NASA STTR 2014 Phase I Solicitation

Small Business Technology Transfer

Launch Propulsion Systems Topic T1
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 Affordable Nano-Launcher Upper Stage Propulsion**

*Lead Center: MSFC*

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

Small satellites are becoming ever more capable of performing valuable missions for both government and commercial customers. However, currently these satellites can only be launched affordably as secondary payloads. This makes it difficult for the small satellite mission to launch when needed, to the desired orbit, and with acceptable risk. A dedicated launch vehicle is needed that will affordably meet the small sat launch needs. This subtopic solicits technology proposals for the upper stage propulsion system of such a launcher. Specifically, the subtopic requests proposals for propulsion design tools, systems, and stages for application as upper stages or orbit insertion stages with the following goals and constraints:

- A recurring stage cost not to exceed $100K (for 8/year).
- The stage shall be capable of providing at least 13,000 fps delta-v to a 150 lbm mass from in vacuum conditions.
- The stage shall be designed to a diameter of 3.0 ft or less.
- The stage shall be capable of compressively supporting 700 lbf on its forward end (in addition to its own loaded mass).
- Total stage wet mass shall not exceed 1800 lbm.
- Other desired functionality include TVC, basic health and status monitoring, and throttling.
- Design analysis techniques that provide rapid, high fidelity insight into the operation of these systems are also needed.

Technologies meeting these goals will support development of an affordable launcher capable of delivering 55 lbm to 100 lbm to low-earth orbit. Phase I activities will develop the data necessary to assert with confidence that the proposed technology solution will meet the goals of the subtopic. Phase II activities will provide functionality verification and substantiation of recurring cost.

Mission Traceability - STMD, HEOMD, and SMD all have missions that would benefit from this technology. In particular, STMD’s SST and GCD Programs have expressed a strong need.

**T1.02 Small Launch Vehicle Propulsion Technology**

*Lead Center: MSFC*
Small satellites are becoming ever more capable of performing valuable missions for both government and commercial customers. However, currently these satellites can only be launched affordably as secondary payloads on large launch vehicles. This makes it difficult for the small satellite mission to launch when needed, to the optimal orbit, and with acceptable risk to the mission. There is no affordable, dedicated launcher available that will meet the small satellite launch needs. This subtopic solicits technology proposals for the boost propulsion system(s) of such a launcher. Specifically, the subtopic requests proposals for propulsion systems for application as first stages or strap-on boosters with the following functional and cost goals and within the following geometric constraints:

- Cost goal - Assuming a production rate of 8 boost systems per year, a recurring stage cost of $400K
- Total Impulse goal - The stage shall be capable of providing 2.5M lbf-sec total impulse
- Delta-V goal - The stage shall be capable of providing 6800 fps delta-v to a 8,000 lbm mass from ground launch.
- Size goal - The stage shall be designed to fit within the size envelope of height of 25 ft and a diameter of 3.5 ft for individual elements. If a cluster of elements is proposed, the central element should stay within this envelope.
- Strength goal - It shall be capable of structurally supporting (compressively) 8,000 lbf/lbm for use as a core booster stage.

Though not explicit goals, other desired functionality in the first stage include thrust vector control (TVC), basic health and status monitoring, and throttling.

Technologies meeting these goals will support development of a 25 kg to 50 kg payload launcher to low-earth orbit. Phase I activities will be used to develop the data necessary to assert with confidence that the proposed technology solution will meet the goals of the subtopic. Phase II activities will include verification of functionality, as much as possible through testing, and substantiation of recurring cost projections. At the end of Phase II there will be sufficient validation of the technology to warrant purchase of one or more stages for initial flight testing under potential follow-on activities.

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

T3.01 Innovative Energy Harvesting Technology Development

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

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. 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 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-servoelastic considerations which are gaining prevalence in advanced aerospace flight vehicles, atmospheric and extra-terrestrial.

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

Development of distributed sensory-driven control-oriented DSE systems is solicited to enable future flight vehicle concepts and designs that manage structural dynamic uncertainty on a vehicle's overall performance. Proposals should assist in revolutionizing improvements in performance to empower a new generation of air and space vehicles to meet the challenges of terrestrial and commercial space concerns with novel concepts and technology developments in systems analysis, integration and evaluation. Higher performance measures include energy efficiency to reduce fuel burn and operability technologies that enable information network decompositions that have different characteristics in efficiency, robustness, and asymmetry of information and control with tradeoff between computation and communication.

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

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

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

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 Communications Systems**

**Lead Center:** GRC

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

Future missions will require end to end communications systems that can support greater levels of autonomy and possess greater awareness of the environment and knowledge of assets that can be used for enhanced reach back and data delivery. Autonomous Communications Systems (ACS) have the potential to improve overall system performance and reduce the user burden associated with configuring and managing communications systems through the use of automated systems-level analysis and configuration control.

An ACS nominally includes the Radio/Optical subsystems and the storage and networking subsystems capable of supporting autonomous network operations. ACS capabilities would also support on-board learning to extract, catalog, and utilize information from both positive and negative experiences to enhance nominal and anomalous situations. Other desired enabling functions would include:

- Ability to increase the capabilities of on-board communications services to make network connections self-configurable and autonomous. Further advances would lead to the ability to determine how a learning system would be implemented in an on-board system, such as Artificial Intelligence.
- Ability to determine the type and how on-board information, including settings, would be exchanged between the communications components.
- Smart environment sensing capable of mitigating outages, interference and performance degradation. This could include Spectrum resource allocation and/or Dynamic frequency assignment capability to enhance throughput and connectivity.
- Low power, low cost, flexible receiver front ends that allows for efficient spectrum utilization (i.e., frequency reconfigurable) and are compatible with SDR/cognitive radio platforms allowing the use of multiple waveforms and autonomous operation to increase capacity and to enable more efficient high-data data handling and delivery, are of interest. In particular, the following enabling technologies should be addressed:
State of the Art - Current NASA flight transceivers are capable of performing communication and radiometrics. With the recent launch of the SCaNTestbed on the ISS, advances in software defined radios (SDRs) that are reconfigurable are now being assessed to support communications, navigation and networking experiments and applications. However, today's flight transceivers and SDRs are not aware of their environment and do not react to it; hence lack ability to support autonomous network operations.

Background/Rationale - NASA HEOMD and SMD conduct scientific exploration that is enabled by access to space and innovative technologies to expand mankind’s understanding of planet earth and the universe. Communications and navigation technologies are integral in projecting humankind’s vantage point into space with observatories in Earth orbit and deep space, spacecraft visiting the Moon and other planetary bodies, and robotic landers, rovers, and sample return missions. As the needs to gather more data and extend mankind’s presence beyond low earth orbit, even more advanced communications and navigation technologies will be essential to deliver orders of magnitude more data and enable greater participation by the public through high-data rate telepresence networks.
interactions yield structured three dimensional porosity. MOFs have several important attributes:

- They have ultrahigh porosity.
- MOFs have demonstrated thermal and chemical stability.
- They can be synthesized into a wide variety of structures with a wide range of pore sizes.
- They can be synthesized to be superhydrophobic.

Because of these attributes, MOFs show promise to improve the efficiency and effectiveness of practical gas separation systems.

To ensure human health for space exploration, NASA seeks the capability to administer therapeutic oxygen in a medical emergency. In a traditional hospital setting, medical oxygen can be delivered, and the excess oxygen is diluted and ventilated. In a confined spacecraft, administering medical oxygen by conventional means can cause ambient oxygen levels to exceed flammability limits. If oxygen could be efficiently concentrated from spacecraft cabin air, medical oxygen could be administered without increasing oxygen levels in the cabin. State of the art oxygen concentrators are too large and use too much energy to effectively operate in a spacecraft environment, in part because the oxygen separation sorbents are adversely affected by the presence of water vapor.

Much attention is being paid on using MOFs to store fuels such as hydrogen under practical conditions. This solicitation, however, is focused on exploiting the properties of MOFs to separate oxygen from cabin air. Thermal and chemical stability, selectivity in the presence of water, and selectivity under dynamic gas separation conditions are especially important. In addition to water selectivity, some operational scenarios require oxygen separation from air that contains elevated levels of CO, CO$_2$, HCN, and HF.

Human Exploration Destination Systems Topic T7
Reserved for future Solicitations.
Sub Topics:
Science Instruments, Observatories and Sensor Systems Topic T8
Science Instruments, Observatories, and Sensor Systems addresses technologies that are primarily of interest for missions sponsored by NASA's Science Mission Directorate and are primarily relevant to space research in Earth science, heliophysics, planetary science, and astrophysics. This topic consists of three Level 2 technology subareas:

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

Sub Topics:
T8.01 Technologies for Planetary Compositional Analysis and Mapping
Lead Center: JPL
Participating Center(s): LaRC
This subtopic is focused on developing and demonstrating technologies for both orbital and in situ compositional analysis and mapping that can be proposed to future planetary missions. Technologies that can increase instrument resolution, precision and sensitivity or achieve new and innovative scientific measurements are solicited. For example missions, see (http://science.hq.nasa.gov/missions [1]). For details of the specific requirements see the National Research Council’s, Vision and Voyages for Planetary Science in the Decade 2013-2022 (http://solarsystem.nasa.gov/2013decadal/ [2]).

Possible areas of interest include:

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

- Technologies for 1-D and 2-D raster scanning from a robot arm.
- Novel approaches that could help enable in situ organic compound analysis from a robot arm (e.g., ultra-miniatuized 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.

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

T8.02 Next Generation Total Lightning Detection Sensor

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

NASA is concerned with the uncertainty of the current lightning detection sensors. The location accuracy and detection efficiency are both lacking, currently at less than 90% and 250m respectively. Total lightning detection with location accuracy in the meters should be the requirement of the next generation launch vehicle and ground operations. NASA seeks to foster research and development that leads to innovative new technologies and methods, or significant improvements in existing technologies, for in-cloud and cloud-to-ground lightning detection. The current total lightning detection technology has been fairly stagnant for the last decade, with the only improvements being small tweaks to location accuracy and classification algorithms and requiring both a suite of cloud-to-ground sensors and inter-cloud sensors. The combination is cost prohibitive to most locations and requires a large array of sensors spanning tens of meters to create solutions. Through current collaborations with other government agencies, the NASA team has come across several universities and at least two small businesses that have conceptual designs that could potentially deliver a brand new sensor with the detection capability to meet the important technology gap. Based on an early assessment of these small business and university concepts, it is likely that systems could be developed within the next 2-3 years, at great cost efficiencies for NASA while providing the needed detection and location accuracy.

Under this subtopic, proposals are invited that explore novel sensors and sensor systems for the detection of both inter-cloud and cloud-to-ground lightning. With regard to detection efficiency and location accuracy, the emphasis is developing systems that have a near total detection and are accurate within 10s of meters. Approaches that use multiple sensors in combination to improve detection and location are also of interest. Technologies may take the form of prototypes and/or devices.
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 Lightweight Structural Nanomaterial Concepts

Lead Center: LaRC

Carbon fiber reinforced polymeric (CFRP) composites are considered state of the art (SOA) for lightweight aerospace structural materials. However, a systems study suggests that having specific mechanical properties that exceed CFRPs by 2-4x will yield significant savings in launch vehicles. Currently, SOA nanomaterials with potential to supplant CFRPs as the lightweight structural material of choice are available in formats possessing mechanical properties far below those measured at the nanoscale. These excellent nanoscale properties have to be demonstrated at scales that permit the evaluation of these materials in structural components with properties that offer mass advantage over CFRPs. Proposals are sought in the following areas:

- Innovative approaches to chemically and/or physically enhance load carrying capability of nanomaterials and influence their macroscale mechanical properties as demonstrated by structural properties on the coupon scale that are at least double the specific strength and stiffness of epoxy CFRPs.
- Manufacturing methods that permit the control of nanostructures at the molecular level to induce structural perfection of such structures as to produce articles at the coupon scale which possess mechanical properties that are at least double those measured for epoxy CFRPs.

T10.02 Smart Structural Composites for Space

Lead Center: JSC

Participating Center(s): GRC, LaRC

Advanced structural composites with the potential for enhanced damage detection are highly desired for spacecraft. Smart aspects, for example structural health monitoring or self-healing, should be introduced through utilization of advanced materials and nano-additives. Such composites could allow for the realization of the mass reduction that composite materials have promised for spacecraft but have not yet achieved.

NASA is currently evaluating composite materials for structures due to their relatively high strength, light weight, and potential low cost. There are a multitude of potential applications to primary and secondary structures, including vehicle, habitat module, and pressure vessel structures. Lighter materials with high specific strength can have drastic reduction in uptake mass, resulting in more cost effective space exploration. Smart materials such as piezoelectric, shape memory, and self-healing materials, will take structural composites to the next level.

One integral and limiting design concern for structural composites is that of damage tolerance. Upon impact, nearly imperceptible cracks may form upon impact, which, while tiny, may have drastic effects on structural integrity. To compensate, structural composites are designed to be thicker and heavier than would otherwise be required, thus negating the weight savings that these materials promise. One way to surmount this challenge and to realize the anticipated weight savings is to design smart materials. For instance, advanced materials and technologies should be developed to detect damage incidents, from tool drops during manufacturing to micrometeoroid and orbital debris impacts on orbit. Monitoring of extent of damage and the initiation of self-healing could reduce the complexity of composite maintenance and increase materials performance lifetime and reliability. Thermal/electrical/mechanical properties may be introduced or enhanced for multi-functionality such as thermal management or electrostatic discharge prevention and resultant weight savings. Overall, smart structures focused on space applications will have a significant impact on NASA's Space Exploration program.

While the subtopic description is broad, the offerer will narrowly define the composite system and intended applications. This subtopic is not intended for materials coupon-level work only; proposed systems should have a targeted demonstrator structure identified as a deliverable. Solutions may employ nanotechnology but are not required to do so. The smart structural composite should be proposed as an alternate material in this identified
structure, with additional or enhanced functionality. In Phase I, composite samples will be fabricated and tested to
demonstrate basic functionality. The targeted demonstrator structure will be identified, and critical test
environments and associated performance predictions will be defined relative to the final operating environment.
Deliverables include composite samples and the associated test data, predictions, and definitions. During Phase II,
while full-scale parts are not required, scaled-up composite samples will be built in application-appropriate
geometries. Samples will be tested in a simulated operational environment for demonstrate of performance in
critical areas. Further scale-up requirements will be defined, and performance predictions will made for subsequent
development phases. Deliverables will include composite samples and the associated test data, definitions, and
predictions.

Modeling, Simulation, Information Technology and Processing Topic T11
Modeling, Simulation, Information Technology and Processing consists of four technology subareas, including
computing, modeling, simulation, and information processing. NASA’s ability to make engineering breakthroughs
and scientific discoveries is limited not only by human, robotic, and remotely sensed observation, but also by the
ability to transport data and transform the data into scientific and engineering knowledge through sophisticated
needs. With data volumes exponentially increasing into the petabyte and exabyte ranges, modeling, simulation,
and information technology and processing requirements demand advanced supercomputing capabilities.
Sub Topics:

T11.01 Information Technologies for Intelligent and Adaptive Space Robotics

Lead Center: ARC
Participating Center(s): JPL, JSC

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
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 and unskilled labor (site clean-
up, close-out tasks, etc).

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 shared-autonomy and remotely operated robots, which facilitate distributed
collaboration, geospatial data visualization, summarization and notification, and robot tasking. This does
NOT include user interfaces for direct teleoperation / purely manual control (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.
- Mobile robot navigation (localization, hazard avoidance, etc.) for operations in man-made (inside human
spacecraft) and unstructured environments (planetary surfaces). 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 sensors, perception algorithms and
software.
- Robot software architecture that radically reduces operator workload for remotely operating mobile robots.
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.

Deliverables to NASA:

- Identify scenarios and use cases.
Define specifications based on design trades.
Develop concepts to address use cases.
Demonstrate prototype systems and technology demonstrations.

**T11.02 Computational Simulation and Engineering**

**Lead Center: JPL**

**Virtual Worlds** - We solicit proposals for development of computational tools that enable rapid demonstration of mission concepts. The intent of such a tool is to enable non-experts in animation to rapidly build mission scenarios and visually express their concepts in a virtual world. These tools should enable full 3D visualization by importing of CAD parts of electromechanical systems (e.g., rovers, landers, orbiters), environment models (height field maps with textures for terrain, star maps and planetary bodies), animation functionality to show temporal progression and movement of appropriate objects in the scene. The tool should support animation of flexible bodies (e.g., solar panel vibrations) along with articulation of components. The tool should feature a ray-tracing engine for good quality visualization with shadowing, ambient lighting, etc. The tool should also be able to demonstrate terrain artifacts such as rocks, dust and ejecta as both static and dynamic objects. An example of a static artifact may be a rock pile that does not move during the animation while a dynamic artifact may be dust rising from a lander thruster interaction with terrain. Note that the emphasis is on visualization and not necessarily on the physics of the problem. However, the tool should have a standard API for integration with physics engines (e.g., ODE, Bullet, Proprietary Code) so that physics simulations can be used to control temporal progression of a scene. While it is preferred to have a representative physics engine coupled to the tool, it is not required. There should also be a functionality to write simple scripts for animating the virtual entities. There should be an avenue for developing a library of animation objects (e.g., rovers, terrains and locations) for re-use in later concept developments. The tools should be cross platform and enable development of animations or movies. The tool should take advantage of graphics processors or enable use of cluster computers for fast rendering of complex scenes. Alternately, the tool could feature a server-based functionality where the front-end user-interactions are through a webpage (using Java, HTML or other alternatives) and the computations are remotely conducted. Support for multiple concurrent users for content creating is desired. Ease of user interaction is key to the success of the tools. It is expected that at the end of Phase I, the performer will deliver an architecture document that captures the full intent of the tool. Similarly, performer will deliver software prototype of the implementation of the tool. It is expected that the software at the end of Phase I will be a prototype and may not have all features implemented or debugged. Performer will identify options for desired licensing options for the software to be developed for Phase II. At the end of Phase II, the performer will deliver all source code associated with the tool and verification test cases demonstrating all the proposed features within the software. The performer will also deliver a document summarizing the installation and usage of the tool and appropriate licensing options. In case of use of any third party software (e.g., open-source code) in this effort, the performer will deliver an acknowledgement that they have complied with appropriate licensing agreements. The anticipated TRL level at the end of Phase II is 5-6.

**Computational Optimization** - We solicit proposals for developing numerical tools that enable robust continuous and discrete optimization as well as sensitivity analysis for physics based computational models. There are a number of open-source and proprietary tools that are capable of meeting this objective at various levels of success. We are interested in proposals that develop a standard API for using the various open-source tools for different kinds of numerical problems. This would be in the form of a cross-platform abstraction API that enables users to have a standard API set for interacting with different optimization engines. We are also interested in software for autonomous optimization (genetic algorithms, simulated annealing, etc.), mixed (discrete and continuous) optimization problems and human-in-the-loop optimization / minimization. Methods for classifying problems (potentially in a catalogue) and associating them with solution methods are also of interest. Methods for measuring the similarity between a new problem with those solved in the past (e.g., those in a catalogue) and hence identifying associated solution method(s) are of high interest. Phase I deliverables should include:

- A document summarizing the different numerical methods that would be implemented in Phase II and representative numerical examples of these methods developed in Matlab or similar program.
- Pseudo-code of the abstraction API.
- Architecture for classification (or cataloguing) problems with their solution methods and measuring similarity between problems.
Performer will identify options for desired licensing options for the software to be developed for Phase II. At the end of Phase II, the performer will deliver all source code associated with the abstraction API and as well as the software tool for interfacing with different numerical engines for solving optimization or sensitivity analysis problems, mechanisms for cataloguing problems and measuring similarity between problems. Performer will deliver verification test cases demonstrating the proposed features within the software. The performer will also deliver a document summarizing the installation and usage of the software and appropriate licensing options. In case of use of any third party software (e.g., open-source code) in this effort, the performer will deliver an acknowledgement that they have complied with appropriate licensing agreements. The anticipated TRL level at the end of Phase II is 4-6.

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 Fidelity Predictions for Spacecraft and Launch Vehicle Vibroacoustic Environments and Coupling

Lead Center: LaRC

Participating Center(s): MSFC, SSC

Fully verified and validated physics-based methods are desired to predict aero-acoustic and buffet loads experienced by launch vehicles and the resulting structural response. Prediction improvements in both the external environments and transmitted internal vibration are needed to better design lighter and cheaper spacecraft and launch vehicle structure as well as lower costs associated with ruggedizing and qualifying spacecraft and launch vehicle secondary structures. New methods are needed to improve environment predictions in terms of absolute levels, spatial definition including cross-spectra, and associated dispersions. Innovations in the following specific areas are solicited:

- Fundamental physics based CFD predictions of the flow over compression and expansions corners and protuberances and the resulting fluctuating pressure loads.
- Wind tunnel and/or flight tests to provide validation data of the cross spectra dynamic loads for the above problem areas and for the influence of protuberance disturbed pressure fields on vibration.
- Innovative approaches to measure full spectrum surface loads over broad areas to 8kHz full scale.
- New techniques to measure and predict rocket plume-induced fluctuating pressure loads.
- Concepts to accurately and efficiently couple these loads to realistic launch vehicle structures.
- Improved deterministic and statistical modeling of the loads and resulting vibration and transmission.
- Improved integration of vibro-acoustic design criteria into early structural design to provide more effective trade-off studies.

T12.02 High Temperature Materials and Sensors for Propulsion Systems

Lead Center: GRC

Participating Center(s): AFRC, ARC, LaRC, MSFC, SSC

Advanced high temperature materials, structures and sensors are crosscutting technologies which are essential in the design, development and health maintenance/detection needs of components and subsystems that will be needed in future generations of aeronautical and space propulsion systems. The extreme temperature and environmental stability requirements posed by aerospace propulsion systems requires material improvements to meet the challenges of systems of the future. Increased temperature capability can be achieved through the development of new and improved materials as well as through innovative designs, with both materials and designs dependent on advanced processing techniques. The combined effect of environment plus mechanical/thermal loading is expected to have a greater degree of influence on the durability of aerospace high temperature
materials. Nanotechnology offers a means to develop higher-temperature/environmentally-resistant structural materials with engineered microstructures that can optimize material properties for propulsion hot section components. Multifunctional materials and structures offer a means to reduce component weight in aerospace flight vehicles, enabling efficiency, performance improvements and reduced fuel burn for aircraft and greater payload mass and launch cost reduction for spacecraft. The small volume and high force-to-weight ratio of shape memory alloys are an attractive actuator replacement for current ones based on electric motors, hydraulic or pneumatic systems. Sensing methods and measurement techniques that are cost-effective and reliably assess the health of aerospace engines and vehicle components in harsh high-temperature environments (to 3000 °F) allow for a proactive approach to maintain capability and safety. Proposals are sought to:

- Develop innovative approaches to enhance the processability, performance and reliability of advanced high temperature materials, including metals, ceramics, polymers, high-strength fibers, composites, hybrids and coatings to improve environmental durability for engine components.
- Develop innovative methods, evaluate and model the impact on the mechanical properties of representative aerospace materials tested while resident in the extreme application environment, to compare to mechanical property testing in air or in vacuum.
- Demonstrate novel processing approaches (simpler, more cost effective) for advanced aerospace materials for propulsion systems.
- Develop physics-based modeling tools to predict durability and life based on damage mechanisms of advanced materials.

T12.03 Additive Manufacturing of metal Plus Insulator Structures with sub-mm Features

Lead Center: GSFC

NASA is interested in investigating additive manufactured structures combining metals and insulators demonstrating multiple layers of 10-500 um lines and spaces, 200 um thick insulator layers, and 200 um diameter blind vias on 400 um centers capable of withstanding ~800 V between layers.

Expected Deliverables: Fabrication of a small area, few cm², micro-well detector with 200 um diameter holes, 200 um deep, on 400 um centers that operates up to ~800 V. Demonstration of scalability to large, ~1 m², area.

Mission Traceability: The Advanced Energetic Pair Telescope (AdEPT), a medium energy gamma-ray polarimeter.

Beyond the initial medium-energy gamma-ray instrument application, NASA foresees a wide range of further scientific space instruments enabled by additive manufacturing (3-D printing) that combines metals and insulators with sub-mm feature sizes. Possibilities include fabrication of electro-mechanical structures for ionization detectors, mass spectrometers, charged particle detectors et cetera for both small and large scale space missions.

In addition, this is a generic technology which would also be suitable for fabrication of commercial grade, micro-scale electronics.

State of the Art: Additive manufacturing with metals or insulators (plastics) is advancing rapidly. SOA is limited in feature size, inability to combine metals and insulators, and surface smoothness needed for high voltage applications. 3-D additive manufacturing that combines insulators and conductors is being pursued by several entities. Combining metals and insulators with sub-mm features would provide significant improvements in performance and size of the micro-well detectors for AdEPT. Current micro-well fabrication using laser micro-machining requires RIE post processing to eliminate residue from laser ablation that leads to high voltage breakdown in the micro-wells.

T12.04 Experimental and Analytical Technologies for Additive Manufacturing

Lead Center: MSFC

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

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

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

- Additive Manufacturing Technologies: Develop real-time additive manufacturing process monitoring for real-time material quality assurance prediction; Finish inspection and qualification of parts for implementation, replacement, and repair; Develop standards for accepting additively manufactured parts for use in space systems.
- Research-grade test beds: Experimental test beds that will allow for detailed study of individual phases of the SLM and other methods of additive manufacturing by NASA scientists, academic groups, etc. (Affordability of test bed will be crucial for fostering a large community of developers for next-generation SLM/AM systems.)
- Physics-based models: Reduced-order physics models for individual phases of additive manufacturing techniques, mainly to enable rapid processing of process data and to facilitate model-based optimal process control. (Note that most, if not all, phases of the SLM cycle requires coupled multi-physics modeling.)
- Analytical Tools: Develop analytical tools to understand effects of process variables on materials evolution to insure expected material microstructure and apply to certification of manufacturing process.
- Digital models: Standardize the use of structured light scanning or equivalent within manufacturing processes; model-based design environment where manufacturing does not rely on both models and drawings for data; standard paperless manufacturing execution system; digital fabrication machines that combine additive, subtractive, and other multi-axial material transformation processes.
- Numerical simulation codes: Software for high-fidelity simulation of various SLM phases for guiding the development, and enabling the subsequent verification, of new analytical physics models.

Mission Traceability - STMD continues to seek manufacturing techniques and capabilities that will allow missions of increased capability and reduced costs. 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.

State of the Art - Advanced Manufacturing is rapidly evolving, and newer technologies are emerging. The first in-space 3-D print experiment will fly in 2014, and related technologies will follow exponentially.

Ground and Launch Systems Processing Topic T13
Reserved for future Solicitations.
Sub Topics:
- Thermal Management Systems Topic T14
Reserved for future Solicitations.
Sub Topics:
- Aeronautics Topic T15
Reserved for future Solicitations.
Sub Topics:
- Affordable Nano-Launcher Upper Stage Propulsion Topic T1.01
Small satellites are becoming ever more capable of performing valuable missions for both government and commercial customers. However, currently these satellites can only be launched affordably as secondary payloads. This makes it difficult for the small satellite mission to launch when needed, to the desired orbit, and with acceptable risk. A dedicated launch vehicle is needed that will affordably meet the small sat launch needs. This subtopic
solicits technology proposals for the upper stage propulsion system of such a launcher. Specifically, the subtopic requests proposals for propulsion design tools, systems, and stages for application as upper stages or orbit insertion stages with the following goals and constraints:

- A recurring stage cost not to exceed $100K (for 8/year).
- The stage shall be capable of providing at least 13,000 fps delta-v to a 150 lbm mass from in vacuum conditions.
- The stage shall be designed to a diameter of 3.0 ft or less.
- The stage shall be capable of compressively supporting 700 lbf on its forward end (in addition to its own loaded mass).
- Total stage wet mass shall not exceed 1800 lbm.
- Other desired functionality include TVC, basic health and status monitoring, and throttling.
- Design analysis techniques that provide rapid, high fidelity insight into the operation of these systems are also needed.

Technologies meeting these goals will support development of an affordable launcher capable of delivering 55 lbm to 100 lbm to low-earth orbit. Phase I activities will develop the data necessary to assert with confidence that the proposed technology solution will meet the goals of the subtopic. Phase II activities will provide functionality verification and substantiation of recurring cost.

Mission Traceability - STMD, HEOMD, and SMD all have missions that would benefit from this technology. In particular, STMD’s SST and GCD Programs have expressed a strong need.

Sub Topics:
- Small Launch Vehicle Propulsion Technology Topic T1.02
  Small satellites are becoming ever more capable of performing valuable missions for both government and commercial customers. However, currently these satellites can only be launched affordably as secondary payloads on large launch vehicles. This makes it difficult for the small satellite mission to launch when needed, to the optimal orbit, and with acceptable risk to the mission. There is no affordable, dedicated launcher available that will meet the small satellite launch needs. This subtopic solicits technology proposals for the boost propulsion system(s) of such a launcher. Specifically, the subtopic requests proposals for propulsion systems for application as first stages or strap-on boosters with the following functional and cost goals and within the following geometric constraints:

  - **Cost goal** - Assuming a production rate of 8 boost systems per year, a recurring stage cost of $400K
  - **Total Impulse goal** - The stage shall be capable of providing 2.5M lbf-sec total impulse
  - **Delta-V goal** - The stage shall be capable of providing 6800 fps delta-v to a 8,000 lbm mass from ground launch.
  - **Size goal** - The stage shall be designed to fit within the size envelope of height of 25 ft and a diameter of 3.5 ft for individual elements. If a cluster of elements is proposed, the central element should stay within this envelope.
  - **Strength goal** - It shall be capable of structurally supporting (compressively) 8,000 lbf/lbm for use as a core booster stage.

  Though not explicit goals, other desired functionality in the first stage include thrust vector control (TVC), basic health and status monitoring, and throttling.

Technologies meeting these goals will support development of a 25 kg to 50 kg payload launcher to low-earth orbit. Phase I activities will be used to develop the data necessary to assert with confidence that the proposed technology solution will meet the goals of the subtopic. Phase II activities will include verification of functionality, as much as possible through testing, and substantiation of recurring cost projections. At the end of Phase II there will be sufficient validation of the technology to warrant purchase of one or more stages for initial flight testing under potential follow-on activities.

Sub Topics:
- Innovative Energy Harvesting Technology Development Topic T3.01
  The NRC has identified a NASA Top Technical Challenge as the need to “Increase Available Power”. Additionally, a NASA Grand Challenge is “Affordable and Abundant Power” for NASA mission activities. As such, 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. 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:
Dynamic Servoelastic (DSE) Network Control, Modeling, and Optimization Topic T4.01
This subtopic addresses advanced control-oriented techniques for dynamic servoelastic (DSE) terrestrial, planetary, and space environment flight systems using distributed network sensor and control systems. Methods include modeling, simulation, optimization and stabilization of DSE systems to actively and/or adaptively control structural dynamic geometry/topology, vibration, atmospheric and intraspace disturbances, static/dynamic loads, and other structural dynamic objectives for enhanced dynamic servoelastic performance and stability characteristics.

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

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

Technical elements for the Phase I proposals may also include:

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

Development of distributed sensory-driven control-oriented DSE systems is solicited to enable future flight vehicle concepts and designs that manage structural dynamic uncertainty on a vehicle’s overall performance. Proposals should assist in revolutionizing improvements in performance to empower a new generation of air and space vehicles to meet the challenges of terrestrial and commercial space concerns with novel concepts and technology developments in systems analysis, integration and evaluation. Higher performance measures include energy efficiency to reduce fuel burn and operability technologies that enable information network decompositions that have different characteristics in efficiency, robustness, and asymmetry of information and control with tradeoff between computation and communication.

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

• 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:
Regolith Resources Robotics - R3 Topic T4.02
The use of robotics for In-Situ Resource Utilization (ISRU) in outer space on various planetary bodies is essential since it uses large quantities of regolith that must be acquired and processed. In some cases this will happen while the crew is not there yet, or it will take place at a remote destination where the crew cannot spend much time due to radiation exposure limits (Asteroids, Mar’s Moons and NEO’s). Communications latencies of greater than 40 minutes at Asteroids mandate autonomous robotics applications. Proposals are sought which provide solutions for the following space resource related technology area:
Asteroid Resource Prospecting and Characterization - The first step towards using resources derived from small bodies in space, such as water, volatiles, metals and organic compounds is to visit the Near Earth Object (NEO) target body and prospect it with sample acquisition devices and subsequently do characterization of these samples. Proposals are sought for innovative resource prospecting mission concepts and associated technology demonstrations such as autonomous small marsupial free flyer prospector spacecraft that can sample an asteroid, comet or Mars moon and transport the sample back to a locally orbiting spacecraft with an associated suite of characterization instruments for analysis.

Sub Topics:

Autonomous Communications Systems Topic T5.01
Future missions will require end to end communications systems that can support greater levels of autonomy and possess greater awareness of the environment and knowledge of assets that can be used for enhanced reach back and data delivery. Autonomous Communications Systems (ACS) have the potential to improve overall system performance and reduce the user burden associated with configuring and managing communications systems through the use of automated systems-level analysis and configuration control.

An ACS nominally includes the Radio/Optical subsystems and the storage and networking subsystems capable of supporting autonomous network operations. ACS capabilities would also support on-board learning to extract, catalog, and utilize information from both positive and negative experiences to enhance nominal and anomalous situations. Other desired enabling functions would include:

- Ability to increase the capabilities of on-board communications services to make network connections self-configurable and autonomous. Further advances would lead to the ability to determine how a learning system would be implemented in an on-board system, such as Artificial Intelligence.
- Ability to determine the type and how on-board information, including settings, would be exchanged between the communications components.
- Smart environment sensing capable of mitigating outages, interference and performance degradation. This could include Spectrum resource allocation and/or Dynamic frequency assignment capability to enhance throughput and connectivity.
- Low power, low cost, flexible receiver front ends that allows for efficient spectrum utilization (i.e., frequency reconfigurable) and are compatible with SDR/cognitive radio platforms allowing the use of multiple waveforms and autonomous operation to increase capacity and to enable more efficient high-data data handling and delivery, are of interest. In particular, the following enabling technologies should be addressed:
  - Frequency, pattern, polarization (FPP) agile reconfigurable antennas.
  - Dynamic impedance matching networks.
  - Digital beam forming antennas.
  - Testbeds addressing one or more of the above.

State of the Art - Current NASA flight transceivers are capable of performing communication and radiometrics. With the recent launch of the SCaNTestbed on the ISS, advances in software defined radios (SDRs) that are reconfigurable are now being assessed to support communications, navigation and networking experiments and applications. However, today's flight transceivers and SDRs are not aware of their environment and do not react to it; hence lack ability to support autonomous network operations.

Background/Rationale - NASA HEOMD and SMD conduct scientific exploration that is enabled by access to space and innovative technologies to expand mankind's understanding of planet earth and the universe. Communications and navigation technologies are integral in projecting humankind's vantage point into space with observatories in Earth orbit and deep space, spacecraft visiting the Moon and other planetary bodies, and robotic landers, rovers, and sample return missions. As the needs to gather more data and extend mankind's presence beyond low earth orbit, even more advanced communications and navigation technologies will be essential to deliver orders of magnitude more data and enable greater participation by the public through high-data rate telepresence networks.

Sub Topics:

Synthetic/Engineering Biology for NASA Applications Topic T6.01
Synthetic Biology (SB) provides a unique opportunity to engineer organisms that reliably perform necessary functions for future exploration activities. NASA is interested in harnessing this emerging field to create technological advances that will benefit both spaceflight and future surface missions in a variety of enabling areas. Proposals must use a biologically-based approach, such as synthetic biology, to engineer novel biologically-based
(or inspired) functions that do not exist in nature. Proposed projects may include creating new capability by
designing microorganisms, plants, and/or cell-free systems for air revitalization, water recovery, in situ resource
utilization, and/or the production of novel chemicals and biomolecules of benefit to space exploration. Applications
may include (but are not limited to) more reliable and efficient life support systems; the acquisition and utilization of
in situ resources; and the production of consumables such as feedstock for advanced manufacturing or food.
Proposals should address how systems and technologies will reduce the required up-mass and dependence on
consumables, resupply, and energy.

Of additional interest is the miniaturization and automation of critical technologies required to monitor and
implement synthetic biology beyond low Earth orbit.

All proposals should consider the novel environment in which these systems will eventually be deployed – this
includes altered gravity, temperature extremes, high radiation, etc.

Sub Topics:

- **Metal Organic Framework Sorbents for Spacecraft Medical Applications Topic T6.02**
  Metal Organic Frameworks (MOFs) are a new class of porous materials in which metal-to-organic ligand
  interactions yield structured three dimensional porosity. MOFs have several important attributes:

  - They have ultrahigh porosity.
  - MOFs have demonstrated thermal and chemical stability.
  - They can be synthesized into a wide variety of structures with a wide range of pore sizes.
  - They can be synthesized to be superhydrophobic.

  Because of these attributes, MOFs show promise to improve the efficiency and effectiveness of practical gas
  separation systems.

  To ensure human health for space exploration, NASA seeks the capability to administer therapeutic oxygen in a
  medical emergency. In a traditional hospital setting, medical oxygen can be delivered, and the excess oxygen is
diluted and ventilated. In a confined spacecraft, administering medical oxygen by conventional means can cause
ambient oxygen levels to exceed flammability limits. If oxygen could be efficiently concentrated from spacecraft
cabin air, medical oxygen could be administered without increasing oxygen levels in the cabin. State of the art
oxygen concentrators are too large and use too much energy to effectively operate in a spacecraft environment, in
part because the oxygen separation sorbents are adversely affected by the presence of water vapor.

  Much attention is being paid on using MOFs to store fuels such as hydrogen under practical conditions. This
solicitation, however, is focused on exploiting the properties of MOFs to separate oxygen from cabin air. Thermal
and chemical stability, selectivity in the presence of water, and selectivity under dynamic gas separation conditions
are especially important. In addition to water selectivity, some operational scenarios require oxygen separation
from air that contains elevated levels of CO, CO₂, HCN, and HF.

  **Sub Topics:**

  Technologies for Planetary Compositional Analysis and Mapping Topic T8.01
  This subtopic is focused on developing and demonstrating technologies for both orbital and in situ compositional
  analysis and mapping that can be proposed to future planetary missions. Technologies that can increase
  instrument resolution, precision and sensitivity or achieve new and innovative scientific measurements are solicited.
  For example missions, see [http://science.hq.nasa.gov/missions](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

  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.

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

Sub Topics:
- Next Generation Total Lightning Detection Sensor Topic T8.02
  NASA is concerned with the uncertainty of the current lightning detection sensors. The location accuracy and detection efficiency are both lacking, currently at less than 90% and 250m respectively. Total lightning detection with location accuracy in the meters should be the requirement of the next generation launch vehicle and ground operations. NASA seeks to foster research and development that leads to innovative new technologies and methods, or significant improvements in existing technologies, for in-cloud and cloud-to-ground lightning detection. The current total lightning detection technology has been fairly stagnant for the last decade, with the only improvements being small tweaks to location accuracy and classification algorithms and requiring both a suite of cloud-to-ground sensors and inter-cloud sensors. The combination is cost prohibitive to most locations and requires a large array of sensors spanning tens of meters to create solutions. Through current collaborations with other government agencies, the NASA team has come across several universities and at least two small businesses that have conceptual designs that could potentially deliver a brand new sensor with the detection capability to meet the important technology gap. Based on an early assessment of these small business and university concepts, it is likely that systems could be developed within the next 2-3 years, at great cost efficiencies for NASA while providing the needed detection and location accuracy.
  
  Under this subtopic, proposals are invited that explore novel sensors and sensor systems for the detection of both inter-cloud and cloud-to-ground lightning. With regard to detection efficiency and location accuracy, the emphasis is developing systems that have a near total detection and are accurate within 10s of meters. Approaches that use multiple sensors in combination to improve detection and location are also of interest. Technologies may take the form of prototypes and/or devices.

Sub Topics:
- Lightweight Structural Nanomaterial Concepts Topic T10.01
  Carbon fiber reinforced polymeric (CFRP) composites are considered state of the art (SOA) for lightweight aerospace structural materials. However, a systems study suggests that having specific mechanical properties that exceed CFRPs by 2-4x will yield significant savings in launch vehicles. Currently, SOA nanomaterials with potential to supplant CFRPs as the lightweight structural material of choice are available in formats possessing mechanical properties far below those measured at the nanoscale. These excellent nanoscale properties have to be demonstrated at scales that permit the evaluation of these materials in structural components with properties that offer mass advantage over CFRPs. Proposals are sought in the following areas:
  
  - Innovative approaches to chemically and/or physically enhance load carrying capability of nanomaterials and influence their macroscale mechanical properties as demonstrated by structural properties on the coupon scale that are at least double the specific strength and stiffness of epoxy CFRPs.
  - Manufacturing methods that permit the control of nanostructures at the molecular level to induce structural
perfection of such structures as to produce articles at the coupon scale which possess mechanical properties that are at least double those measured for epoxy CFRPs.

Sub Topics:

Smart Structural Composites for Space Topic T10.02

Advanced structural composites with the potential for enhanced damage detection are highly desired for spacecraft. Smart aspects, for example structural health monitoring or self-healing, should be introduced through utilization of advanced materials and nano-additives. Such composites could allow for the realization of the mass reduction that composite materials have promised for spacecraft but have not yet achieved.

NASA is currently evaluating composite materials for structures due to their relatively high strength, light weight, and potential low cost. There are a multitude of potential applications to primary and secondary structures, including vehicle, habitat module, and pressure vessel structures. Lighter materials with high specific strength can have drastic reduction in uptake mass, resulting in more cost effective space exploration. Smart materials such as piezoelectric, shape memory, and self-healing materials, will take structural composites to the next level.

One integral and limiting design concern for structural composites is that of damage tolerance. Upon impact, nearly imperceptible cracks may form upon impact, which, while tiny, may have drastic effects on structural integrity. To compensate, structural composites are designed to be thicker and heavier than would otherwise be required, thus negating the weight savings that these materials promise. One way to surmount this challenge and to realize the anticipated weight savings is to design smart materials. For instance, advanced materials and technologies should be developed to detect damage incidents, from tool drops during manufacturing to micrometeoroid and orbital debris impacts on orbit. Monitoring of extent of damage and the initiation of self-healing could reduce the complexity of composite maintenance and increase materials performance lifetime and reliability. Thermal/electrical/mechanical properties may be introduced or enhanced for multi-functionality such as thermal management or electrostatic discharge prevention and resultant weight savings. Overall, smart structures focused on space applications will have a significant impact on NASA's Space Exploration program.

While the subtopic description is broad, the offerer will narrowly define the composite system and intended applications. This subtopic is not intended for materials coupon-level work only; proposed systems should have a targeted demonstrator structure identified as a deliverable. Solutions may employ nanotechnology but are not required to do so. The smart structural composite should be proposed as an alternate material in this identified structure, with additional or enhanced functionality. In Phase I, composite samples will be fabricated and tested to demonstrate basic functionality. The targeted demonstrator structure will be identified, and critical test environments and associated performance predictions will be defined relative to the final operating environment. Deliverables include composite samples and the associated test data, predictions, and definitions. During Phase II, while full-scale parts are not required, scaled-up composite samples will be built in application-appropriate geometries. Samples will be tested in a simulated operational environment for demonstrate of performance in critical areas. Further scale-up requirements will be defined, and performance predictions will made for subsequent development phases. Deliverables will include composite samples and the associated test data, definitions, and predictions.

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

The objective of this subtopic is to develop information technologies that enable robots to better support space exploration. 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 and unskilled labor (site clean-up, close-out tasks, etc).

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 shared-autonomy and remotely operated robots, which facilitate distributed
collaboration, geospatial data visualization, summarization and notification, and robot tasking. This does
NOT include user interfaces for direct teleoperation / purely manual control (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.
• Mobile robot navigation (localization, hazard avoidance, etc.) for operations in man-made (inside human
spacecraft) and unstructured environments (planetary surfaces). 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 sensors, perception algorithms and
software.
• Robot software architecture that radically reduces operator workload for remotely operating mobile robots.
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.

Deliverables to NASA:

• Identify scenarios and use cases.
• Define specifications based on design trades.
• Develop concepts to address use cases.
• Demonstrate prototype systems and technology demonstrations.

Sub Topics:

Computational Simulation and Engineering Topic T11.02

Virtual Worlds - We solicit proposals for development of computational tools that enable rapid demonstration of
mission concepts. The intent of such a tool is to enable non-experts in animation to rapidly build mission scenarios
and visually express their concepts in a virtual world. These tools should enable full 3D visualization by importing of
CAD parts of electromechanical systems (e.g., rovers, landers, orbiters), environment models (height field maps
with textures for terrain, star maps and planetary bodies), animation functionality to show temporal progression and
movement of appropriate objects in the scene. The tool should support animation of flexible bodies (e.g., solar
panel vibrations) along with articulation of components. The tool should feature a ray-tracing engine for good
quality visualization with shadowing, ambient lighting, etc. The tool should also be able to demonstrate terrain
artifacts such as rocks, dust and ejecta as both static and dynamic objects. An example of a static artifact may be a
rock pile that does not move during the animation while a dynamic artifact may be dust rising from a lander thruster
interaction with terrain. Note that the emphasis is on visualization and not necessarily on the physics of the
problem. However, the tool should have a standard API for integration with physics engines (e.g., ODE, Bullet,
Proprietary Code) so that physics simulations can be used to control temporal progression of a scene. While it is
preferred to have a representative physics engine coupled to the tool, it is not required. There should also be a
functionality to write simple scripts for animating the virtual entities. There should be an avenue for developing a
library of animation objects (e.g., rovers, terrains and locations) for re-use in later concept developments. The tools
should be cross platform and enable development of animations or movies. The tool should take advantage of
graphics processors or enable use of cluster computers for fast rendering of complex scenes. Alternately, the tool
could feature a server-based functionality where the front-end user-interactions are through a webpage (using
Java, HTML or other alternatives) and the computations are remotely conducted. Support for multiple concurrent
users for content creating is desired. Ease of user interaction is key to the success of the tools. It is expected that
at the end of Phase I, the performer will deliver an architecture document that captures the full intent of the tool.
Similarly, performer will deliver software prototype of the implementation of the tool. It is expected that the software
at the end of Phase I will be a prototype and may not have all features implemented or debugged. Performer will
identify options for desired licensing options for the software to be developed for Phase II. At the end of Phase II,
the performer will deliver all source code associated with the tool and verification test cases demonstrating all the
proposed features within the software. The performer will also deliver a document summarizing the installation and
usage of the tool and appropriate licensing options. In case of use of any third party software (e.g., open-source
code) in this effort, the performer will deliver an acknowledgement that they have complied with appropriate
licensing agreements. The anticipated TRL level at the end of Phase II is 5-6.

Computational Optimization - We solicit proposals for developing numerical tools that enable robust continuous and
discrete optimization as well as sensitivity analysis for physics based computational models. There are a number of
open-source and proprietary tools that are capable of meeting this objective at various levels of success. We are
interested in proposals that develop a standard API for using the various open-source tools for different kinds of numerical problems. This would be in the form of a cross-platform abstraction API that enables users to have a standard API set for interacting with different optimization engines. We are also interested in software for autonomous optimization (genetic algorithms, simulated annealing, etc.), mixed (discrete and continuous) optimization problems and human-in-the-loop optimization / minimization. Methods for classifying problems (potentially in a catalogue) and associating them with solution methods are also of interest. Methods for measuring the similarity between a new problem with those solved in the past (e.g., those in a catalogue) and hence identifying associated solution method(s) are of high interest. Phase I deliverables should include:

- A document summarizing the different numerical methods that would be implemented in Phase II and representative numerical examples of these methods developed in Matlab or similar program.
- Pseudo-code of the abstraction API.
- Architecture for classification (or cataloguing) problems with their solution methods and measuring similarity between problems.

Performer will identify options for desired licensing options for the software to be developed for Phase II. At the end of Phase II, the performer will deliver all source code associated with the abstraction API and as well as the software tool for interfacing with different numerical engines for solving optimization or sensitivity analysis problems, mechanisms for cataloguing problems and measuring similarity between problems. Performer will deliver verification test cases demonstrating the proposed features within the software. The performer will also deliver a document summarizing the installation and usage of the software and appropriate licensing options. In case of use of any third party software (e.g., open-source code) in this effort, the performer will deliver an acknowledgement that they have complied with appropriate licensing agreements. The anticipated TRL level at the end of Phase II is 4-6.

Sub Topics:

High Fidelity Predictions for Spacecraft and Launch Vehicle Vibroacoustic Environments and Coupling Topic T12.01

Fully verified and validated physics-based methods are desired to predict aero-acoustic and buffet loads experienced by launch vehicles and the resulting structural response. Prediction improvements in both the external environments and transmitted internal vibration are needed to better design lighter and cheaper spacecraft and launch vehicle structure as well as lower costs associated with ruggedizing and qualifying spacecraft and launch vehicle secondary structures. New methods are needed to improve environment predictions in terms of absolute levels, spatial definition including cross-spectra, and associated dispersions. Innovations in the following specific areas are solicited:

- Fundamental physics based CFD predictions of the flow over compression and expansions corners and protuberances and the resulting fluctuating pressure loads.
- Wind tunnel and/or flight tests to provide validation data of the cross spectra dynamic loads for the above problem areas and for the influence of protuberance disturbed pressure fields on vibration.
- Innovative approaches to measure full spectrum surface loads over broad areas to 8kHz full scale.
- New techniques to measure and predict rocket plume-induced fluctuating pressure loads.
- Concepts to accurately and efficiently couple these loads to realistic launch vehicle structures.
- Improved deterministic and statistical modeling of the loads and resulting vibration and transmission.
- Improved integration of vibro-acoustic design criteria into early structural design to provide more effective trade-off studies.

Sub Topics:

High Temperature Materials and Sensors for Propulsion Systems Topic T12.02

Advanced high temperature materials, structures and sensors are crosscutting technologies which are essential in the design, development and health maintenance/detection needs of components and subsystems that will be needed in future generations of aeronautical and space propulsion systems. The extreme temperature and environmental stability requirements posed by aerospace propulsion systems requires material improvements to meet the challenges of systems of the future. Increased temperature capability can be achieved through the development of new and improved materials as well as through innovative designs, with both materials and designs dependent on advanced processing techniques. The combined effect of environment plus mechanical/thermal loading is expected to have a greater degree of influence on the durability of aerospace high temperature
materials. Nanotechnology offers a means to develop higher-temperature/environmentally-resistant structural materials with engineered microstructures that can optimize material properties for propulsion hot section components. Multifunctional materials and structures offer a means to reduce component weight in aerospace flight vehicles, enabling efficiency, performance improvements and reduced fuel burn for aircraft and greater payload mass and launch cost reduction for spacecraft. The small volume and high force-to-weight ratio of shape memory alloys are an attractive actuator replacement for current ones based on electric motors, hydraulic or pneumatic systems. Sensing methods and measurement techniques that are cost-effective and reliably assess the health of aerospace engines and vehicle components in harsh high-temperature environments (to 3000 °F) allow for a proactive approach to maintain capability and safety. Proposals are sought to:

- Develop innovative approaches to enhance the processability, performance and reliability of advanced high temperature materials, including metals, ceramics, polymers, high-strength fibers, composites, hybrids and coatings to improve environmental durability for engine components.
- Develop innovative methods, evaluate and model the impact on the mechanical properties of representative aerospace materials tested while resident in the extreme application environment, to compare to mechanical property testing in air or in vacuum.
- Demonstrate novel processing approaches (simpler, more cost effective) for advanced aerospace materials for propulsion systems.
- Develop physics-based modeling tools to predict durability and life based on damage mechanisms of advanced materials.

Sub Topics:
- **Additive Manufacturing of metal Plus Insulator Structures with sub-mm Features Topic T12.03**
  NASA is interested in investigating additive manufactured structures combining metals and insulators demonstrating multiple layers of 10-500 um lines and spaces, 200 um thick insulator layers, and 200 um diameter blind vias on 400 um centers capable of withstanding ~800 V between layers.

**Expected Deliverables:** Fabrication of a small area, few cm², micro-well detector with 200 um diameter holes, 200 um deep, on 400 um centers that operates up to ~800 V. Demonstration of scalability to large, ~1 m², area.

**Mission Traceability:** The Advanced Energetic Pair Telescope (AdEPT), a medium energy gamma-ray polarimeter.

Beyond the initial medium-energy gamma-ray instrument application, NASA foresees a wide range of further scientific space instruments enabled by additive manufacturing (3-D printing) that combines metals and insulators with sub-mm feature sizes. Possibilities include fabrication of electro-mechanical structures for ionization detectors, mass spectrometers, charged particle detectors et cetera for both small and large scale space missions.

In addition, this is a generic technology which would also be suitable for fabrication of commercial grade, micro-scale electronics.

**State of the Art:** Additive manufacturing with metals or insulators (plastics) is advancing rapidly. SOA is limited in feature size, inability to combine metals and insulators, and surface smoothness needed for high voltage applications. 3-D additive manufacturing that combines insulators and conductors is being pursued by several entities. Combining metals and insulators with sub-mm features would provide significant improvements in performance and size of the micro-well detectors for AdEPT. Current micro-well fabrication using laser micro-machining requires RIE post processing to eliminate residue from laser ablation that leads to high voltage breakdown in the micro-wells.

**Sub Topics:**
- **Experimental and Analytical Technologies for Additive Manufacturing Topic T12.04**
  Additive manufacturing is becoming a leading method for reducing costs, increasing quality, and shortening schedules for production of innovative parts and component that were previously not possible using more traditional methods of manufacturing. In the past decade, methods such as selective laser melting (SLM) have emerged as the leading paradigm for additive manufacturing (AM) of metallic components, promising very rapid, cost-effective, and on-demand production of monolithic, lightweight, and arbitrarily intricate parts directly from a CAD file. In the push to commercialize the SLM technology, however, the modeling of the AM process and physical properties of the resulting artifact were paid little attention. As a result, commercially available systems are based largely on hand-tuned parameters determined by trial and error for a limited set of metal powders. The system operation is far from optimal or efficient, and the uncertainty in the performance of the produced component
is too large. This, in turn, necessitates a long and costly certification process, especially in a highly risk-aware community such as aerospace.

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

- Additive Manufacturing Technologies: Develop real-time additive manufacturing process monitoring for real-time material quality assurance prediction; Finish inspection and qualification of parts for implementation, replacement, and repair; Develop standards for accepting additively manufactured parts for use in space systems.
- Research-grade test beds: Experimental test beds that will allow for detailed study of individual phases of the SLM and other methods of additive manufacturing by NASA scientists, academic groups, etc. (Affordability of test bed will be crucial for fostering a large community of developers for next-generation SLM/AM systems.)
- Physics-based models: Reduced-order physics models for individual phases of additive manufacturing techniques, mainly to enable rapid processing of process data and to facilitate model-based optimal process control. (Note that most, if not all, phases of the SLM cycle requires coupled multi-physics modeling.)
- Analytical Tools: Develop analytical tools to understand effects of process variables on materials evolution to insure expected material microstructure and apply to certification of manufacturing process.
- Digital models: Standardize the use of structured light scanning or equivalent within manufacturing processes; model-based design environment where manufacturing does not rely on both models and drawings for data; standard paperless manufacturing execution system; digital fabrication machines that combine additive, subtractive, and other multi-axial material transformation processes.
- Numerical simulation codes: Software for high-fidelity simulation of various SLM phases for guiding the development, and enabling the subsequent verification, of new analytical physics models.

Mission Traceability - STMD continues to seek manufacturing techniques and capabilities that will allow missions of increased capability and reduced costs. 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.

State of the Art - Advanced Manufacturing is rapidly evolving, and newer technologies are emerging. The first in-space 3-D print experiment will fly in 2014, and related technologies will follow exponentially.

Sub Topics: