sensors, passive wireless sensor-tags, flexible sensors for highly curved surfaces, flexible strain and load sensors
for softgoods products (broadcloth, webbing or cordage), direct-write film sensors, and others. Damage detection
modes include leak detection, ammonia detection, micrometeoroid impact and others. Reduction in the complexity
of standard wires and connectors and enabling sensing functions in locations not normally accessible is also
desirable. Proposed techniques should be capable of long term service with little or no intervention. Sensor
systems should be capable of identifying material state awareness and distinguish aging related phenomena and
damage conditions in complex composite and metallic materials. Techniques and analysis methods related to
quantifying material properties, density, microcrack formation, fiber buckling and breakage, etc. in complex
composite, metallic and softgoods material systems, adhesively bonded/built-up and/or polymer-matrix composite
sandwich structures are of particular interest. Some consideration will be given to the IVHM /SHM ability to survive
in on-orbit and deep space conditions, allow for changes late in the development process and enable on orbit
modifications. System should allow NASA to gain insight into performance and safety of NASA vehicles as well as
commercial launchers, vehicles, inflatable structures and payloads supporting NASA missions. Inclusion of a plan
for detailed technical operation and deployment is highly favored.

State of the Art

Current tools for SHM are rudimentary and or need development for future space missions. Current data analysis
methods are frequently non-ideal for the large scales of data needed for SHM analysis and/or require expert
involvement in interpretation of data.

This technology enables:

- Monitoring of advanced structures/vehicles.
- Cost-effective methods for optimizing SHM techniques.
- Feasible methods for validating structural health monitoring systems.

Once developed this technology can be infused in any program requiring advanced structures/vehicles Aerospace
companies are very interested in this enabling technology.

STMD/NASA/NARP/National - Directly aligns with NASA space technology roadmaps and Strategic Space
Technology Investment plan.

Sub Topics:

Technologies to Enable Novel Composite Repair Methods Topic T12.02
As composite structures become more prevalent on launch vehicles, it will become necessary to have the capability
to inspect and repair these structures during ground processing prior to launch. Current composite repair methods
developed for the aviation industry are time consuming and require complex infrastructure in order to restore the
structural strength. Aerospace structures have structural and thermal profiles which are different than aircraft and
require different considerations; for example, unlike a commercial aircraft, a launch vehicle sees high loading but is only a one time use vehicle. Advancements are needed to repair materials and methods which allow for a structural repair to be performed in locations with minimal access and in a short time frame. Small damages may be accepted by analysis with no repair. Large damages may require extensive repair or component replacement. This subtopic focuses on developing novel composite repair methods for damages that fall in between these two categories. These novel materials and methods should consider the following:

- Use of out of autoclave composite materials and processes, which are being investigated for large launch vehicle components, such as fairings, skirts and tanks on the Space Launch System vehicle. Advancements in these material systems has begun to approach properties of autoclave materials but allow for larger structures to be fabricated.
- Simplified preparation of the damaged structure. Current methods require very precise methods, which is time consuming and can be a risk for further damage.
- Material systems and methods which reduce or eliminate the need for external heat and/or vacuum. These require complex infrastructure, which can be difficult to accommodate at the launch pad, and can be time consuming, which could cause a launch delay.
- Ability to acquire data on the state of the repair, during repair and/or during the launch. This may include data such as temperature at the bondline during cure, strain across the repair patch, etc.

Development of a material system and repair method which increases the performance of the repair and reduces the complexity and time required to perform a repair increases the launch capability and success rate. Improvements or modifications to current materials and processes can be made to meet NASA requirements. This technology can also be expanded to develop methods for in-situ repairs to spacecraft on long missions.

