Includes all propulsion technologies required to deliver space missions from the surface of the Earth to Earth orbit or Earth escape, including solid rocket propulsion systems, liquid rocket propulsion systems, air breathing propulsion systems, ancillary propulsion systems, and unconventional/other propulsion systems. The Earth to orbit launch industry is currently reliant on very mature technologies, to which only small incremental improvements are possible. Breakthrough technologies are not on the near horizon, therefore research and development efforts will require both significant time and financial investments.

Sub Topics:

T1.01 Launch Vehicle Propulsion Technologies

Lead Center: MSFC
Participating Center(s): SSC

Heavy lift launch vehicles envisioned for exploration beyond low Earth orbit (LEO) will require large first stage propulsion systems. For some heavy lift vehicles, the total thrust produced at lift-off will exceed 6 million pounds. There are currently available practical propulsion options for such a vehicle. However, the cost for outfitting the booster with the required propulsion systems is in the hundreds of millions of dollars. This cost severely limits what missions NASA can perform. Low cost design concepts and manufacturing techniques are needed to make future exploration affordable. This topic seeks technologies that will fulfill the following objectives:

- Development of propulsion concepts whose cost is less than 50% of currently available but with similar performance.
- Development and demonstration of low-cost manufacturing techniques.
- Techniques for evaluating and analyzing low-cost, easily manufacturable design concepts.

Example technologies of interest include:

- Ablative materials and manufacturing techniques.
- Innovative chamber cooling concepts that reduce manufacturing complexity without reducing performance.
- Low-cost nozzle materials, manufacturing techniques, and coatings.
- Ignition concepts that require low part count and/or low energy to be used as either primary or redundant ignition sources.
- Manufacturing techniques that lower the cost of manufacturing complex components such as injectors and
coolant channels. Examples include, but are not limited to, development and demonstration of rapid prototype techniques for metallic parts, powder metallurgy techniques, and application of nano-technology for manufacturing of near net shape manufacturing.

- Increased efficiency and fidelity analysis tools.

The development of future propulsion systems for deep-space exploration are directly dependent on the development of technologies such as those listed. Furthermore, affordable, reliable access to space technology is a strong need across all of NASA’s space exploration activities (HEOMD, OCT, SMD). While revolutionary advances in launch vehicle technologies are not foreseen to be developed in the immediate future, a practice of employing methodical continuous technology development in the direction of lowering the cost and improving the reliability of launch propulsion systems will addresses this critical need of lowering the cost of earth-to-orbit launch systems and capabilities.

In-Space Propulsion Technologies Topic T2

Includes all propulsion technologies required to deliver space missions from the surface of the Earth to Earth orbit or Earth escape, including solid rocket propulsion systems, liquid rocket propulsion systems, air breathing propulsion systems, ancillary propulsion systems, and unconventional/other propulsion systems. The Earth to orbit launch industry is currently reliant on very mature technologies, to which only small incremental improvements are possible. Breakthrough technologies are not on the near horizon, therefore research and development efforts will require both significant time and financial investments.

Sub Topics:

T2.01 Space Power and Propulsion

Lead Center: GRC
Participating Center(s): KSC

Development of innovative technologies are sought that will result in durable, long-life, lightweight, high performance space power and in-space propulsion systems to substantially enhance or enable future missions.

Innovations in the form of advanced concepts, technology demonstrations and processes are sought for Space Power and Propulsion.

Space Power areas of particular interest include solar photovoltaic, nuclear power, power distribution and transmission, conversion and regulation, batteries and fuel cells. Solar photovoltaic cell, blanket, and array technologies are sought for improved efficiency, power density, specific power and mass, and application to NASA-unique environmental conditions (high radiation, extreme temperatures, varying light intensity, etc.). Nuclear power
technologies that provide high efficiency, high specific power, and long life for deep space and planetary surface applications including radioisotope power generation for power levels between 100 watts and 1 kilowatt and fission power generation for power levels from kilowatts to megawatts. Battery technologies include novel battery chemistries that offer improvements in safety, volume and mass above and beyond those offered by Lithium-ion technology. Fuel cell (and electrolyzer) technologies include novel membrane materials and geometries and advanced concepts. Power management and distribution technologies include modular "smart" systems and advanced materials and component research and development.

In-Space Propulsion areas of particular interest include electric propulsion, micro-propulsion, nuclear thermal propulsion, and propellant storage and transfer, which were identified as the highest priority ISP technologies by the NRC's "NASA Space Technology Roadmaps and Priorities." Technologies for electric propulsion include high-power long-lived thrusters and low specific mass power processing systems. Micro-propulsion technologies include chemical or non-chemical systems for micro-satellites. Technologies for nuclear thermal propulsion include advanced high temperature fuel forms, innovative testing methods and non-nuclear subsystems. Propellant technologies include subsystems and components to enable long-duration storage in space and low-gravity liquid transfer.

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 Harvesting Technology Development**

*Lead Center: SSC*

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

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, novel energy harvesting technologies are critical toward supporting future power generation systems to begin to meet these challenges. This subtopic addresses the potential for deriving power from waste engine heat, warm soil, liquids, kinetic motion, piezoelectric materials or other naturally occurring energy sources, etc. (re: TA-3; 2.2.1.1).

Development of energy harvesting (both capture and conversion) technologies would also address the national need for novel new energy systems and alternatives to reduce energy consumption.

Areas of special focus for this subtopic include consideration of:
Innovative technologies for the efficient capture and/or conversion of acoustic, kinetic, 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.

Innovations in miniaturization and suitability for manufacturing of energy capture and conversion 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 to capture and convert. 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.

Robotics, Tele-Robotics and Autonomous Systems Topic T4

The topic for Robotics, Tele-Robotics and Autonomous Systems, consists of seven technology subareas: Sensing and Perception; Mobility; Manipulation; Human-Systems Integration; Autonomy; Autonomous Rendezvous and Docking (AR&D); and Robotics, Tele-Robotics and Autonomous Systems Engineering. Robotics, Tele-Robotics and Autonomous Systems supports NASA space missions with the development of new capabilities, and can extend the reach of human and robotic exploration through a combination of dexterous robotics, better human/robotic interfaces, improved mobility systems, and greater sensing and perception. The Robotics, Tele-Robotics and Autonomous Systems topics focuses on several key issues for the future of robotics and autonomy: 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 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. Robots are already at work in all of NASA's Mission Directorates and will be critical to the success of future exploration missions. The NASA "Robotics, Tele-Robotics, and Autonomous Systems" roadmap (TA04) indicates that extensive and pervasive use of robots can significantly enhance exploration, particularly for missions that are progressively longer, complex, and operate with fewer ground control resources.

Intelligent robots can do a variety of work to increase the productivity of planetary exploration. Robots can perform tasks that are highly-repetitive, long-duration, or tedious. Robots can perform tasks that help prepare for subsequent human missions. Robots can perform "follow-up" work, completing tasks started by astronauts. Example robotic tasks include:

- Scouting.
- Site surveys.
- Sampling.
- Payload deployment.
- EVA close-out work.

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

- Advanced user interfaces for telerobotics, which facilitate distributed collaboration, geospatial data visualization, summarization and notification, and robot tasking. This does NOT include user interfaces for direct teloperation (e.g., joystick-based rate control), telepresence, or immersive virtual reality. The primary objective is to enable more effective and efficient interaction with semi-autonomous telerobots. (TA04 roadmap technical area 4.4).

- Mobile robot navigation (localization, hazard detection and avoidance, etc) for operations in man-made and unstructured environments. 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 advanced on-board software. (TA04 roadmap technical areas 4.1 and 4.2).

- Robot software architecture that radically reduces operator workload for remotely operating planetary rovers. This includes frameworks for adjustable autonomy, on-board health management and prognostics, automated data triage, and high-performance robot middleware. The primary objective is to facilitate the creation, extensibility and maintenance of complex robot systems. (TA04 roadmap technical area 4.5).

T4.02 Dynamic Servoelastic (DSE) Network Control, Modeling, and Optimization

Lead Center: AFRC
Participating Center(s): ARC, 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-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.

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.

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.

T4.03 Extreme Particle Flow Physics Simulation Capability
Lead Center: KSC

Advanced computer modeling software is sought to provide the ability to predict the flow of granular materials in space and/or planetary environments. Proposals are sought for software capable of handling one of more of the following applications in one or more relevant environments for space exploration:

- Rovers driving on planetary regolith.
- Rocket engines blowing planetary regolith.
- Excavators and resource extraction systems moving and conveying planetary regolith.
- Technologies that burrow or drill into planets and asteroids for scientific access.
- Transport of granulated metal hydrides as hydrogen fuel systems.
- 3-D printing technologies that use powders in space manufacturing.

The relevant environments, or "extreme environments," are the environments encountered in space exploration but not normally encountered in terrestrial industry. These may include supersonic gas flow, rarefied atmospheres, low gravity, or zero gravity, where we have less terrestrial experience in the behaviors of granular flow.

This modeling capability will be useful as part of the engineering design and checkout process for aerospace systems, notably the technologies that will interact with planetary soil. The technologies that are sought are different than prior state-of-the-art (SOA) in granular modeling insofar as prior SOA often utilized ad hoc algorithms, empirical relationships, and "rules of thumb" to estimate granular behavior, and relied on "tweaking" model parameters until the modeling approximated experimental data over a limited range of application. (Granular flow is challenging due to meso-scale granularity that produces a bewildering array of emergent, macro-scale phenomena.) Prior SOA was therefore not truly predictive and therefore of limited power, but it was useful for modest extrapolation around a range of behaviors that has been previously validated by experiment. In contrast, advances in granular physics theory over the past 5 years are surprisingly far ahead of expectations and it is now possible to develop new modeling methods that are truly predictive for the previously unpredictable regimes of solid-like, fluid-like and gas-like flow of granular materials integrated with gas flow and mechanical devices, including extreme environments (rarefied/supersonic flow, planetary surfaces, etc.). While it is still too early to expect a software package to be capable of modeling all granular phenomena across all ranges of behavior and all environments, it is now possible to create software packages capable of handling one or more of the areas that are important to NASA and necessary for NASA's mission.

Relevant advances in granular physics that may be incorporated into the new software may include (but are not limited to):
- Granular gas theory equivalent to Boltzmann's Transport Equation.
- Application of granular gas theory to continuous particle size distribution to predict transport coefficients.
- Successful prediction of dense flow as a function of particle shape.
- A useful technology will be one that can be applied in the real-world engineering design process for the design and checkout of NASA spaceflight technologies.

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 Navigation in GNSS-Denied Environments**

*Lead Center: LaRC*

*Participating Center(s): KSC*

Current NASA research/development and mission capabilities for exploration of remote planetary surfaces and UASs are primarily focused on automated telerobotic systems dependent on human control. More fully autonomous systems will be required for future missions, particularly where communications with Earth may be limited, unavailable for extended periods of time and have significant delays.

This subtopic is to investigate the autonomous navigation capabilities required for land and possibly aerial vehicle operation in areas lacking GNSS and/or magnetic compass to expanded exploration roles within planetary environments. A specific area of interest is to investigate biologically inspired algorithms and capabilities, such as techniques used by insects, such as Honey Bees, to accomplish this goal. Optical flow, image motion across the field of vision, offers unique capabilities for hazard detection and avoidance, landmark navigation, distance judgment, cave navigation, speed regulation, and visual odometry. Current technology is very computationally intensive. It is desired that with hardware support, high speed optic flow measurements can be obtained to speed up and simplify the extraction of motion information from the visual scene, which would both enhance obstacle and hazard detection and avoidance, as well as speed up the navigation process. This will be very critical if VTOL flight can be achieved, as a fuel-limited, in-motion VTOL vehicle is ill positioned to wait for a complicated and time consuming image analysis to be accomplished. Additionally, current laser scanner/imaging technology used for generating terrestrial 3-D maps have mass and power requirements that are excessive for smaller planetary robotic exploration systems. Low mass, low power 3-D mapping systems accommodated on planetary missions could be employed to support autonomous vehicle navigation and maneuvering operations. One example would be a parent vehicle that could launch multiple smaller vehicles that would autonomously explore larger regions and then
navigate back to the parent vehicle to transmit data and refuel. In addition to navigation, these vehicles could
gather detailed, photorealistic 3-D maps that can be fused with associated science data and used by scientists,
students, and the general public for “participatory exploration” activities.

Initial activities would include an assessment of current technology capabilities that could be compared to
requirements to identify technology gaps and lay out a technology development roadmap. Subsequent activities
would include component and system developments in accordance with the roadmap, leading to the development
of a prototype system capable autonomous navigation in environments that do not allow GNSS or magnetic
compass navigation and have limited or no communication between vehicles.

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 Synthetic Biology and Food Production Technologies for Space Exploration

Lead Center: ARC

Participating Center(s): JSC, KSC

Space Synthetic Biology: Synthetic Biology (SB) provides a unique opportunity to design 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 spaceflight and future surface missions in a variety of enabling
areas. Of particular interest is the use of SB, including bioelectrical systems/organisms and technologies, that will
reduce the required up-mass and dependence on consumables, resupply, and energy. This may be done through
in situ resource utilization (ISRU) and/or the development of more sustainable and efficient systems. Specifically,
ISRU technologies should address how SB-based systems may use in situ resources (e.g., regolith, CO₂) to
fabricate advanced materials and/or produce building materials, fuels and plastics. SB-based food production is
another area of interest. SB based Environmental Control and Life Support Systems (ECLSS) should focus on
increasing efficiency/reliability/regenerability of air, water and waste management. Prototype hardware to support
SB-based systems and modified cell lines - (particularly BES) with potential application for ISRU, ECLSS and food
production would all be of interest to NASA. A prototype DNA "writer" technology for transmitting new DNA
sequences to SB systems would be considered an enabling technology.

Food Production Technologies for Space Exploration: NASA is interested in food production and related food
safety technologies for both near term transit (μ-gravity) missions and eventual surface missions (fractional gravity). Of special interest is the use of plants (e.g., crops) to photosynthetically produce food, and contribute to cabin O₂ production and CO₂ removal. Food production technologies should address how quantum and/or radiation use efficiency will be improved to reduce energy costs, including advanced lighting concepts. Improved concepts for gravity independent watering techniques will also be needed. Complementary approaches might consider selecting or adapting the plants for optimal performance for the constraints of space environments, which could include smaller growing volumes, micro to fractional g, elevated radiation, super-elevated CO₂ concentrations (e.g., >5000 ppm or 0.5 kPa), and narrow band light spectra. Related technologies for sanitizing or reducing the microbial loads to reduce the safety risks of preparing and consuming space grown foods are also needed. All systems should consider minimizing power, mass, consumables, and biologically produced waste, while maximizing reliability and efficiency.

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, and in situ instruments/sensors.

Sub Topics:

**T8.01 Innovative Subsystems for Small Satellite Applications**

*Lead Center:* GSFC  
*Participating Center(s):* ARC

This STTR solicitation is to help provide advanced technologies for satellites with masses less than approximately 20 kg and volumes less than approximately 10,000 cm³. Components or subsystems are sought that demonstrate a capability that is applicable to orbital missions to 800 km and mission durations up to 2 years. New approaches, subsystems, and components are sought that will:

- Substantially reduce the resources (cost, mass, volume, or power).
- Provide satellite bus capabilities that increase the capabilities of very small satellites while meeting the significant constraints imposed by the very limited size and mass of the observatory.

Components and subsystems are required that consider the severe mass, volume, and power constraints imposed by very small spacecraft.
T8.02 Technologies for Planetary Compositional Analysis and Mapping

Lead Center: JPL

This subtopic addresses the need for low mass, low power technologies that support orbital and in situ compositional analysis and mapping. The focus is on developing and demonstrating technologies that can be proposed to future planetary missions. Technologies that can increase instrument resolution, precision and sensitivity, or achieve new & innovative scientific measurements, are solicited. Two areas are of particular interest: micro-scale analysis and mapping of the mineralogy, organic compounds, chemistry and elemental composition of planetary materials, related to rock fabrics and textures; and remote mapping of geologic outcrops and features. Such technologies are particularly relevant for future landed missions to the Moon, comets, asteroids, Mars, Europa, Titan, and other planetary bodies. 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.

- Advantages of the proposed technology compared to the competition.

- Relevance of the technology to NASA's planetary exploration science goals.
T8.03 Science Instruments for Small Missions (SISM)

Lead Center: ARC

Advancements in supporting spacecraft technologies are making small spacecraft more and more capable. Features such as extensive computing power, attitude determination and control systems, and even propulsion are allowing mission designers to consider small and very small spacecraft to perform operational and scientific investigations. However, one area that is lagging is the miniaturization of instrument systems that would be compatible with this new class of small spacecraft. Until science instruments can be downsized in order for them to be accommodated on small spacecraft, the utility of cubesats, nanosats, and mini-spacecraft platforms will be limited.

To stimulate and create scientific instrument technologies that are compatible with small spacecraft, this subtopic seeks to identify, develop, and prepare for flight demonstration, scientific instruments compatible with one or more of the small spacecraft platforms described at the end of this solicitation. Science applications may be in Astrophysics, Earth Science, Heliophysics, Planetary Science, or Astrobiology.

Examples for proposals sought include, but are not limited to:

Astrophysics:

- **Need** - Ability to view diffuse / dispersed / low-intensity astrophysical phenomena requiring zero light background without high spatial resolution; good for full-sky mapping applications.

- **Instrument** - Multiband / hyperspectral imaging compact telescope

- **Measurement** - ERE emission from bright ionized (HII) regions, e.g., Orion Bar ionization edge, and correlation of ERE and PAH emissions from any orbit with at least multi-month lifetime.

- **Impact** - Understanding of astrophysical phenomena, esp. those relevant to carbon sources. Such measurement will demonstrate the science capability on small spacecraft.

Earth Science:

- **Need** - Mapping terrestrial phenomena with multiple low-cost imagers for short-revisit period capability.

- **Instrument** - Hyperspectral Earth imager (including constellations of multiple imagers)

- **Measurement** - Ocean color due to algal blooms and other natural phenomena, or anthropogenic impact due to deforestation, CO₂ emissions, etc. Such measurements may require spectral mapping of large areas with short re-map period. Demonstration may be from a sun synchronous low earth orbit.
• **Impact** - Better tracking / understanding of algal blooms sources, CO₂ sources, etc. Such measurement will demonstrate science capability on small spacecraft.

**Earth Science:**

• **Need** - Long-path atmospheric analysis (using sun as light source)

• **Instrument** - Compact (FT)IR spectrometer w/ telescope

• **Measurement** - Assess highly dilute inorganics or organics in upper atmosphere due to pollution or meteoritic infall, from Low Earth Orbit.

• **Impact** - Improved understanding of pollutant dynamic mobility/ degradation and/or cosmic organic sources. Such measurement will demonstrate science capability on small spacecraft.

**Planetary Science:**

• **Need** -
  - Evaluating the reactivity / habitability of extraterrestrial surfaces.
  - On orbit analysis of materials exposed to the space environment.

• **Instrument** - Compact XPS (X-ray photoelectron spectrometer) for surface chemistry analysis - moon, Mars, NEOs, beyond.

• **Measurement** - Characterization of regolith chemical reactivity: quantify reactive inorganic ions & radicals incl. oxyhalides, peroxides, superoxides, odd-O/odd-H species; regolith organic alteration products. Subsurface measurement of supports for and threats to life: energy sources; possible toxic & reactive compounds; soluble anions/cations & dissolved gases.

• **Impact** - Buy down of long term risk. Demonstrating on-orbit material analysis capability, for technology that will be deployed on landers or rovers, will lead to better understanding of surface conditions that impact survival of organics, biomarkers, and life.

**Planetary Science:**

• **Need** -
  - Investigating the Reactivity / habitability / evolution of extraterrestrial surfaces.
  - On orbit analysis of materials exposed to the space environment.

• **Instrument** - Compact SIMS (secondary ion mass spectrometer) or LDMS (laser desorption mass spec) for surface mass & chemistry analysis - moon, Mars, NEOs, beyond.

• **Measurement** - Characterization of regolith chemical reactivity: quantify reactive inorganic ions & radicals incl. oxyhalides, peroxides, superoxides, odd-O/odd-H species; regolith organic alteration products. Subsurface measurement of supports for and threats to life: energy sources; possible toxic & reactive
compounds; soluble anions/cations& dissolved gases.

- **Impact** - Buy down of long term risk. Demonstrating on-orbit material analysis capability, for technology that will be deployed on landers or rovers, will lead to better understanding of surface conditions that impact survival of organics, biomarkers, and life.

Astrobiology:

- **Need** - Evaluate rates and nature of mutations caused by the space environment.

- **Instrument** - Miniaturized DNA sequencer to study mutations

- **Measurement** - Cultures of cells or small organisms supported in space radiation environment for months: evaluate genetic profile after 1000's of generations Location would be High Earth Orbit, geo-syn, or various libration points.

- **Impact** - Understand how mutation can play a role in rapid evolution in response to radiation stressors. Miniaturization and demonstration on a small spacecraft mission may eventually lead to a compact sequencer for personalized medicine.

Proposals are sought that significantly advance state of the art for scientific measurements. Proposals for science instruments that represent only incremental improvements in the state-of-the-art capabilities, or are of interest to relatively few users are not appropriate for this solicitation. Proposed concepts should show a relevance to external customers or stakeholders needs.

Proposer shall describe the proposed design, development, analysis, testing and evaluation needed for the technology; and outline a concept of operations for demonstration of the technology on a small mission platform. How the proposed technology is differentiated from currently available technologies must be clearly communicated.

Phase I contracts will be expected to demonstrate feasibility, and Phase II contracts will be expected to fabricate and complete ground testing on an actual instrument/test article for potential demonstration on a small mission.

**Small Spacecraft Platforms**

**Cubesats** - Cubesats are usually 10 x 10 x 10 cm (for a 1U) or 10 x 10 x 30 cm (for a 3U) nanosatellites. Other sizes are also in development, such as a 6U. Cubesats are typically launched as auxiliary spacecraft. Multiple cubesats may also be launched simultaneously in order to create constellations and other useful space architectures.

Specifications and standards for cubesats may be found at [http://www.cubesat.org/](http://www.cubesat.org/).

**University Nanosats** - University Nanosats are typically 50 x 50 x 60 cm and weigh less than 50 kg. They are also auxiliary spacecraft launched with other spacecraft on rideshare missions, typically using 15” or 8” Lightband

The Air Force Research Lab has sponsored the development of these spacecraft via the University Nanosat Program (see http://prs.afrl.kirtland.af.mil/UNP/ [5]).

**Technology Demonstration Spacecraft** - A larger spacecraft platform for the demonstration of a number of instrument payloads was illustrated by the recent NASA/MSFC FASTSAT mission. FASTSAT is an ESPA-class spacecraft, deployed via a 15” Lightbanddeployer, and is designed to accommodate a number of independent instrument systems. FASTSAT provides basic power, data/communications, and thermal management support for these payloads as part of an integrated space flight demonstration mission.

Entry, Descent and Landing Systems Topic T9

Entry, Descent, and Landing, consists of four sub-technology areas:

- Aeroassist and entry.
- Descent.
- Landing.
- Vehicle systems technology.

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 Technologies for Aerospace Experimental Capabilities**

**Lead Center:** AFRC

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

The emphasis of this subtopic is proving feasibility, developing, and demonstrating technologies for advanced
Aerospace research experimentation that matures new methodologies, technologies, and concepts. It seeks advancements that promise significant gains in NASA’s experimental research capabilities or addresses barriers to measurements, operations, safety, and cost in all flight regimes from low sub-sonic to high supersonic to space. This subtopic solicits innovative technologies that enhance experimental research competencies by advancing capabilities for ground and in-flight experimentation. Proposals that demonstrate and confirm reliable application of concepts and technologies suitable for flight research and the test environment are a high priority.

Measurement techniques are needed to acquire aerodynamic, structural, flight control, and propulsion system performance characteristics to safely expand the flight envelope of aerospace vehicles. Spacecraft guidance, navigation and Control validation techniques are needed. The goals are to improve the effectiveness of flight-testing by simplifying and minimizing sensor installation, measuring parameters in novel ways, improving the quality of measurements, and minimizing the disturbance to the measured parameter from the sensor presence. Sensors and systems are required to have fast response, low volume, minimal intrusion, and high accuracy and reliability. Special areas of interest include:

- Testing and Validation for Lightweight structures and materials.
- Methods and associated technologies for conducting flight research and acquiring test information in flight.
- Numerical methods for the planning, prediction, analysis and validation of flight-test experimentation.
- Sensors and data systems that have fast response, low volume, minimal intrusion, and increased accuracy and reliability.
- Innovative techniques that decrease turn-around time for inspections and assessments for safe operations of aircraft and spacecraft (e.g., non destructive examination of composites through ultrasonic techniques).
- Advanced design and manufacturing techniques for improved upper stage performance for nano- & small-satellite booster technologies (e.g., manufacturability, affordability, and performance of a small upper-stage booster rocket motors for small & nano-satellites).
- Aerodynamic boundary layer and laminar flow control and drag reduction.
- Precision landing systems.
- Autonomous, fault-tolerant GN&C.
- Autonomous Rendezvous and Docking.

Nanotechnology Topic T10

Nanotechnology, addresses four subareas: engineered materials and structures, energy generation and storage, propulsion, and sensors, electronics, and devices. Nanotechnology describes the manipulation of matter and forces at the atomic and molecular levels and includes materials or devices that possess at least one dimension within a size range of 1-100nm. At this scale, quantum mechanical forces become important in that the properties of nano-
sized materials or devices can be substantially different than the properties of the same material at the macro scale. Nanotechnology can provide great enhancement in properties, and materials engineered at the nano-scale will shift the paradigm in space exploration, sensors, propulsion, and overall systems design.

Sub Topics:

**T10.01 Innovative Refractory Materials for Rocket Propulsion Testing**

**Lead Center:** SSC  
**Participating Center(s):** KSC

NASA has identified the advancement of materials as a critical technological need in supporting future space flight and rocket test operations. Specifically, innovative materials for thermal management applications have been targeted with the additional goal of furthering nanotechnology. With the development of these new multi-functional, high-temperature materials comes the requirement for verification and validation of the predictability of their thermal behavior.

The current subtopic is to develop innovative refractory materials which use nano-particle additives and/or unconventional non-cement based refractories that can withstand the extreme plume heating environments experienced during rocket propulsion testing. The material should provide a revolutionary improvement over conventional castable refractories. Explicitly, the nano-based or multi-functional material should provide substantial improvements in several of the following areas:

- Compressive and flexural strength.
- Thermal, abrasion and corrosion resistance.
- Operating temperatures at or above 4000 °F.
- Excellent workability for potential lining of vertical walls/pipes.
- Ultra-low porosity.

Demonstration of the performance of these materials in environments similar to rocket plume environments will be a critical aspect of the success and usefulness of the proposed technology. In addition, verification and validation of the predictability of the material behavior during ablative heating is of high importance to the mission of NASA.

Other potential applications of nano-particle/multi-functional refractory materials might be use in expendable (or even reusable) rocket engine thrust chambers, control system thrusters, and nozzles to extend the life of the testing infrastructure and components. These engine components could be for launch or in-space propulsion systems. This application would add a requirement to be light weight and provide manufacturability for use in coatings or production of components.
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 Software Framework & Infrastructure Development of Spaceborne Hybrid Multicore/FPGA Architectures

Lead Center: GSFC
Participating Center(s): ARC, JPL, KSC

Future high-performance on board computing systems will likely employ hybrid architectures consisting of both advanced multi-core processors and reconfigurable Field Programmable Gate Arrays (FPGAs), which may include additional embedded hard and/or soft core processors along with processing functions implemented in the FPGA logic. Advanced software architectures, software infrastructure elements and software design tools are needed to compliment these advanced hardware platforms and enable their efficient/effective use. The intent of this subtopic is to develop these software architectures, infrastructure elements and tools.

Desired technologies include multi-core software frameworks, multi-core operating system components, hardware/software abstraction layers & interfaces, and development systems/tools/simulators. Additionally, middleware/hypervisors are needed that can perform memory protection and run-time allocation of tasks to processing resources, and address performance optimization, energy management, and fault mitigation.

T11.02 Distributed Simulation for Design and Manufacturing

Lead Center: KSC

NASA is embarking on missions to new environments with new technologies and new systems to take us far beyond where any human has gone before.

Understanding, managing and leveraging the associated complexity will require new tools, new methods, new ways of managing data and, in the long run, entirely new types of data as well. Simulation plays a key role in each of these areas with advanced tools and processes already in use to define architectures, study options and integrate alternatives into the overarching plan. However, today's tools, and even tomorrow's tools, lack the ability to integrate and share information on the physical and temporal scale necessary to efficiently and effectively enable these systems.

Desired product is a prototype suite of tools, systems and processes to allow researchers, innovators and
operational organizations to share simulation based needs, technologies, concepts and opportunities over large distances (planets) and large increments of time (decades). The system should utilize existing Industry and NASA standards and interfaces for simulation data, suggest new ones, or both. Emphasis should be placed on interfaces like XML to both extend the lifecycle of data elements into the 50 year range as well as interface with the emerging set of NASA tools.

Distributed Simulation of this nature has been identified by the National Research Council as one of the 83 high priority technologies for NASA as a part of the OCT roadmap team efforts. It is a part of TA 11 (modeling, simulation, information technology and processing) and is one of the 4 high priority technologies identified for that roadmap. It directly supports any complex design and development efforts directly and supports technology push and pull by better communicating programmatic needs and technology solutions in relevant operational environments.

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 High Temperature Materials and Sensors for Propulsion Systems

Lead Center: GRC

Advanced high temperature materials and sensors are crosscutting technologies which can be used in component and subsystem applications essential in the design, development and health maintenance/detection needs of future generations of aeronautical and space propulsion systems. Proposals are sought that address:

- Advanced high temperature materials technologies, both design and development, needed to meet application challenges associated with propulsion systems. Proposals must be linked to improvements in future performance indicators, such as vehicle weight, fuel consumption, noise, lift, drag, durability, and emissions for aircraft, and/or reduced mass components and thermal management properties to meet space vehicle propulsion needs. Technology interests include:
  - Innovative approaches to enhance the durability, processability, performance and reliability of advanced materials (super alloys, high strength fibers and environmental barrier coatings for ceramic matrix composites with temperature capability greater than 2700 °F, and corrosion/oxidation resistant coatings for turbine disk materials operating at temperatures in excess
of 1400 °F, innovative joining methodologies for bonding powder metallurgy disk material to
directionally solidified/single crystal rim alloy for a hybrid disk);

- High temperature shape memory alloys and methods to integrate these materials into propulsion
  system structures for changing component shape and actuation devices;

- High temperature magnets with greater than 500 °F capability;

- Multifunctional high temperature materials, combining structural properties with a second capability,
such as power harvesting, thermal management, self-sensing, and materials for wireless sensing
  and actuation;

- Environmentally-friendly manufacturing processes for high temperature polymer materials with
temperature capability 500 °F or higher.

- Innovative smart sensing methods and associated measurement techniques for the cost-effective, reliable
  assessment of the health of aerospace engine and vehicle components in harsh high-temperature
  environments (1900 °F - 3000 °F) allowing a proactive approach to maintain capability and safety. Engine
  and vehicle structures ground and flight testing applications can lead to thermal and other environmental
  conditions beyond the limits of current sensing technology. Sensors and systems are required to have fast
  response, low volume and weight, be minimally intrusive and possess high accuracy and reliability. Special
  areas of interest include:

  - Development and validation of innovative sensors and improved methods for attaching to advanced
    high-temperature materials and integrating sensors into systems (wireless, wired or fiber optic).

  - Approaches to measure strain, temperature, heat flux, deflection, acoustics and/or acceleration of
    structural components are sought.

  - Compact, non-contact, full-field sensing systems for structural information.

  - Nanotechnology offers a means to: a. develop higher-temperature/environmentally-resistant
    structural materials with engineered micro structures that can optimize material properties for
    propulsion hot section components; b. enables tailoring the thermal conductivity of materials,
    making them more efficient conductors or insulators; c. permits targeted sensor applications that
    can improve functional efficiency; d. supports developing nano-sensors that may be incorporated in
    hot section structures/systems that are smaller, more energy efficient and potentially providing more
    sensitive health assessments capability.

  - Design Methods/Tools, which are robust and efficient, to design advanced materials based on first
    principles and micro structural models that can be used in a multi-scale framework.

Proposed Deliverable to NASA: Advanced high temperature materials, high strength fibers, protective coatings;
new sensors, attachment techniques, beta versions of sensor systems; and new computational models.

What would be the major implication of not having this subtopic? High temperature materials technologies are
required to meet the flight vehicle hot surface needs and to enable development of the advanced aerospace
propulsion systems necessary to the NASA mission success. Industry looks to NASA to provide these technologies
and capabilities to help them meet/exceed the National goals - environmental regulations, contributing to green
energy and meeting and customer performance requirements. Novel sensor systems are critical to moving the
technology from the laboratory environment to ground test activities and flight vehicle applications.
NASA Relevance: High temperature materials and advanced sensors were each highlighted as high priority needs in both the National Aeronautics Plan for Aeronautics Research and the National Research Council's report, NASA Space Technology Roadmaps and Priorities, documents.

Aeronautics:

- Mobility R&D Goal 5 Far-term Objective 3
- National Security and Homeland Defense R&D Goal 3 Far-term Objective 1 and Goal 4 Far-term Objective 2
- Aviation Safety Goal 1 Far-term Objectives 1 and 3
- Energy and Environment R&D Goal 2 Far-term Objective 2, 3 and 4

Space:

- Reduce vehicle mass and/or improve thermal management performance by employing nanotechnologies to develop lighter-weight multifunctional materials/ (structures) and sensors with unique capabilities and better performing.
- Structural health monitoring/sensors for long duration missions/responsive on-board systems:
  - Reduced propulsion structure mass.
  - Computational modeling design/analysis/simulation methods for materials certification/reliability.

Center relevance, i.e., project, program and mission:

- ARMD Programs.
- OCT.
- Space Exploration Mission Directorate.

List any commercialization plans or possible mission opportunities for technologies: Upcoming ARMD and reimbursable testing activities

Other potential government funding or applications:

- ARMD Seedling.
- Fundamental Aeronautics at higher TRL.
Identify OCT Mission Directorate and/or Field Center advocate(s) committed to support development through a Phase III award:

- Leslie A. Greenbauer-Seng (GRC/Deputy Structures and Materials Division).
- Tim Risch (DRFC/Deputy Chief Aerostructures Branch).

### T12.02 Materials and Manufacturing Technologies

**Lead Center:** MSFC  
**Participating Center(s):** GRC, JSC, LaRC

NASA’s science and exploration missions continue to seek materials and manufacturing techniques and capabilities that will allow missions of increased capability and reduced costs. These future missions depend highly on advancements such as lighter and stronger materials and manufacturing methods. Materials and manufacturing technologies have high value and make a significant contribution to the interests of others outside of NASA, specifically those that address broader national needs as well as the needs of the commercial space industry. The portfolio of advanced materials and manufacturing technologies is extremely broad and cross-cutting with complex interactions between core disciplines (e.g., materials and structures), applied R&D, innovation, and production.

In reference to the recent report from the National Research Council on the Space Technology Roadmaps produced by NASA’s Office of Chief Technologist, the report ranks lightweight and Multifunctional Materials and Structures as an area of high priority development to be emphasized over the next 5 years. This topic seeks technologies that support these needs:

- Lightweight and multifunctional materials concepts including, advanced composite, metallic, and ceramic materials that significantly enhance future exploration and science missions and enable new missions.
- Digital/Model-based Manufacturing technologies that enable cost-effective manufacturing for reliable high-performance structures and made in low-unit production, including in-space manufacturing.
- In-space and additive manufacturing that offers the potential for game-changing weight savings and new mission opportunities.

University researchers are well-positioned to make a positive contribution within the time and funding allocation vis-à-vis a concept demonstration, enhancement of an existing component through a clever innovation, working
Ground and Launch Systems Processing Topic T13

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 Risk Engineering, Sciences, Computation, and Informed Decisions

Lead Center: JSC

Participating Center(s): KSC

Human spaceflight missions in the early twenty-first century are still inherently complex and risky. While it takes a very talented and courageous flight crew to achieve a mission's objectives, it takes many more people on the ground to plan, prepare, and support the flight crew during the mission to ensure the safety of the crew and the success of the mission. For every human spaceflight mission, many decisions are made before each mission and more decisions are made during the mission in responding to changes in the environments or space vehicle systems. As in many other complex operations in harsh environments on Earth, labor-intensive information research and analyses is necessary to weigh the benefits versus the risks of each alternative in order to make accurate risk-informed decisions. Often these decisions need to be made in a short period of time before space vehicle systems are out of consumables or the risk of continuing the mission becomes unacceptable. Sometimes a decision that reduces risk in one limited perspective or frame of reference inadvertently increases system-level or end-to-end mission risk due to impacts that were not foreseen due to limited human ability to consider and assess all relevant data.

This STTR subtopic seeks to advance the state-of-the-art in knowledge management, information management, information technology, and artificial intelligence leading toward the ability for computer systems to assist humans in timely and correctly identifying, quantifying, characterizing, mitigating, and communicating risks to inform decision makers of risks before the decisions are made. Application of advanced computer-based decision support technologies to identify and assess relevant data, identify alternatives, and model consequences will significantly reduce the cost of development, deployment, and sustainment of complex space systems and significantly increase safety of crew during space missions. Below are some examples of technologies that would be appropriate for this sub-topic:
Timely Risk Identification - For several decades, the Failure Modes and Effects Analysis has been used to identify risks inherent in space system designs. Analysis results are frequently not available until the system design has matured to the point where it is ready for final development, test, and or deployment. Changes late in the design lifecycle often cannot be accommodated due to significant schedule delay and cost increase. Although designing out hazards is the most effective and preferred means of control, mitigations for identified risks at this time are usually limited to procedural controls which require recurring attention throughout the operational phase. This often results in operational complexity, higher risk, and higher sustaining cost. An automated failure modes and effects simulation technology would be a game-changer by identifying safety and technical risks of the design early and quickly so that design changes or trades may be made to eliminate these risks at a much lower lifecycle cost and significantly improve safety and system reliability.

Risk-Informed Decision Making - As space systems become more complex and human space exploration destinations get farther away from Earth, the flight crew may be forced to make timely decisions in responding to imminent hazardous conditions without the assistance of the ground crew. Risk-informed decision support technologies would assist the flight crew by suggesting possible actions that have the highest probability of success.

Context-Based Software Risk Modeling - Space system designers are considering incorporating or increasing levels of automation in their systems to achieve a sustainable human space exploration program. Although the desired outcome is a net reduction of overall mission risk, more automation will result in increasing the complexity of the software systems, and thus increase the proportion of risk attributable to software faults as a component of system risk. NASA is seeking Context-Based Software Risk Model technologies to address the risks of software required functionality that would be compatible and consistent with the standard Probabilistic Risk Assessment methodology now employed by NASA. An effective integration of the PRA and CSRM techniques would facilitate comparative evaluations of automation design options for effectiveness in reducing mission risks.

Cross-cutting 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.
• 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 Cross cutting Avionics for Beyond Earth Orbit Space Exploration

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

As NASA human exploration and science missions move further from Earth and become increasingly more complex, they present unique challenges to the on-board avionics systems. Avionics systems in space vehicles are significant size, weight and power (SWaP) as well as cost drivers. Future destinations such as L2, near-earth asteroid, Mars, etc. are characterized by long durations, vast distances and harsh environments and call for significant advances in on-board processing, autonomy, reliability, fault-tolerance and redundancy. Advanced technologies and approaches to avionics systems and its components are needed to support these challenging mission requirements and to safely bring crew back to Earth.

Avionics provides cross- capabilities across different sub-systems and is a prime candidate for commonality between different missions and programs leading to savings in the design, development and testing, logistics (sparing, reuse, and re-purposing of hardware) and operational costs.

To support exploration mission objectives and requirements, advances in emerging avionics technologies (processors, networks and network devices, memory cards, human interfaces including visual, tactile and auditory interfaces, etc.) and associated foundational technology are required. Areas addressing miniaturization, radiation and extreme temperature environments such as radiation hardened by design, Rad-hard extreme temperature technology, and electronics packaging, etc. are of particular interest.

The focus of this subtopic is to support the development and advancement of cost-effective avionics technologies while keeping a unified approach to promote commonality of systems between multiple missions and/or programs. The ultimate goal is to develop a common avionics framework and a catalog of components that can be integrated into a space vehicle in the next 6-10 years.

T15.02 Autonomous Systems for Atmospheric Flight

Lead Center: LaRC
Participating Center(s): KSC

With increasing levels of automation capabilities in the aviation arena, provides unique opportunities and
challenges for civil aviation, and the aerial transport communities. Flight will be transformed as these capabilities mature and evolve in to integrated systems. In particular, autonomous and robotic, manned and unmanned civil aircraft systems will lead to a plethora of new markets, vehicle, and missions. These new systems with broad range of capabilities, and a huge diversity of shapes and sizes, must safely utilize the future National Airspace System. Both operational and machine autonomy will require tremendous breakthroughs through the new technology frontiers in machine intelligence, autonomy, robotics, and inter-connections of these technologies. Breakthroughs in these areas could lead to such societal capabilities as autonomous cargo carrying, surveillance, air taxis, small unmanned civil aircraft, Zip aircraft, on-demand VTOL aviation, airborne wind energy platforms and a host of other emerging distributed aviation systems.

The goal of this topic area is to develop technologies and capabilities that will lead to fully autonomous systems that are able to learn and adapt to changes in their environment that were not predicted, and yet still accomplish the mission goals, with minimal or no human involvement required.

For purposes of this solicitation, autonomous vehicles have varying levels of autonomy and range from automated capability to fully autonomous flight where the system has the ability to learn, reason, and adapt. Military applications have demonstrated the ability to do automated flight but their use in civil aviation requires additional research and development. The primary interest of this sub-topic is to advance the technologies for robotic and autonomous vehicle perception, cognition, as well as system integration. Proposals should be written around one of the following themes described below:

- **Autonomous or robotic pilot** - Autonomous systems can be applied far beyond remotely piloted aircraft. Maximum machine effectiveness can only be realized through vehicle autonomous systems ability to learn, reason and adapt. Current practice is to have a reliance on stored information, which is complemented by GPS position information. If there is an on-board, real-time means to sense and react to the local environment (including air and ground features and traffic), then autonomous and robotic air-vehicle can be fully utilized. But addressing how adaptive systems can still be ‘trusted’ in critical flight environments and achieve FAA certification is a technical issue that must be resolved. Proposals are sought to develop innovate approaches and enabling technologies for autonomous, robotic, and embodied intelligent air-vehicles. Example scenarios could include but are not limited to carrying passengers and cargo through the NAS, search, rescue, and surveillance operations, and sentries to patrol coastal waters, and land borders. Proposal should consider perception, cognition, as well as GPS enabled, GPS-denied, and cooperating and non-cooperating traffic environments.

- **Autonomy for flight, the robotic test pilot.** Adaptive and robust controllers designed to autonomously fly and optimize around multiple vehicles. Products would be aerodynamic coefficients such as coefficient of lift and drag as well as controller effectiveness.

- **Autonomous intelligence, surveillance and reconnaissance.** A next generation system would entail a "smart payload" with a UAS designed around it to accomplish specific missions. Example missions might include, but are not limited to disaster relief, fire monitoring, launch vehicle tracking, or hurricane tracking. The payload would ultimately permit autonomous target acquisition, tracking, and aircraft attitude/orientation to optimize data collection, or ensuring mission completion. Initial activities would include an assessment of current technology capabilities that could be compared to requirements for a next generation autonomously controlled sensor and platform system to identify technology gaps and lay out a technology development road map. Subsequent activities would include component and system developments and integration in accordance with the road map, leading to the development of a prototype system capable of integrating with a UAS.
Launch Vehicle Propulsion Technologies Topic T1.01

Heavy lift launch vehicles envisioned for exploration beyond low Earth orbit (LEO) will require large first stage propulsion systems. For some heavy lift vehicles, the total thrust produced at lift-off will exceed 6 million pounds. There are currently available practical propulsion options for such a vehicle. However, the cost for outfitting the booster with the required propulsion systems is in the hundreds of millions of dollars. This cost severely limits what missions NASA can perform. Low cost design concepts and manufacturing techniques are needed to make future exploration affordable. This topic seeks technologies that will fulfill the following objectives:

- Development of propulsion concepts whose cost is less than 50% of currently available but with similar performance.
- Development and demonstration of low-cost manufacturing techniques.
- Techniques for evaluating and analyzing low-cost, easily manufacturable design concepts.

Example technologies of interest include:

- Ablative materials and manufacturing techniques.
- Innovative chamber cooling concepts that reduce manufacturing complexity without reducing performance.
- Low-cost nozzle materials, manufacturing techniques, and coatings.
- Ignition concepts that require low part count and/or low energy to be used as either primary or redundant ignition sources.
- Manufacturing techniques that lower the cost of manufacturing complex components such as injectors and coolant channels. Examples include, but are not limited to, development and demonstration of rapid prototype techniques for metallic parts, powder metallurgy techniques, and application of nano-technology for manufacturing of near net shape manufacturing.
- Increased efficiency and fidelity analysis tools.

The development of future propulsion systems for deep-space exploration are directly dependent on the development of technologies such as those listed. Furthermore, affordable, reliable access to space technology is a strong need across all of NASA's space exploration activities (HEOMD, OCT, SMD). While revolutionary advances in launch vehicle technologies are not foreseen to be developed in the immediate future, a practice of employing methodical continuous technology development in the direction of lowering the cost and improving the reliability of launch propulsion systems will addresses this critical need of lowering the cost of earth-to-orbit launch systems and capabilities.
Development of innovative technologies are sought that will result in durable, long-life, lightweight, high performance space power and in-space propulsion systems to substantially enhance or enable future missions.

Innovations in the form of advanced concepts, technology demonstrations and processes are sought for Space Power and Propulsion.

Space Power areas of particular interest include solar photovoltaic, nuclear power, power distribution and transmission, conversion and regulation, batteries and fuel cells. Solar photovoltaic cell, blanket, and array technologies are sought for improved efficiency, power density, specific power and mass, and application to NASA-unique environmental conditions (high radiation, extreme temperatures, varying light intensity, etc.). Nuclear power technologies that provide high efficiency, high specific power, and long life for deep space and planetary surface applications including radioisotope power generation for power levels between 100 watts and 1 kilowatt and fission power generation for power levels from kilowatts to megawatts. Battery technologies include novel battery chemistries that offer improvements in safety, volume and mass above and beyond those offered by Lithium-ion technology. Fuel cell (and electrolyzer) technologies include novel membrane materials and geometries and advanced concepts. Power management and distribution technologies include modular “smart” systems and advanced materials and component research and development.

In-Space Propulsion areas of particular interest include electric propulsion, micro-propulsion, nuclear thermal propulsion, and propellant storage and transfer, which were identified as the highest priority ISP technologies by the NRC’s “NASA Space Technology Roadmaps and Priorities.” Technologies for electric propulsion include high-power long-lived thrusters and low specific mass power processing systems. Micro-propulsion technologies include chemical or non-chemical systems for micro-satellites. Technologies for nuclear thermal propulsion include advanced high temperature fuel forms, innovative testing methods and non-nuclear subsystems. Propellant technologies include subsystems and components to enable long-duration storage in space and low-gravity liquid transfer.

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, novel energy
harvesting technologies are critical toward supporting future power generation systems to begin to meet these challenges. This subtopic addresses the potential for deriving power from waste engine heat, warm soil, liquids, kinetic motion, piezoelectric materials or other naturally occurring energy sources, etc. (re: TA-3; 2.2.1.1). Development of energy harvesting (both capture and conversion) technologies would also address the national need for novel new energy systems and alternatives to reduce energy consumption.

Areas of special focus for this subtopic include consideration of:

- Innovative technologies for the efficient capture and/or conversion of acoustic, kinetic, 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.
- Innovations in miniaturization and suitability for manufacturing of energy capture and conversion 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 to capture and convert. 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.

Sub Topics:
Information Technologies for Intelligent and Adaptive Space Robotics Topic T4.01
The objective of this subtopic is to develop information technologies that enable robots to better support space exploration. Robots are already at work in all of NASA's Mission Directorates and will be critical to the success of future exploration missions. The NASA "Robotics, Tele-Robotics, and Autonomous Systems" roadmap (TA04) indicates that extensive and pervasive use of robots can significantly enhance exploration, particularly for missions that are progressively longer, complex, and operate with fewer ground control resources.

Intelligent robots can do a variety of work to increase the productivity of planetary exploration. Robots can perform tasks that are highly-repetitive, long-duration, or tedious. Robots can perform tasks that help prepare for
subsequent human missions. Robots can perform "follow-up" work, completing tasks started by astronauts. Example robotic tasks include:

- Scouting.
- Site surveys.
- Sampling.
- Payload deployment.
- EVA close-out work.

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

- Advanced user interfaces for telerobotics, which facilitate distributed collaboration, geospatial data visualization, summarization and notification, and robot tasking. This does NOT include user interfaces for direct teloperation (e.g., joystick-based rate control), telepresence, or immersive virtual reality. The primary objective is to enable more effective and efficient interaction with semi-autonomous telerobots. (TA04 roadmap technical area 4.4).

- Mobile robot navigation (localization, hazard detection and avoidance, etc) for operations in man-made and unstructured environments. 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 advanced on-board software. (TA04 roadmap technical areas 4.1 and 4.2).

- Robot software architecture that radically reduces operator workload for remotely operating planetary rovers. This includes frameworks for adjustable autonomy, on-board health management and prognostics, automated data triage, and high-performance robot middleware. The primary objective is to facilitate the creation, extensibility and maintenance of complex robot systems. (TA04 roadmap technical area 4.5).

Sub Topics:
Dynamic Servoelastic (DSE) Network Control, Modeling, and Optimization Topic T4.02
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.

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.

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:
Extreme Particle Flow Physics Simulation Capability Topic T4.03
Advanced computer modeling software is sought to provide the ability to predict the flow of granular materials in space and/or planetary environments. Proposals are sought for software capable of handling one of more of the following applications in one or more relevant environments for space exploration:
- Rovers driving on planetary regolith.
- Rocket engines blowing planetary regolith.
- Excavators and resource extraction systems moving and conveying planetary regolith.
- Technologies that burrow or drill into planets and asteroids for scientific access.
- Transport of granulated metal hydrides as hydrogen fuel systems.
- 3-D printing technologies that use powders in space manufacturing.

The relevant environments, or "extreme environments," are the environments encountered in space exploration but not normally encountered in terrestrial industry. These may include supersonic gas flow, rarefied atmospheres, low gravity, or zero gravity, where we have less terrestrial experience in the behaviors of granular flow.

This modeling capability will be useful as part of the engineering design and checkout process for aerospace systems, notably the technologies that will interact with planetary soil. The technologies that are sought are different than prior state-of-the-art (SOA) in granular modeling insofar as prior SOA often utilized ad hoc algorithms, empirical relationships, and "rules of thumb" to estimate granular behavior, and relied on "tweaking" model parameters until the modeling approximated experimental data over a limited range of application. (Granular flow is challenging due to meso-scale granularity that produces a bewildering array of emergent, macro-scale phenomena.) Prior SOA was therefore not truly predictive and therefore of limited power, but it was useful for modest extrapolation around a range of behaviors that has been previously validated by experiment. In contrast, advances in granular physics theory over the past 5 years are surprisingly far ahead of expectations and it is now possible to develop new modeling methods that are truly predictive for the previously unpredictable regimes of solid-like, fluid-like and gas-like flow of granular materials integrated with gas flow and mechanical devices, including extreme environments (rarefied/supersonic flow, planetary surfaces, etc.). While it is still too early to expect a software package to be capable of modeling all granular phenomena across all ranges of behavior and all environments, it is now possible to create software packages capable of handling one or more of the areas that are important to NASA and necessary for NASA’s mission.

Relevant advances in granular physics that may be incorporated into the new software may include (but are not limited to):

- Granular gas theory equivalent to Boltzmann’s Transport Equation.
- Application of granular gas theory to continuous particle size distribution to predict transport coefficients.
- Successful prediction of dense flow as a function of particle shape.
- A useful technology will be one that can be applied in the real-world engineering design process for the design and checkout of NASA spaceflight technologies.
Sub Topics:  
Autonomous Navigation in GNSS-Denied Environments Topic T5.01

Current NASA research/development and mission capabilities for exploration of remote planetary surfaces and UASs are primarily focused on automated telerobotic systems dependent on human control. More fully autonomous systems will be required for future missions, particularly where communications with Earth may be limited, unavailable for extended periods of time and have significant delays.

This subtopic is to investigate the autonomous navigation capabilities required for land and possibly aerial vehicle operation in areas lacking GNSS and/or magnetic compass to expanded exploration roles within planetary environments. A specific area of interest is to investigate biologically inspired algorithms and capabilities, such as techniques used by insects, such as Honey Bees, to accomplish this goal. Optical flow, image motion across the field of vision, offers unique capabilities for hazard detection and avoidance, landmark navigation, distance judgment, cave navigation, speed regulation, and visual odometry. Current technology is very computationally intensive. It is desired that with hardware support, high speed optic flow measurements can be obtained to speed up and simplify the extraction of motion information from the visual scene, which would both enhance obstacle and hazard detection and avoidance, as well as speed up the navigation process. This will be very critical if VTOL flight can be achieved, as a fuel-limited, in-motion VTOL vehicle is ill positioned to wait for a complicated and time consuming image analysis to be accomplished. Additionally, current laser scanner/imaging technology used for generating terrestrial 3-D maps have mass and power requirements that are excessive for smaller planetary robotic exploration systems. Low mass, low power 3-D mapping systems accommodated on planetary missions could be employed to support autonomous vehicle navigation and maneuvering operations. One example would be a parent vehicle that could launch multiple smaller vehicles that would autonomously explore larger regions and then navigate back to the parent vehicle to transmit data and refuel. In addition to navigation, these vehicles could gather detailed, photorealistic 3-D maps that can be fused with associated science data and used by scientists, students, and the general public for “participatory exploration” activities.

Initial activities would include an assessment of current technology capabilities that could be compared to requirements to identify technology gaps and lay out a technology development roadmap. Subsequent activities would include component and system developments in accordance with the roadmap, leading to the development of a prototype system capable autonomous navigation in environments that do not allow GNSS or magnetic compass navigation and have limited or no communication between vehicles.

Sub Topics:  
Space Synthetic Biology and Food Production Technologies for Space Exploration Topic T6.01

Space Synthetic Biology: Synthetic Biology (SB) provides a unique opportunity to design 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 spaceflight and future surface missions in a variety of enabling areas. Of particular interest is the use of SB, including bioelectrical systems/organisms and technologies, that will reduce the required up-mass and dependence on consumables, resupply, and energy. This may be done through in situ resource utilization (ISRU) and/or the development of more sustainable and efficient systems. Specifically, ISRU technologies should address how SB-based systems may use in situ resources (e.g., regolith, CO\textsubscript{2}) to fabricate advanced materials and/or produce building materials, fuels and plastics. SB-based food production is another area of interest. SB based Environmental Control and Life Support Systems (ECLSS) should focus on increasing efficiency/reliability/regenerability of air, water and waste management. Prototype hardware to support
SB-based systems and modified cell lines - (particularly BES) with potential application for ISRU, ECLSS and food production would all be of interest to NASA. A prototype DNA "writer" technology for transmitting new DNA sequences to SB systems would be considered an enabling technology.

Food Production Technologies for Space Exploration: NASA is interested in food production and related food safety technologies for both near term transit (µ-gravity) missions and eventual surface missions (fractional gravity). Of special interest is the use of plants (e.g., crops) to photosynthetically produce food, and contribute to cabin O₂ production and CO₂ removal. Food production technologies should address how quantum and/or radiation use efficiency will be improved to reduce energy costs, including advanced lighting concepts. Improved concepts for gravity independent watering techniques will also be needed. Complementary approaches might consider selecting or adapting the plants for optimal performance for the constraints of space environments, which could include smaller growing volumes, micro to fractional g, elevated radiation, super-elevated CO₂ concentrations (e.g., >5000 ppm or 0.5 kPa), and narrow band light spectra. Related technologies for sanitizing or reducing the microbial loads to reduce the safety risks of preparing and consuming space grown foods are also needed. All systems should consider minimizing power, mass, consumables, and biologically produced waste, while maximizing reliability and efficiency.

Sub Topics:
Innovative Subsystems for Small Satellite Applications Topic T8.01
This STTR solicitation is to help provide advanced technologies for satellites with masses less than approximately 20 kg and volumes less than approximately 10,000 cm³. Components or subsystems are sought that demonstrate a capability that is applicable to orbital missions to 800 km and mission durations up to 2 years. New approaches, subsystems, and components are sought that will:

- Substantially reduce the resources (cost, mass, volume, or power).
- Provide satellite bus capabilities that increase the capabilities of very small satellites while meeting the significant constraints imposed by the very limited size and mass of the observatory.

Components and subsystems are required that consider the severe mass, volume, and power constraints imposed by very small spacecraft.

Sub Topics:
Technologies for Planetary Compositional Analysis and Mapping Topic T8.02
This subtopic addresses the need for low mass, low power technologies that support orbital and in situ compositional analysis and mapping. The focus is on developing and demonstrating technologies that can be
proposed to future planetary missions. Technologies that can increase instrument resolution, precision and sensitivity, or achieve new & innovative scientific measurements, are solicited. Two areas are of particular interest: micro-scale analysis and mapping of the mineralogy, organic compounds, chemistry and elemental composition of planetary materials, related to rock fabrics and textures; and remote mapping of geologic outcrops and features. Such technologies are particularly relevant for future landed missions to the Moon, comets, asteroids, Mars, Europa, Titan, and other planetary bodies. 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.
- Advantages of the proposed technology compared to the competition.
- Relevance of the technology to NASA's planetary exploration science goals.

Sub Topics:
Science Instruments for Small Missions (SISM) Topic T8.03
Advancements in supporting spacecraft technologies are making small spacecraft more and more capable. Features such as extensive computing power, attitude determination and control systems, and even propulsion are allowing mission designers to consider small and very small spacecraft to perform operational and scientific
investigations. However, one area that is lagging is the miniaturization of instrument systems that would be compatible with this new class of small spacecraft. Until science instruments can be downsized in order for them to be accommodated on small spacecraft, the utility of cubesats, nanosats, and mini-spacecraft platforms will be limited.

To stimulate and create scientific instrument technologies that are compatible with small spacecraft, this subtopic seeks to identify, develop, and prepare for flight demonstration, scientific instruments compatible with one or more of the small spacecraft platforms described at the end of this solicitation. Science applications may be in Astrophysics, Earth Science, Heliophysics, Planetary Science, or Astrobiology.

Examples for proposals sought include, but are not limited to:

**Astrophysics:**
- **Need** - Ability to view diffuse / dispersed / low-intensity astrophysical phenomena requiring zero light background without high spatial resolution; good for full-sky mapping applications.
- **Instrument** - Multiband / hyperspectral imaging compact telescope
- **Measurement** - ERE emission from bright ionized (HII) regions, e.g., Orion Bar ionization edge, and correlation of ERE and PAH emissions from any orbit with at least multi-month lifetime.
- **Impact** - Understanding of astrophysical phenomena, esp. those relevant to carbon sources. Such measurement will demonstrate the science capability on small spacecraft.

**Earth Science:**
- **Need** - Mapping terrestrial phenomena with multiple low-cost imagers for short-revisit period capability.
- **Instrument** - Hyperspectral Earth imager (including constellations of multiple imagers)
- **Measurement** - Ocean color due to algal blooms and other natural phenomena, or anthropogenic impact due to deforestation, CO₂ emissions, etc. Such measurements may require spectral mapping of large areas with short re-map period. Demonstration may be from a sun synchronous low earth orbit.
- **Impact** - Better tracking / understanding of algal blooms sources, CO₂ sources, etc. Such measurement will demonstrate science capability on small spacecraft.

**Earth Science:**
- **Need** - Long-path atmospheric analysis (using sun as light source)
- **Instrument** - Compact (FT)IR spectrometer w/ telescope
- **Measurement** - Assess highly dilute inorganics or organics in upper atmosphere due to pollution or...
meteoritic infall, from Low Earth Orbit.

- **Impact** - Improved understanding of pollutant dynamic mobility/ degradation and/or cosmic organic sources. Such measurement will demonstrate science capability on small spacecraft.

Planetary Science:

- **Need** -
  - Evaluating the reactivity / habitability of extraterrestrial surfaces.
  - On orbit analysis of materials exposed to the space environment.

- **Instrument** - Compact XPS (X-ray photoelectron spectrometer) for surface chemistry analysis - moon, Mars, NEOs, beyond.

- **Measurement** - Characterization of regolith chemical reactivity: quantify reactive inorganic ions & radicals incl. oxyhalides, peroxides, superoxides, odd-O/odd-H species; regolith organic alteration products. Subsurface measurement of supports for and threats to life: energy sources; possible toxic & reactive compounds; soluble anions/cations& dissolved gases.

- **Impact** - Buy down of long term risk. Demonstrating on-orbit material analysis capability, for technology that will be deployed on landers or rovers, will lead to better understanding of surface conditions that impact survival of organics, biomarkers, and life.

Planetary Science:

- **Need** -
  - Investigating the Reactivity / habitability / evolution of extraterrestrial surfaces.
  - On orbit analysis of materials exposed to the space environment.

- **Instrument** - Compact SIMS (secondary ion mass spectrometer) or LDMS (laser desorption mass spec) for surface mass & chemistry analysis - moon, Mars, NEOs, beyond.

- **Measurement** - Characterization of regolith chemical reactivity: quantify reactive inorganic ions & radicals incl. oxyhalides, peroxides, superoxides, odd-O/odd-H species; regolith organic alteration products. Subsurface measurement of supports for and threats to life: energy sources; possible toxic & reactive compounds; soluble anions/cations& dissolved gases.

- **Impact** - Buy down of long term risk. Demonstrating on-orbit material analysis capability, for technology that will be deployed on landers or rovers, will lead to better understanding of surface conditions that impact survival of organics, biomarkers, and life.

Astrobiology:

- **Need** - Evaluate rates and nature of mutations caused by the space environment.

- **Instrument** - Miniaturized DNA sequencer to study mutations
• **Measurement** - Cultures of cells or small organisms supported in space radiation environment for months: evaluate genetic profile after 1000’s of generations. Location would be High Earth Orbit, geo-syn, or various libration points.

• **Impact** - Understand how mutation can play a role in rapid evolution in response to radiation stressors. Miniaturization and demonstration on a small spacecraft mission may eventually lead to a compact sequencer for personalized medicine.

Proposals are sought that significantly advance state of the art for scientific measurements. Proposals for science instruments that represent only incremental improvements in the state-of-the-art capabilities, or are of interest to relatively few users are not appropriate for this solicitation. Proposed concepts should show a relevance to external customers or stakeholders needs.

Proposer shall describe the proposed design, development, analysis, testing and evaluation needed for the technology; and outline a concept of operations for demonstration of the technology on a small mission platform. How the proposed technology is differentiated from currently available technologies must be clearly communicated.

Phase I contracts will be expected to demonstrate feasibility, and Phase II contracts will be expected to fabricate and complete ground testing on an actual instrument/test article for potential demonstration on a small mission.

**Small Spacecraft Platforms**

**Cubesats** - Cubesats are usually 10 x 10 x 10 cm (for a 1U) or 10 x 10 x 30 cm (for a 3U) nanosatellites. Other sizes are also in development, such as a 6U. Cubesats are typically launched as auxiliary spacecraft. Multiple cubesats may also be launched simultaneously in order to create constellations and other useful space architectures.

Specifications and standards for cubesats may be found at [http://www.cubesat.org/](http://www.cubesat.org/)

**University Nanosats** - University Nanosats are typically 50 x 50 x 60 cm and weigh less than 50 kg. They are also auxiliary spacecraft launched with other spacecraft on rideshare missions, typically using 15” or 8” Lightband deployment systems (see [http://www.planetarysystemsincorp.com/](http://www.planetarysystemsincorp.com/) for more info on Lightband and Planetary Systems, Corp.).

The Air Force Research Lab has sponsored the development of these spacecraft via the University Nanosat Program (see [http://prs.afrl.kirtland.af.mil/UNP/](http://prs.afrl.kirtland.af.mil/UNP/)).

**Technology Demonstration Spacecraft** - A larger spacecraft platform for the demonstration of a number of instrument payloads was illustrated by the recent NASA/MSFC FASTSAT mission. FASTSAT is an ESPA-class spacecraft, deployed via a 15” Lightband deployer, and is designed to accommodate a number of independent instrument systems. FASTSAT provides basic power, data/communications, and thermal management support for
these payloads as part of an integrated space flight demonstration mission.

Sub Topics:
Technologies for Aerospace Experimental Capabilities Topic T9.01
The emphasis of this subtopic is proving feasibility, developing, and demonstrating technologies for advanced Aerospace research experimentation that matures new methodologies, technologies, and concepts. It seeks advancements that promise significant gains in NASA's experimental research capabilities or addresses barriers to measurements, operations, safety, and cost in all flight regimes from low sub-sonic to high supersonic to space. This subtopic solicits innovative technologies that enhance experimental research competencies by advancing capabilities for ground and in-flight experimentation. Proposals that demonstrate and confirm reliable application of concepts and technologies suitable for flight research and the test environment are a high priority.

Measurement techniques are needed to acquire aerodynamic, structural, flight control, and propulsion system performance characteristics to safely expand the flight envelope of aerospace vehicles. Spacecraft guidance, navigation and Control validation techniques are needed. The goals are to improve the effectiveness of flight-testing by simplifying and minimizing sensor installation, measuring parameters in novel ways, improving the quality of measurements, and minimizing the disturbance to the measured parameter from the sensor presence. Sensors and systems are required to have fast response, low volume, minimal intrusion, and high accuracy and reliability. Special areas of interest include:

- Testing and Validation for Lightweight structures and materials.
- Methods and associated technologies for conducting flight research and acquiring test information in flight.
- Numerical methods for the planning, prediction, analysis and validation of flight-test experimentation.
- Sensors and data systems that have fast response, low volume, minimal intrusion, and increased accuracy and reliability.
- Innovative techniques that decrease turn-around time for inspections and assessments for safe operations of aircraft and spacecraft (e.g., non destructive examination of composites through ultrasonic techniques).
- Advanced design and manufacturing techniques for improved upper stage performance for nano- & small-satellite booster technologies (e.g., manufacturability, affordability, and performance of a small upper-stage booster rocket motors for small & nano-satellites).
- Aerodynamic boundary layer and laminar flow control and drag reduction.
- Precision landing systems.
- Autonomous, fault-tolerant GN&C.
- Autonomous Rendezvous and Docking.
Sub Topics:
Innovative Refractory Materials for Rocket Propulsion Testing Topic T10.01

NASA has identified the advancement of materials as a critical technological need in supporting future space flight and rocket test operations. Specifically, innovative materials for thermal management applications have been targeted with the additional goal of furthering nanotechnology. With the development of these new multi-functional, high-temperature materials comes the requirement for verification and validation of the predictability of their thermal behavior.

The current subtopic is to develop innovative refractory materials which use nano-particle additives and/or unconventional non-cement based refractories that can withstand the extreme plume heating environments experienced during rocket propulsion testing. The material should provide a revolutionary improvement over conventional castable refractories. Explicitly, the nano-based or multi-functional material should provide substantial improvements in several of the following areas:

- Compressive and flexural strength.
- Thermal, abrasion and corrosion resistance.
- Operating temperatures at or above 4000 °F.
- Excellent workability for potential lining of vertical walls/pipes.
- Ultra-low porosity.

Demonstration of the performance of these materials in environments similar to rocket plume environments will be a critical aspect of the success and usefulness of the proposed technology. In addition, verification and validation of the predictability of the material behavior during ablative heating is of high importance to the mission of NASA.

Other potential applications of nano-particle/multi-functional refractory materials might be use in expendable (or even reusable) rocket engine thrust chambers, control system thrusters, and nozzles to extend the life of the testing infrastructure and components. These engine components could be for launch or in-space propulsion systems. This application would add a requirement to be light weight and provide manufacturability for use in coatings or production of components.
Sub Topics:

Software Framework & Infrastructure Development of Spaceborne Hybrid Multicore/FPGA Architectures Topic T11.01

Future high-performance on board computing systems will likely employ hybrid architectures consisting of both advanced multi-core processors and reconfigurable Field Programmable Gate Arrays (FPGAs), which may include additional embedded hard and/or soft core processors along with processing functions implemented in the FPGA logic. Advanced software architectures, software infrastructure elements and software design tools are needed to compliment these advanced hardware platforms and enable their efficient/effective use. The intent of this subtopic is to develop these software architectures, infrastructure elements and tools.

Desired technologies include multi-core software frameworks, multi-core operating system components, hardware/software abstraction layers & interfaces, and development systems/tools/simulators. Additionally, middleware/hypervisors are needed that can perform memory protection and run-time allocation of tasks to processing resources, and address performance optimization, energy management, and fault mitigation.

Sub Topics:

Distributed Simulation for Design and Manufacturing Topic T11.02

NASA is embarking on missions to new environments with new technologies and new systems to take us far beyond where any human has gone before.

Understanding, managing and leveraging the associated complexity will require new tools, new methods, new ways of managing data and, in the long run, entirely new types of data as well. Simulation plays a key role in each of these areas with advanced tools and processes already in use to define architectures, study options and integrate alternatives into the overarching plan. However, today's tools, and even tomorrow's tools, lack the ability to integrate and share information on the physical and temporal scale necessary to efficiently and effectively enable these systems.

Desired product is a prototype suite of tools, systems and processes to allow researchers, innovators and operational organizations to share simulation based needs, technologies, concepts and opportunities over large distances (planets) and large increments of time (decades). The system should utilize existing Industry and NASA standards and interfaces for simulation data, suggest new ones, or both. Emphasis should be placed on interfaces like XML to both extend the lifecycle of data elements into the 50 year range as well as interface with the emerging set of NASA tools.

Distributed Simulation of this nature has been identified by the National Research Council as one of the 83 high priority technologies for NASA as a part of the OCT roadmap team efforts. It is a part of TA 11 (modeling, simulation, information technology and processing) and is one of the 4 high priority technologies identified for that roadmap. It directly supports any complex design and development efforts directly and supports technology push and pull by better communicating programmatic needs and technology solutions in relevant operational environments.
Advanced high temperature materials and sensors are crosscutting technologies which can be used in component and subsystem applications essential in the design, development and health maintenance/detection needs of future generations of aeronautical and space propulsion systems. Proposals are sought that address:

- Advanced high temperature materials technologies, both design and development, needed to meet application challenges associated with propulsion systems. Proposals must be linked to improvements in future performance indicators, such as vehicle weight, fuel consumption, noise, lift, drag, durability, and emissions for aircraft, and/or reduced mass components and thermal management properties to meet space vehicle propulsion needs. Technology interests include:
  - Innovative approaches to enhance the durability, processability, performance and reliability of advanced materials (super alloys, high strength fibers and environmental barrier coatings for ceramic matrix composites with temperature capability greater than 2700 °F, and corrosion/oxidation resistant coatings for turbine disk materials operating at temperatures in excess of 1400 °F, innovative joining methodologies for bonding powder metallurgy disk material to directionally solidified/single crystal rim alloy for a hybrid disk);
  - High temperature shape memory alloys and methods to integrate these materials into propulsion system structures for changing component shape and actuation devices;
  - High temperature magnets with greater than 500 °F capability;
  - Multifunctional high temperature materials, combining structural properties with a second capability, such as power harvesting, thermal management, self-sensing, and materials for wireless sensing and actuation;
  - Environmentally-friendly manufacturing processes for high temperature polymer materials with temperature capability 500 °F or higher.

- Innovative smart sensing methods and associated measurement techniques for the cost-effective, reliable assessment of the health of aerospace engine and vehicle components in harsh high-temperature environments (1900 °F - 3000 °F) allowing a proactive approach to maintain capability and safety. Engine and vehicle structures ground and flight testing applications can lead to thermal and other environmental conditions beyond the limits of current sensing technology. Sensors and systems are required to have fast response, low volume and weight, be minimally intrusive and possess high accuracy and reliability. Special areas of interest include:
  - Development and validation of innovative sensors and improved methods for attaching to advanced high-temperature materials and integrating sensors into systems (wireless, wired or fiber optic).
Approaches to measure strain, temperature, heat flux, deflection, acoustics and/or acceleration of structural components are sought.

Compact, non-contact, full-field sensing systems for structural information.

Nanotechnology offers a means to: a. develop higher-temperature/environmentally-resistant structural materials with engineered micro structures that can optimize material properties for propulsion hot section components; b. enables tailoring the thermal conductivity of materials, making them more efficient conductors or insulators; c. permits targeted sensor applications that can improve functional efficiency; d. supports developing nano-sensors that may be incorporated in hot section structures/systems that are smaller, more energy efficient and potentially providing more sensitive health assessments capability.

Design Methods/Tools, which are robust and efficient, to design advanced materials based on first principles and micro structural models that can be used in a multi-scale framework.

Proposed Deliverable to NASA: Advanced high temperature materials, high strength fibers, protective coatings; new sensors, attachment techniques, beta versions of sensor systems; and new computational models.

What would be the major implication of not having this subtopic? High temperature materials technologies are required to meet the flight vehicle hot surface needs and to enable development of the advanced aerospace propulsion systems necessary to the NASA mission success. Industry looks to NASA to provide these technologies and capabilities to help them meet/exceed the National goals - environmental regulations, contributing to green energy and meeting and customer performance requirements. Novel sensor systems are critical to moving the technology from the laboratory environment to ground test activities and flight vehicle applications.

NASA Relevance: High temperature materials and advanced sensors were each highlighted as high priority needs in both the National Aeronautics Plan for Aeronautics Research and the National Research Council's report, NASA Space Technology Roadmaps and Priorities, documents.

Aeronautics:

- Mobility R&D Goal 5 Far-term Objective 3
- National Security and Homeland Defense R&D Goal 3 Far-term Objective 1 and Goal 4 Far-term Objective 2
- Aviation Safety Goal 1 Far-term Objectives 1 and 3
- Energy and Environment R&D Goal 2 Far-term Objective 2, 3 and 4

Space:

- Reduce vehicle mass and/or improve thermal management performance by employing nanotechnologies to develop lighter-weight multifunctional materials/ (structures) and sensors with unique capabilities and better performing.
• Structural health monitoring/sensors for long duration missions/responsive on-board systems:
  
  ° Reduced propulsion structure mass.
  ° Computational modeling design/analysis/simulation methods for materials certification/reliability.

Center relevance, i.e., project, program and mission:

• ARMD Programs.
• OCT.
• Space Exploration Mission Directorate.

List any commercialization plans or possible mission opportunities for technologies: Upcoming ARMD and reimbursable testing activities

Other potential government funding or applications:

• ARMD Seedling.
• Fundamental Aeronautics at higher TRL.
• OCT CIF.
• DOD.
• DOE.
• DARPA.

Identify OCT Mission Directorate and/or Field Center advocate(s) committed to support development through a Phase III award:

• Leslie A. Greenbauer-Seng (GRC/Deputy Structures and Materials Division).
• Tim Risch (DRFC/Deputy Chief Aerostructures Branch).

Sub Topics:
Materials and Manufacturing Technologies Topic T12.02
NASA's science and exploration missions continue to seek materials and manufacturing techniques and capabilities that will allow missions of increased capability and reduced costs. These future missions depend highly on advancements such as lighter and stronger materials and manufacturing methods. Materials and manufacturing
technologies have high value and make a significant contribution to the interests of others outside of NASA, specifically those that address broader national needs as well as the needs of the commercial space industry. The portfolio of advanced materials and manufacturing technologies is extremely broad and cross-cutting with complex interactions between core disciplines (e.g., materials and structures), applied R&D, innovation, and production.

In reference to the recent report from the National Research Council on the Space Technology Roadmaps produced by NASA's Office of Chief Technologist, the report ranks lightweight and Multifunctional Materials and Structures as an area of high priority development to be emphasized over the next 5 years. This topic seeks technologies that support these needs:

- Lightweight and multifunctional materials concepts including, advanced composite, metallic, and ceramic materials that significantly enhance future exploration and science missions and enable new missions.
- Digital/Model-based Manufacturing technologies that enable cost-effective manufacturing for reliable high-performance structures and made in low-unit production, including in-space manufacturing.
- In-space and additive manufacturing that offers the potential for game-changing weight savings and new mission opportunities.

University researchers are well-positioned to make a positive contribution within the time and funding allocation vis-a-vis a concept demonstration, enhancement of an existing component through a clever innovation, working prototype, etc. Also, this topic of materials and manufacturing technologies supports and is closely aligned with the President's National Strategic Plan for Advanced Manufacturing.

Sub Topics:
Risk Engineering, Sciences, Computation, and Informed Decisions Topic T13.01
Human spaceflight missions in the early twenty-first century are still inherently complex and risky. While it takes a very talented and courageous flight crew to achieve a mission's objectives, it takes many more people on the ground to plan, prepare, and support the flight crew during the mission to ensure the safety of the crew and the success of the mission. For every human spaceflight mission, many decisions are made before each mission and more decisions are made during the mission in responding to changes in the environments or space vehicle systems. As in many other complex operations in harsh environments on Earth, labor-intensive information research and analyses is necessary to weigh the benefits versus the risks of each alternative in order to make accurate risk-informed decisions. Often these decisions need to be made in a short period of time before space vehicle systems are out of consumables or the risk of continuing the mission becomes unacceptable. Sometimes a decision that reduces risk in one limited perspective or frame of reference inadvertently increases system-level or end-to-end mission risk due to impacts that were not foreseen due to limited human ability to consider and assess all relevant data.
This STTR subtopic seeks to advance the state-of-the-art in knowledge management, information management, information technology, and artificial intelligence leading toward the ability for computer systems to assist humans in timely and correctly identifying, quantifying, characterizing, mitigating, and communicating risks to inform decision makers of risks before the decisions are made. Application of advanced computer-based decision support technologies to identify and assess relevant data, identify alternatives, and model consequences will significantly reduce the cost of development, deployment, and sustainment of complex space systems and significantly increase safety of crew during space missions. Below are some examples of technologies that would be appropriate for this sub-topic:

- **Timely Risk Identification** - For several decades, the Failure Modes and Effects Analysis has been used to identify risks inherent in space system designs. Analysis results are frequently not available until the system design has matured to the point where it is ready for final development, test, and or deployment. Changes late in the design lifecycle often cannot be accommodated due to significant schedule delay and cost increase. Although designing out hazards is the most effective and preferred means of control, mitigations for identified risks at this time are usually limited to procedural controls which require recurring attention throughout the operational phase. This often results in operational complexity, higher risk, and higher sustaining cost. An automated failure modes and effects simulation technology would be a game-changer by identifying safety and technical risks of the design early and quickly so that design changes or trades may be made to eliminate these risks at a much lower lifecycle cost and significantly improve safety and system reliability.

- **Risk-Informed Decision Making** - As space systems become more complex and human space exploration destinations get farther away from Earth, the flight crew may be forced to make timely decisions in responding to imminent hazardous conditions without the assistance of the ground crew. Risk-informed decision support technologies would assist the flight crew by suggesting possible actions that have the highest probability of success.

- **Context-Based Software Risk Modeling** - Space system designers are considering incorporating or increasing levels of automation in their systems to achieve a sustainable human space exploration program. Although the desired outcome is a net reduction of overall mission risk, more automation will result in increasing the complexity of the software systems, and thus increase the proportion of risk attributable to software faults as a component of system risk. NASA is seeking Context-Based Software Risk Model technologies to address the risks of software required functionality that would be compatible and consistent with the standard Probabilistic Risk Assessment methodology now employed by NASA. An effective integration of the PRA and CSRM techniques would facilitate comparative evaluations of automation design options for effectiveness in reducing mission risks.

Sub Topics:

Cross cutting Avionics for Beyond Earth Orbit Space Exploration Topic T15.01

As NASA human exploration and science missions move further from Earth and become increasingly more complex, they present unique challenges to the on-board avionics systems. Avionics systems in space vehicles are significant size, weight and power (SwAP) as well as cost drivers. Future destinations such as L2, near-earth asteroid, Mars, etc. are characterized by long durations, vast distances and harsh environments and call for significant advances in on-board processing, autonomy, reliability, fault-tolerance and redundancy. Advanced technologies and approaches to avionics systems and its components are needed to support these challenging mission requirements and to safely bring crew back to Earth.
Avionics provides cross- capabilities across different sub-systems and is a prime candidate for commonality between different missions and programs leading to savings in the design, development and testing, logistics (sparing, reuse, and re-purposing of hardware) and operational costs.

To support exploration mission objectives and requirements, advances in emerging avionics technologies (processors, networks and network devices, memory cards, human interfaces including visual, tactile and auditory interfaces, etc.) and associated foundational technology are required. Areas addressing miniaturization, radiation and extreme temperature environments such as radiation hardened by design, Rad-hard extreme temperature technology, and electronics packaging, etc. are of particular interest.

The focus of this subtopic is to support the development and advancement of cost-effective avionics technologies while keeping a unified approach to promote commonality of systems between multiple missions and/or programs. The ultimate goal is to develop a common avionics framework and a catalog of components that can be integrated into a space vehicle in the next 6-10 years.

Sub Topics:

**Autonomous Systems for Atmospheric Flight Topic T15.02**

With increasing levels of automation capabilities in the aviation arena, provides unique opportunities and challenges for civil aviation, and the aerial transport communities. Flight will be transformed as these capabilities mature and evolve in to integrated systems. In particular, autonomous and robotic, manned and unmanned civil aircraft systems will lead to a plethora of new markets, vehicle, and missions. These new systems with broad range of capabilities, and a huge diversity of shapes and sizes, must safely utilize the future National Airspace System. Both operational and machine autonomy will require tremendous breakthroughs through the new technology frontiers in machine intelligence, autonomy, robotics, and inter-connections of these technologies. Breakthroughs in these areas could lead to such societal capabilities as autonomous cargo carrying, surveillance, air taxis, small unmanned civil aircraft, Zip aircraft, on-demand VTOL aviation, airborne wind energy platforms and a host of other emerging distributed aviation systems.

The goal of this topic area is to develop technologies and capabilities that will lead to fully autonomous systems that are able to learn and adapt to changes in their environment that were not predicted, and yet still accomplish the mission goals, with minimal or no human involvement required.

For purposes of this solicitation, autonomous vehicles have varying levels of autonomy and range from automated capability to fully autonomous flight where the system has the ability to learn, reason, and adapt. Military applications have demonstrated the ability to do automated flight but their use in civil aviation requires additional research and development. The primary interest of this sub-topic is to advance the technologies for robotic and autonomous vehicle perception, cognition, as well as system integration. Proposals should be written around one of the following themes described below:

- **Autonomous or robotic pilot** - Autonomous systems can be applied far beyond remotely piloted aircraft. Maximum machine effectiveness can only be realized through vehicle autonomous systems ability to learn, reason and adapt. Current practice is to have a reliance on stored information, which is complemented by GPS position information. If there is an on-board, real-time means to sense and react to the local environment (including air and ground features and traffic), then autonomous and robotic air-vehicle can be
fully utilized. But addressing how adaptive systems can still be ‘trusted’ in critical flight environments and achieve FAA certification is a technical issue that must be resolved. Proposals are sought to develop innovative approaches and enabling technologies for autonomous, robotic, and embodied intelligent air-vehicles. Example scenarios could include but are not limited to carrying passengers and cargo through the NAS, search, rescue, and surveillance operations, and sentries to patrol coastal waters, and land borders. Proposal should consider perception, cognition, as well as GPS enabled, GPS-denied, and cooperating and non-cooperating traffic environments.

- **Autonomy for flight, the robotic test pilot.** Adaptive and robust controllers designed to autonomously fly and optimize around multiple vehicles. Products would be aerodynamic coefficients such as coefficient of lift and drag as well as controller effectiveness.

- **Autonomous intelligence, surveillance and reconnaissance.** A next generation system would entail a "smart payload" with a UAS designed around it to accomplish specific missions. Example missions might include, but are not limited to disaster relieve, fire monitoring, launch vehicle tracking, or hurricane tracking. The payload would ultimately permit autonomous target acquisition, tracking, and aircraft attitude/orientation to optimize data collection, or ensuring mission completion. Initial activities would include an assessment of current technology capabilities that could be compared to requirements for a next generation autonomously controlled sensor and platform system to identify technology gaps and lay out a technology development road map. Subsequent activities would include component and system developments and integration in accordance with the road map, leading to the development of a prototype system capable of integrating with a UAS.