Sub Topics:

Increasing Predictability of Softgoods Material Behavior for Inflatable Space Structures Topic T12.03

This subtopic is seeking innovative design and fabrication methodologies that increase the predictability and repeatability of the mechanical behavior of softgoods material architectures, including broadcloth, webbing and cordage that are used in expandable space habitats. To date, high-strength softgoods materials used in deployable habitats have been manufactured to industrial or Mil-Spec standards that only require meeting a minimum strength requirement for acceptance. NASA is seeking high-strength softgoods material architectures and processes that significantly improve pristine repeatability on strength and stiffness, and provide improved predictability of mechanical properties when loaded over time. In addition, these materials may be packaged in an unloaded state for long periods of time prior to deployment, thus methods for maintaining predictability after a period of relaxation are being sought.

Integration of indicator fibers or yarns into these materials during manufacture is also of interest, to identify damaged or stressed areas of the softgoods during and after fabrication, and to provide a measure of the softgoods structural integrity over time. Post-fabrication integration of advanced health monitoring sensors, such as for strain and load, are covered under a separate subtopic.

NASA is also interested in modeling and simulation approaches that can model the effects and impact of the space environment (thermal, radiation, vacuum) on these materials over time to maintain structural margins. These modeling techniques in combination with materials built for higher predictability and integrated health monitoring should allow prediction of residual strength and remaining safe life for missions of several years.

In summary NASA seeks innovations in:

- Designing and fabricating high-strength softgoods material architectures with highly predictable strength and stiffness in the pristine state, with improved predictability of long-term behavior after extended packaged or inflated conditions in a space environment.
- Integrating specialized indicator fibers or yarns into these materials during fabrication, to enable evaluation of structural integrity.
- Advanced modeling and simulation methodologies to predict mechanical behavior of these materials after long-term exposure to the space environment.

Contractors should prove the feasibility of proposed innovations using suitable analyses and small scale tests in Phase I. In Phase II, significant testing / fabrication or software capabilities should be developed and demonstrated.
A Technology Readiness Level (TRL) at the end of Phase II of 4 is desired. 

Sub Topics:

Experimental and Analytical Technologies for Additive Manufacturing Topic T12.04

Additive manufacturing is becoming a leading method for reducing costs, increasing quality, and shortening schedules for production of innovative parts and component that were previously not possible using more traditional methods of manufacturing. In the past decade, methods such as selective laser melting (SLM) have emerged as the leading paradigm for additive manufacturing (AM) of metallic components, promising very rapid, cost-effective, and on-demand production of monolithic, lightweight, and arbitrarily intricate parts directly from a CAD file. In the push to commercialize the SLM technology, however, the modeling of the AM process and physical properties of the resulting artifact were paid little attention. As a result, commercially available systems are based largely on hand-tuned parameters determined by trial and error for a limited set of metal powders. The system operation is far from optimal or efficient, and the uncertainty in the performance of the produced component is too large. This, in turn, necessitates a long and costly certification process, especially in a highly risk-aware community such as aerospace. Modeling and real time process control of selective laser melting is needed coupled with statistically significant correlations and understanding of the important process parameters and the resultant microstructural and mechanical properties, validated with detailed metallurgical investigations of the as-fabricated structures. 

State of the Art

This topic seeks technologies that close critical gaps between SOA and needed technology in both experimental and analytical areas in materials design, process modeling and material behavior prediction to reduce time and cost for materials development and process qualification for SLM.

Technological advancements are needed in the areas of:

- Real-time additive manufacturing process monitoring for real-time material quality assurance prediction.
- Reduced-order physics models for individual phases of additive manufacturing technique.
- Analytical tools to understand effects of process variables on materials evolution.
- Digital models to standardize the use of structured light scanning or equivalent within manufacturing processes.
- Software for high-fidelity simulation of various SLM phases for guiding the development, and enabling the subsequent verification.

Sub Topics:

Embedded Intelligent Sensor Systems Topic T13.01

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 eliminating cabling and auxiliary power.

Rocket propulsion test facilities within NASA provide excellent test beds for testing and using the innovative technologies discussed above. Rocket propulsion development is enabled by rigorous ground testing 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 primary emphasis is to develop near-term products that augment and enhance proven, state-of-the-art propulsion test facilities. But the ultimate goal is develop sensor technologies capable of being embedded in structures and systems that are smaller, more energy efficient allowing for more complete and accurate vehicle health assessments. Development of a range of self-powered devices that maximize the safety and reliability of extended missions will enhance human space flight capabilities in support of human and robotic exploration missions. It is anticipated these sensor system will achieve orders of magnitude reduction in mass and size in the future.

Specific technology needs include the following:
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 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.

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.). Sensors are needed with capability to function reliably in extreme environments. 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. The proposed innovative systems must lead to improved safety and reduced test costs by allowing real-time analysis of data, information, and knowledge through efficient interfaces to enable integrated awareness of the system condition by users.

Sub Topics:
Power Systems for Hybrid Electric Propulsion Topic T15.01
Proposals are sought which support the technology development of power systems for aircraft hybrid electric propulsion. Hybrid electric propulsion systems, involving distributed propulsion provided by an electric power system, requires the integration of propulsion, electric power, and aerodynamics.

Distributed propulsion systems using electric motor driven fans, with power electronics used for voltage and frequency control, and having peak load equal to the total power generation provides unique challenges associated with the power system control and protection methods. The nonlinear, constant power propulsor loads also complicate the stable operation of the power control, and the limited capacity of the generators complicates the protection system and recovery control following faulted operation. Proposals addressing the power management and stability issues inherent in these kinds of power systems, and the power control methods that can be exploited to enable the power system for distributed hybrid electric propulsion are needed.

The inclusion of electric power for distributed propulsion, with much faster dynamics, also requires innovative methods for simulation of the integrated system. Advanced hybrid (algebraic and dynamic) power system simulations using load flows methods in conjunction with dynamics as needed to allow for an integrated simulation capability are also of interest.

New approaches for advanced power electronic switching devices that go beyond wide band gap semiconductors and utilize graphene or carbon nanotubes, and added manufacturing methods that can be utilized to manufacture an integrated electro-magnetic and electrical structure for electric machines are also of interest.

Sub Topics:
Aeronautical Communications, Navigation, Surveillance and Information (CNSI) Systems for UAS Topic T15.02
Under the Aeronautics Research Mission Directorate, work will be performed to conduct fundamental, cutting-edge research into new aircraft technologies as well as the integration of new operations concepts and technologies into the Next Generation Air Transportation System (NextGen). Communications, Navigation, Surveillance and Information (CNSI) technology development supports the goals of these research programs in such areas as increasing airspace system capacity and efficiency, improving aviation system safety, and advancing the integration of unmanned aircraft into the national airspace system (NAS). Aviation nationally and globally is being developed upon a new paradigm of digital information transaction, supporting coordination and collaboration between airspace users and service providers based on collection and sharing of information on a much greater scale than ever before. NASA has contributed to this technological advance through the testing of control communications for unmanned aircraft, development of aircraft antennas for high frequency satellite communications, testing and demonstration of secure, high-rate wireless communications for airports, ground and flight testing of air-ground communications channels, and simulation, modeling and analysis of digital air traffic
communications. Future research and technology development supports such initiatives as autonomous NAS operations and vehicles, mobile components of system-wide information management, beyond-line-of-sight control communications for unmanned aircraft, and national airspace system-wide performance assessments.

This solicitation seeks innovative approaches to Unmanned Aircraft Systems (UAS) communications for civil aviation in the current and future NAS, including for small UAS (< 55 lbs).

Desired focus areas include:

- CNSI operations technologies supporting unmanned vehicle integration into the national and global airspace systems, including advanced civil aviation air traffic control systems (including UAV traffic management), air traffic management, and airspace operations.
- CNSI system concepts, architectures and networks.
- Aeronautical CNSI components and subsystems for operation in civil aviation bands. These designs must account for all applicable aircraft certification and airworthiness requirements.
- Beyond line of sight communications technologies for UAS.

Sub Topics: