NASA SBIR 2010 Phase I Solicitation

Space Operations

Space Communications Topic O1

NASA’s communications capability is based on the premise that communications shall enable and not constrain missions. Communications must be robust to support the numerous missions for space science, Earth science and exploration of the universe. Technologies such as optical communications, RF including antennas and ground based Earth stations, surface networks, access links, reprogrammable communications systems, advanced antenna technology, transmit array concepts and communications in support of launch services including space based assets are very important to the future of exploration and science activities of the Agency. Emphasis is placed on size, weight and power improvements. Even greater emphasis is placed on these attributes as small satellites (e.g., micro and nano satellite) technology matures. Innovative solutions centered on operational issues are needed in all of the aforementioned areas. Communication technologies enabling acquisition of range safety data from sensitive instruments is imperative. All technologies developed under this topic area to be aligned with the Architecture Definition Document and technical direction as established by the NASA Office of Space Communications and Navigation (SCaN). For more details, see:

https://www.spacecomm.nasa.gov/spacecomm/ [1]

A typical approach for flight hardware would include: Phase I – Research to identify and evaluate candidate telecommunications technology applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration.

Bench or lab-level demonstrations are desirable. Phase II – Emphasis should be placed on developing and demonstrating the technology under simulated flight conditions. The proposal shall outline a path showing how the technology could be developed into space-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. Some of the subtopics in this topic could result in products that may be included in a future flight opportunity. Please see the following for more details:

SMD Topic S4 for more details concerning requirements for Small Satellite flight opportunities.

Note: Communications technologies for space-based range must be highly integrated with required navigation components; hence, space-based range technologies are solicited in Space Transportation Subtopic O2.03 – Spaceport Enhancements and Improvements.

Sub Topics:

O1.01 Antenna Technology

Lead Center: GRC
Participating Center(s): AFRC, GSFC, JPL, JSC, LaRC

NASA seeks advanced antenna technologies in the following areas: phased array antennas; ground-based uplink antenna array designs; large aperture deployable antennas; novel materials for next generation antennas; smart, reconfigurable antennas; and antenna concepts for harsh environments.

Phased Array Antennas

High performance phased array antennas are needed for high-data rate communication at Ka-Band frequencies and above as well as for remote sensing applications. Communications applications include: planetary exploration,
landers, probes, rovers, EVA, suborbital vehicles, sounding rockets, balloons, unmanned aerial vehicles (UAVs), TDRSS communication, and expendable launch vehicles (ELV’s). Also of interest are multi-band phased array antennas (e.g., X- and Ka-band) and RF/optical shared aperture dual use antennas, which can dynamically reconfigure active elements in order to operate in either band as required in order to maximize flexibility, efficiency and minimize the mass of hardware delivered to space. Phased array antennas for space-based range applications to accommodate dynamic maneuvers are also of interest. The arrays are required to be aerodynamic or conformal in shape for sounding rockets, UAV’s, and expendable platforms and must be able to withstand the launch environment. Potential remote sensing applications include: radiometers, passive radar interferometer platforms, and synthetic aperture radar (SAR) platforms for planetary science.

**Ground-based Uplink Antenna Array Designs**

NASA is considering arrays of ground-based antennas to increase capacity and system flexibility, to reduce reliance on large antennas and high operating costs, and eliminate single point of failure of large antennas. A large number of smaller antennas arrayed together results in a scalable, evolvable system, which enables a flexible schedule and support for more simultaneous missions. A significant challenge is the implementation of an array for transmitting (uplinking), which may or may not use the same antennas that are used for receiving. Arraying concepts that can enable a single network (i.e., DSN, NEN, and SN) at Ka-band frequencies and above are highly desired.

**Large Aperture Deployable Antennas**

Large aperture deployable antennas with surface root-mean-square (rms) quality better than ?/40 at Ka-Band frequencies and above, are desired. In addition, these antennas should significantly reduce stowage volume (packaging efficiencies as high as 50:1), provide high deployment reliability, and significantly reduced mass density (i.e., ?1kg/m2). These large Gossamer-like antennas are required to provide high-capacity communication links with low fabrication costs from deep space (Mars and beyond). Applicability to Ka-Band or higher frequencies is required. Concepts addressing antenna adaptive beam correction with pointing control are also of interest.

**Novel Materials for Next Generation Antennas**

NASA is interested in exploiting novel materials approaches for next generation antennas. For example, “smart” materials such as shape memory polymers or ionic polymer metal composites to permit active shape control or beam correction are of interest. Artificial electromagnetic media for phase velocity control and impedance tuning to improve the efficiency and bandwidth of electrically small antennas is of interest. Ferroelectric based technologies as well as multiferroics and spintronics concepts leading to new antenna designs are desirable.

**Smart, Reconfigurable Antennas**

Smart, reconfigurable antennas for applications in planetary operations are of interest. The characteristics to consider include the frequency, polarization, and the radiation pattern. Low-cost approaches are encouraged to reduce the number of antenna apertures needed to meet the requirements associated with rovers, pressurized surface vehicles, habitats, etc. for planetary surface exploration. Desirable features include multi-beam operation to support connectivity to different communication nodes on planetary surfaces, or in support of communication links for satellite relays around planetary orbits. Innovative receiver front-ends or technologies that allow for the DSP to move closer to the antenna terminal furthering the impact of the aforementioned, revolutionary “game-changing” antenna technology concepts are highly desirable.

**Antenna Concepts for Harsh Environments**

Novel, “Game Changing”, robust antenna concepts that can perform optimally and reliably in harsh environments such as those imposed by the Lunar regolith/dust and Martian dust are highly desirable. For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: A final report containing optimal design for the technology concept including feasibility of concept, and a detailed path towards Phase II hardware demonstration. The report shall also provide options for commercialization opportunities after Phase II.

Phase II Deliverables: A working proof-of-concept demonstrated and delivered to NASA for testing and verification. Exit TRL 5 is expected at the end of Phase II.
O1.02 Reconfigurable/Reprogrammable Communication Systems

Lead Center: GRC
Participating Center(s): AFRC, GSFC, JPL, JSC

This solicitation seeks advancements in reconfigurable transceiver and associated component technology. The goal of the subtopic is to provide flexible, reconfigurable communications capability while minimizing on-board resources and cost. Areas of interest to develop and/or demonstrate are as follows:

- Software/firmware for the management of waveform or functional reconfiguration. Simultaneous operation while reconfiguration takes place and an adherence to the Space Telecommunications Radio System (STRS) v 1.02.1 document is desired, which will soon be publicly available at https://www.spacecomm.nasa.gov/spacecomm/default.cfm [9]
  - Goal: Simultaneous operation while reconfiguration takes place.
  - Goal: STRS compliance
- Methods and tools for the development of software/firmware components that are portable across multiple platforms. Standards-based approaches are preferred.
  - Goal: Tool chain and/or development processes that result in 80% portability between 2 standards-based SDR platforms.
- Dynamic/distributed on-board processing architectures that are scalable and are designed to operate in various space environments.
  - Goal: 10x processing capability increase for fixed SWaP.
- Component technology advancements in bandwidth capacity and reduced resource consumption.
  - Goal: 5x bandwidth processing increase, 2x decrease in resource consumption.
- Analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities.
  - Goal: 3x increase in sampling resolution capabilities.
- Novel techniques or processes to increase memory densities.
  - Goal: 5x increase in memory per unit volume.
- Novel approaches to mitigate device susceptibility to radiation effects.
  - Goal: Target payload class SEU and latch-up mitigation techniques to achieve requirements for various class payloads in the desired space environment at lowest SWaP cost.

NASA also seeks to populate a repository for STRS compliant waveforms. These waveforms may be field or ported to available STRS-compliant SDRs. The description of STRS-compliance is available in the STRS 1.02.1 document, soon to be publicly available at https://www.spacecomm.nasa.gov/spacecomm/default.cfm. [9]

Note that NASA not only seeks reconfigurable/reprogrammable communication systems for flight applications, but also for the additional capabilities reconfigurable/reprogrammable systems may add to R&D and interoperability test labs. NASA centers have varying roles, capabilities, and R&D interests/priorities. Therefore, this year’s call will also take into consideration how the products from O1.03 (Phase I, II, and III) will contribute to the current administration’s vision for NASA and its commercial and international partners, and where these products may be relevant within our collection of terrestrial labs and/or flight systems.

The advancement of component technology for reconfigurable/reprogrammable communications systems is highly desirable for the insertion of these systems into space missions. Further adoption of reconfigurable/reprogrammable communications systems allow NASA science and human space flight missions to reduce risk and evolve as future requirements mature. These component technologies address either the reduction of size, weight, and power of these systems, or the costs associated with development.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: The Phase I deliverable consists of a report detailing the technical feasibility of the innovation and it’s contribution to the advancement of the state-of-the-art. The Phase I technology is expected to result in the component technology developed to TRL 2-3.
Phase II Deliverables: The Phase II deliverable consists of a demonstration of hardware and/or software prototype(s) with the intent of integration or testing in a relevant NASA laboratory, with a corresponding report detailing operating instructions for the component technology. The Phase II technology is expected to result in the component technology developed to TRL 5-6.

O1.03 Game Changing Technologies

Lead Center: GRC

Participating Center(s): ARC, JSC

NASA seeks revolutionary, highly innovative, game changing technologies that have the potential to enable order of magnitude performance improvements for space communications and navigation. Fundamental, strategic R&D is a critical element in developing innovative and superior technologies for space communication and navigation systems by addressing deficiencies in the current space communications network infrastructure to enhance performance, improve efficiency and reduce cost.

Research is geared towards emphasizing research and space technologies that are far-term focused in (but not limited to) the following areas:

- **Low SWAP Transceivers**: Develop novel techniques to reduce the size, weight, and power (SWAP) requirements for communications transceivers and software-defined radios for space missions. Address SWAP challenges by addressing digital processing and logic implementation tradeoffs, static vs. dynamic power, voltage and frequency scaling, hardware and software partitioning such that operational modes are effectively managed. Use of open, interoperable standards is encouraged.
- **Ka-band RF Devices and Components**: Investigate novel RF (especially Ka-band) communications technologies and innovative approaches for high bandwidth, Ka-band devices and components (transceivers, modulators, highly efficient amplifiers, etc.). Approaches to significantly reducing size, mass, and power requirements for these components are paramount as well.
- **High Performance Ultra Low-Power ADCs and DACs**: The high power consumption and lack of flexibility to reconfigure on-the-fly make off-the-shelf analog-to-digital converters (ADCs) devices ill-suited for digital radio applications. To en-able next-generation radios and support the ever-increasing user demands of high resolution (6 GS/s) and input bandwidths (2.5 GHz), breakthroughs in high-speed, low power ADCs are needed. Assume dynamically adjustable resolution up to 16 bits and on-board ultra-low jitter clock circuit to enhance spectral power distribution. A deep sleep mode feature is highly desirable to conserve power. Currently, state-of-the-art high rate digital-to-analog converters (DACs) are power prohibitive. To increase robustness, spectral efficiency, and compactness, NASA seeks to develop complementary DACs. For example, at a scant total power budget of 4 watts, ADCs and DACs will facilitate breakthroughs in S-band digital transceivers with fewer parts, smaller form factors, and greater design flexibility.
- **Nanotechnology**: High-performance, multi-functional, nano-structured materials for communications applications. Single wall carbon nano-tubes exhibit extraordinary mechanical, electrical, and thermal properties at the nano-scale level and possess exceptionally high surface area to volume ratio. The development of nano-scale communication devices and systems including nano-antennas, nano-transceivers, etc. are of interest for nano-spacecraft applications.
- **Quantum Entanglement**: Innovative breakthroughs in quantum information physics has sparked interest to specifically address this phenomenon and the critical unknowns relevant to revolutionary improvements in communicating data, information or knowledge. Methods or techniques that demonstrate extremely novel means of effectively packaging, storing, encrypting, and/or transferring information are sought.
- **RF MEMS Integrated Components**: RF micro-electromechanical systems (MEMS) offer exceptional RF performance and power characteristics that can lead to dramatic advantages for novel radio applications. Such as wireless filter banks, switching matrices, and instrumentation. Although low-power, high efficiency charge pumps can be integrated into advanced communication systems that employ novel MEMS devices (e.g. switches or varactors) or circuits (e.g. tunable filters or power amplifiers), there are some long-term challenges with power handling and non-linear behavior for power levels of 1 Watt. Because high-Q varactors and filters are not well understood, NASA seeks to advance revolutionary MEMS devices and architectures that are immune to bias noise.
- **Trans-Horizon Communications**: Innovative approaches to use of medium to high frequency (300
KH-30MHz) bands for applications benefiting future surface landing missions. Concepts, studies, development of key technologies are needed to perform non-line-of-sight communication for potential use on the surfaces of celestial bodies. For example, the lunar exosphere may have the ability to support such communications, if fully understood. Modulation and coding techniques, antennas, solid-state amplifiers, digital baseband circuitry, etc. are required to be developed and/or validated to enable over the horizon communication and communications into craters for robotic and human missions. Range of communications on the order of 10-20 kilometers at a data rate of 128 kbps is envisioned to support many of these types of surface communications links.

- Navigation: In adopting any proposed game-changing technologies, the capability for provision of high-quality metric tracking observables for orbit determination and other tracking services must be considered. Proposers should recognize that NASA may not be able to adopt certain game-changers in communications and navigation technology if they do not support at least NASA's current needs for metric tracking data services. Proposals in this area should document any potential performance enhancements, and especially any foreseeable compatibility issues associated with metric tracking data services.

- Low-Power High Stability Reference Sources: Highly stable clocks and oscillators play a pivotal role in a myriad of space communications and navigation applications. Atomic (cesium) clocks used today have time measurement accuracies on the order of 2 nanoseconds per day. New research (optical, quantum) into improving time measurement accuracy, size, reliability for space communications and navigation are of interest. Highly stable clock sources for wireless communications devices can improve network synchronization and channel selection to enhance security and anti-jamming capabilities.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Deliverables expected at the end of Phase I include trade studies, conceptual designs, simulations, analyses, reports, etc. at TRL 1-2.

Phase II Deliverables: Demonstrate performance of technique or product through simulations and models, hardware or software prototypes. It is expected that at the end of the Phase II award period, the resulting deliverables/products will be at or above TRL 3.

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O1.04 Long Range Optical Telecommunications

Lead Center: JPL

Participating Center(s): GRC, GSFC

This subtopic seeks innovative technologies for long range Optical Telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

Systems and technologies relating to acquisition, tracking and sub-micro-radian pointing of the optical communications beam under typical deep-space ranges (to 40 AU) and spacecraft micro-vibration environments, as follows:

- **Small lightweight two-axis gimbals:** Flight qualifiable, less than 2 kg in mass capable to actuating payload mass of approximately 3 kg at rates up to 5 degrees/second, less than 30 micro-radian jitter, 30 micro-radian rms error and blind-pointing accuracy of less than 35 micro-radian. Proposals should come up with innovative pragmatic designs that can be flown in space.

- **Photon counting Si, InGaAs, and HgCdTe detectors and arrays:** For the 1000 to 1600 nm wavelength range with single photon detection efficiencies greater than 60% and output jitters less than 20 pico-second, active area greater than 20 microns/pixel, and 1 dB saturation rates of at least 100 mega-photons (detected) per pixel and dark count rates of less than 1 MHz/square-mm.

- **Single-photon-sensitive, high-bandwidth, linear mode photo-detectors:** With high bandwidth (>1GHz), high gain (>1000), low-noise (<1kcps), large diameter (200 micron), HgCdTe avalanche photodiode and/or (small diameter) arrays for optical detection at 1060 nm or 1550 nm.
• **Uncooled photon counting imagers:** With >1024 x 1024 formats, ultra low dark count rates and visible to near-IR sensitivity.

• **Ultra-low fixed pattern non-uniformity NIR imagers:** With large format (1024x1024), non-uniformity of less than 0.1%, low noise (<1e- read, <1ke/pix/s dark) and high (>0.7) quantum efficiency.

• **Radiation hard photon counting detectors and arrays:** For the 1000 to 1600 nm wavelength range with single photon detection efficiencies greater than 40% and 1dB saturation rates of at least 30 megaphotons/pixel and operational temperatures above 220K and dark count rates of <10 MHz/mm. Radiation levels of at least 300 krad (unprotected).

• **Isolation platforms:** Compact, lightweight, low power, broad bandwidth (0.1 Hz -3 kHz) disturbance rejection.

• **Laser transmitters:** Space qualifiable, greater than 20% wall plug efficiency, lightweight, 20-500 pico-second pulse-width (10 to >100 MHz PRF), tunable (~0.2 nm) pulsed 1064-nm or 1550-nm laser transmitter fiber or planar-waveguide MOPA sources with greater than 1 kW of peak power per pulse (over the entire pulse-repetition rate), with Stimulated Brillouin Scattering suppression and >10 W of average power, near transform limited spectral width, and less than 10 pico-second pulse rise and fall times. Also of interest for the laser transmitter are: robust and compact packaging with radiation tolerant electronics inherent in the design, and high speed electrical interface to support output of pulse position modulation encoding of sub nanosecond pulses and inputs such as Spacewire, Firewire or Gigabit Ethernet. Detailed description of approaches to achieve the stated efficiency is a must.

• **Low-cost ground-based telescope assembly:** With diameter greater than 2-m, primary mirror with f–number of ~1.1 and Cassegrain focus to be used as optical communication receiver optics. Maximum RMS surface figure error of 1-wave at 1000 nm wavelength. Telescope shall be positioned with a two-axis gimbal capable of 0.25mrad pointing. Combined telescope, gimbal and dome shall be manufacturable in quantity (tens) for ~$3 M each.

• **Daytime atmospheric compensation techniques:** Capable of removing all significant atmospheric turbulence distortions (tilt and higher-order components) on an uplink laser beam; and/or for a 2-m diameter downlink receiver telescope. Also of interest are technologies to actively compensate for the static and dynamic (gravity sag and thermal) aberrations of 2-m diameter telescopes with a surface figure of 10’s of waves (down to less than 1-wave at 1000 nm).

Research should be conducted to convincingly prove technical feasibility during Phase I, with clear pathways to demonstrating and delivering functional hardware, meeting all objectives and specifications, in Phase II.

**Phase I Deliverables:**

- Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 3-4)
- Verification matrix of measurements to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

**Phase II Deliverables:**

- Working brassboard model of proposed product, along with full report of development and measurements, including populated verification matrix from phase II (TRL 5).
- Opportunities and plans should also be identified and summarized for potential commercialization.

**O1.05 Long Range Space RF Telecommunications**

**Lead Center:** JPL

**Participating Center(s):** ARC, GRC, GSFC

This solicitation seeks to develop innovative long-range RF telecommunications technologies supporting the needs of space missions. The ultimate objective is to maximize aggregate mission data return per unit mass, unit volume, unit cost and unit power consumed by the spacecraft telecommunications subsystem.

In the future, spacecraft with increasingly capable instruments producing large quantities of data will be visiting the moon and the planets. To support the communication needs of these missions and maximize the data return to
Earth, innovative long-range telecommunications technologies that maximize power efficiency, transmitted power density and data rate, while minimizing size, mass and power are required.

The current state-of-the-art in long-range RF space telecommunications is 6 Mbps from Mars using microwave communications systems (X-Band and Ka-Band) with output power levels in the low tens of Watts and DC-to-RF efficiencies in the range of 10-25%.

This solicitation seeks proposals in the following areas:

- Ultra-small, light-weight, low-cost, low-power, modular deep-space transceivers, transponders and components, incorporating MMICs and Bi-CMOS circuits;
- MMIC modulators with drivers to provide a wide range of linear phase modulation (greater than 2.5 rad), high-data rate (10 - 200 Mbps) BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (26 GHz, 32 GHz and 38 GHz);
- High-efficiency (> 60%), low mass Solid-State Power Amplifiers (SSPAs), of both medium output power (10 W-50 W) and high-output power (150 W-1 KW), using power combining and/or wide band-gap semiconductors at X-band (8.4 GHz) and Ka-band (26 GHz, 32 GHz and 38 GHz);
- Utilization of nano-materials and/or other novel materials and techniques for improving the power efficiency or reducing the cost of reliable vacuum electronics amplifier components (e.g., TWTAs and Klystrons);
- Ultra low-noise amplifiers (MMICs or hybrid) for RF front-ends (< 50 K noise temperature);
- MEMS-based integrated RF subsystems that reduce the size and mass of space transceivers and transponders. Frequencies of interest include UHF, X- and Ka-Band. Of particular interest is Ka-band from 25.5 - 27 GHz and 31.5 - 34 GHz.
- Ultra low mass, high gain, high efficiency spacecraft antennas using advanced light materials and structures.
- Novel, hybrid spacecraft antenna designs that can act as efficient reflectors/concentrators of both RF (X- and Ka-Band) and optical (1550 nm) electromagnetic waves.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 3-4). Verification matrix of measurements to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

Phase II Deliverables: Working engineering model of proposed product, along with full report of development and measurements, including populated verification matrix from Phase II (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.

O1.06 Space Networking

Lead Center: GRC
Participating Center(s): GSFC, JPL, JSC

NASA’s Space Communications and Navigation Program (SCaN) is integrating its current agency networks: Deep Space Network (DSN), Space Network (SN), TDRSS spacecraft, Near Earth Network (NEN), and future Exploration Destination networks into a single Integrated Architecture circa 2018. Technologies must be adaptable to a variety of network operating environments ranging from the long-latency limited bandwidths of deep space communications to near Earth environments with traffic flow over global partner assets and the future internet. It is also important to note that NASA systems include ground-to-ground segments in addition to space-to-ground links. Solutions must keep in mind the “big picture” and be capable of seamlessly integrating with future ground systems.

Emerging space communications environments are expected to be shaped in various ways: small mobile mission clusters; traditional large spacecraft and launch vehicles; complexities of commercial and international partnering on the network and user sides; increasing threats to US space communications and navigation assets; and NASA’s need for 40% reduction in network operating costs.
NASA seeks space-networking technologies, which add network intelligence and learning capabilities to increase network efficiency; provide tailored user services; reduce network operating costs through automation; and increase security and resiliency.

Several technologies with promise to meet some of these challenges are listed below with their purpose current state-of-the-art, and performance metrics desired. Proposals should focus on one or two of these technologies, or for the more complex topics, single implementation aspects.

- Dynamic traffic prioritization provides a means to quickly isolate different types of traffic schemes across the space network. Current technologies allow for such features in the ground environment and the study should leverage those techniques as appropriate. The proposed approach should identify what is necessary for prioritization to be leveraged across multiple space organizations. It should also identify how decisions may impact the performance of different types of data streams.
- Adaptive autonomous network management is to enable smart network elements to make decisions within a predetermined playbook based upon awareness of local network conditions, policies and network end-to-end-objectives. Examples such as automated uplink/downlink scheduling have been demonstrated and are in operational use in limited circumstances. The concept is to shorten the time between a particular network anomaly and the resulting response by mission control allowing for more efficient utilization of the network. Studies must show how the shortened control loop yields better efficiency and how both conditions and automated responses are relayed back to a human operator.
- Cognitive networking with learning is to enable intelligent network elements to reason about reconfiguration decisions [at any layer in the protocol stack] even in unexpected conditions [whether to make decisions autonomously or to offer quantitative support to human operators] based upon situational awareness of network conditions and statistical learning about network behavior and consequences of prior interventions. Software defined and cognitive radios have been demonstrated for terrestrial use and are progressing towards broader cognitive network applications with limited and specific terrestrial demonstrations. Cognitive networking with learning is currently at the forefront of the state-of-the-art, with a multiplicity of approaches being developed for diverse applications such as Future Internet, mobile wireless, and tactical communications. Bidders are encouraged to narrow their focus to specific implementation issues in the domain and focus on adaptation for SCaN space networks. Desired performance metrics are relevant analytical estimates of potential benefits and feature cost-benefit.
- Enhanced security and trust management services for missions that have limited computational and power resources. Contact should not be assumed to be continuous and approaches should leverage proven security techniques where appropriate and provide a means to authenticate between assets and to provide a means to securely update network information (i.e. route injection). It will be important to identify how the proposed approach mitigates particular security risks while also remaining efficient in the space environment.
- Novel techniques for position determination, timing, and route computation are to provide essential services for missions that venture beyond GPS coverage and SCaN infrastructure particularly for missions limited in equipage they can carry or in the face of intentional service disruption. Human missions develop positional uncertainty at a rate of 10 km/hr due to random accelerations. Early lunar missions like LRO are without timing service. Route computation requirements emerge with formation flight, delta-V sensitive libration point and planetary highway orbits, and robotic surface exploration. [Metrics: convergence time, overhead (number of bytes used by routing algorithm to reach steady state)].

For more information on NASA's future space communication plans, please see the Space Communications and Navigation website at [https://www.spacecomm.nasa.gov/](https://www.spacecomm.nasa.gov/) [10]

Performance metrics are listed by technology above.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Phase I report will analytically demonstrate technical feasibility of one or more space
networking technologies identified above by characterizing:

- Technical requirements flow-down from generic objectives and summary of state-of-the-art to SCaN network-specific requirements on key performance metrics
- Identification of specific technical challenges to implementation for SCaN networks.
- Analysis of at least three alternative approaches to obtain this performance for SCaN networks.
- Assessment of cost-benefit of each (e.g. risk, complexity, added overhead)
- Selection of software or hardware concept and emphasis topics for further investigation.
- Plan for Phase II resolution of issues or uncertainties and hardware and software demonstration.
- Target TRL 3 at the end of Phase I efforts.

Phase II Deliverables: Phase II report will document:

- Updates to the technical requirements flow-down, identified technical challenges, and selected hardware or software concept based upon further investigation in Phase II.
- Analytical or experimental investigations undertaken to resolve issues and further definition of the selected approach.
- Design and test approach selected for hardware or software demonstration with detailed description of assumptions and parameters.
- Conclusions based upon test results and recommendations for further investigation including any plans for commercialization or further development.
- Target TRL of 5 at the end of Phase II efforts.

Space Transportation Topic O2

Achieving space flight remains a challenging enterprise. It is an undertaking of great complexity, requiring numerous technological and engineering disciplines and a high level of organizational skill. Overcoming Earth’s gravity to achieve orbit demands collections of quality data to maintain the security required of the range. The harsh environment of space puts tight constraints on the equipment needed to perform the necessary functions. Not only is there a concern for safety but the 2004 Space Transportation Policy directive states that the U.S. should maintain robust transportation capabilities to assure access to space. This crosscutting SBIR Topic seeks to enable commercial solutions for U.S. space transportation systems providing significant reductions in cost, and increases in reliability, flight-rate, and frequency of access to space. The goal is a breakthrough in cost and reliability for a wide range of payload sizes and types (including passenger transportation) supporting future orbital flight that can be demonstrated on interim suborbital vehicles. The vision is a competitive marketplace with multiple commercial providers of highly reusable space transportation systems and services with aircraft-like operations, high-flight rates, and short turnaround times (days-to-hours, rather than months). Lower cost and reliable space access will provide significant benefits to civil space (human and robotic exploration beyond Earth as well as Earth science), to commercial industry, to educational institutions, for support to the International Space Station National Laboratory, and to national security. While other strategies can support frequent, low-cost and reliable space access, this topic focuses on the technologies that dramatically alter reusability, reliability and operability of next generation space access systems.

Sub Topics:

O2.01 Secondary/Auxiliary Payload-to-Launch Vehicle Interface Technologies

Lead Center: KSC

Participating Center(s): AFRC

This subtopic includes two major technology areas:

(1) Small payload standard interface technologies (SPSIT)
Entry and ascent experimental platform technologies (EAEPT)

Proposals will be accepted for either area.

Many expendable launch vehicle (ELV) launches do so with excess capacity. The utilization of specific excess volumes within a launch system must be accomplished at a low cost with minimal to no additional risk to the primary payload or launch vehicle. This subtopic seeks to develop commercial solutions that will allow and encourage new enabling launch capabilities and standardization of key payload-to-launch vehicle processes and interface standards with the goal of producing a low cost, low risk platform or process for integrating secondary or auxiliary payloads on existing NASA ELV launches.

The goal is to develop new launch vehicle capabilities such as adapters/platforms, processes, and/or avionics interface standards that can be collectively used to:

- Minimize integration tasks and/or duration of integration efforts to install secondary/auxiliary payloads onto NASA ELV launches
- Facilitate secondary/auxiliary spacecraft and subsystem design while reducing testing duration and complexity
- Impose no additional risk to the primary mission
- Enable novel mission concepts for secondary/auxiliary payloads

Small Payload Standard Interface Technologies

Currently, the Poly-Picosatellite Orbital Deployer (PPOD) provides a cost-efficient standard interface and deployment system for CubeSats in the 1 to 3 kg mass range. In addition, the Evolved ELV (EELV) Secondary Payload Adapter (ESPA) provides a standard structural interface for secondary payloads up to 180 kg and is designed for interface into Atlas V and Delta IV launch vehicles. A smaller version of the ESPA ring has been conceptualized for smaller launch vehicles. Both the ESPA and the small ESPA are most cost effective when they accommodate 6 payloads. In addition, for the most part, the avionics and electrical power interfaces are unique to each launch vehicle fleet. This subtopic seeks to develop commercial solutions that could allow the cost effective launch of one or more secondary/auxiliary payloads via an interface (structural, avionics and electrical) that is standard or expandable/upgradable to be compatible with the maximum number of domestic launch vehicles. NASA currently has Pegasus XL, Taurus XL, Falcon 1, Falcon 9, Atlas V and Delta IV on contract.

A significant fraction of mission costs are typically unique designs and approaches to perform relatively routine functions such as launch accommodations and subsystem-to-subsystem interface and communications. By standardizing many of these approaches, spacecraft and payload developers can design their systems with an expectation of a predictable, low-cost integration flow. Launch service providers can mitigate mission risk through the use of predictable and proven interfaces standardized to streamline analytical/physical integration processes and test flows.
This subtopic will focus on new interfaces for payloads in the mass range of 3 to 180 kg, which can be grouped as needed for any modularization concepts. A range of 11 to 100 kg has been specifically identified as a region where critical technology demonstrations and new space technologies could use affordable orbital launch opportunities to increase their TRL, potentially reducing their overall cost and risk to development. Enabling affordable launch capabilities in these ranges could also allow scientific and educational spacecraft (s/c) developers the ability to design to a specific mass range that will result in on-orbit research.

The technologies in this subtopic are highly desirable because although adapters that could support most missions exist, having multiple systems across multiple launch vehicles fleets will contribute to higher integration costs. Standards amongst the s/c and adapter community will reduce integration cost and therefore the per-kilogram cost-to-orbit.

Areas of interest (SPSIT):

- Launch adapters and systems and associated spacecraft standards
- Standardized spacecraft and/or payload integration test flows, processes and qualification techniques
- Standardized electrical interfaces, sometimes known as plug and play electrical power and data bus standards for streamlined subsystem integration.

The critical requirement for all areas of interest identified above is that the design, integration or implementation shall not increase base line risk to the primary spacecraft or the launch vehicle mission success. Implementation of the above enables support for any upcoming missions needing the capability to demonstrate new technology on-orbit by using a standard interface or process.

Phase I Deliverables (SPSIT):

- Assessments of current and future spacecraft/mission/space technologies in the mass ranges will identify current adapter systems, processes and determine the TRL for each system within 3 year timeframe from award date
- Develop draft standards for both spacecraft, adapter, integration process and avionics interfaces

At the completion of phase I, the goal is to have achieved a TRL 3 or better for the adapter systems and processes.

Phase II Deliverables (SPSIT):
Finalize standards within the mass range

Complete adapter hardware designs

"Plug-n-play" avionics standards hardware/software

Conduct PDR and CDR of new technologies

Finalize standards for the integration process

Higher TRL levels at the completion of Phase II will increase the likelihood of a path for infusion into NASA missions.

Entry and Ascent Experimental Platform Technologies

Current launch capabilities for aerodynamic and hypersonic research are limited to either high cost launches as a primary payload on a launch vehicle, or small packages (typical sounding rocket payload volume and mass ~ 10 ft³, 300 lbm). Sounding rockets that provide the technology testing capabilities are also limited in the altitude and the speeds they can achieve. Therefore, the conceptual design for a new platform is being sought to fill the technology-testing gap. For example, if the vehicle configuration had spare solid rocket motor capacity, this experimental platform could launch as a secondary payload, by occupying the location of a solid rocket motor on a launch vehicle such as the Atlas V or Delta IV.

The new experimental platform would provide expanded testing capabilities to accommodate payloads with larger (2-10 times) size and weight, obtaining greater altitudes and speeds than currently provided using sounding rockets. The platform would pro-vide an affordable way to demonstrate and test new technologies through hypersonic, intra-atmospheric, and reentry phases. The launch vehicle can be any vehicle used by NASA (currently, Pegasus XL, Taurus XL, Falcon 1, Falcon 9, Atlas V and Delta IV are on contract) and must be integrated onto the first stage of a vehicle per the areas of interest listed in Areas of interest section below.

Usage of this experimental platform could support development of a number of advanced technologies through flight-testing in representative environments, where their TRL could be validated and advanced. Such technologies could then be considered viable options for atmospheric entry and ascent technologies for governmental and commercial applications.

Technologies that could be tested in this experimental platform include but are not limited to:

- Thermal protection materials,
- Guidance, navigation and control,
- Vehicle configuration concepts for investigation of both ascent and entry designs for earth, lunar, and Mars space vehicles under supersonic and hypersonic conditions

Objective (EAEPT): Design a cost effective experimental platform with associated payload interface that minimizes
the impact to the primary payload and launch vehicle's processing and certification for flight.

Areas of interest (EAEPT): NASA seeks platform designs incorporating the following characteristics:

- Ability to integrate with the launch vehicle late in the mission integration phase,
- Ability to fly a dummy payload(s) (in case the secondary payload does not meet the launch readiness date),
- Mo required mission unique interfaces with the launch vehicle (electrical, environmental control, etc.)
- Does not impose additional risk on the success of the primary mission
- Enables maximum use of the existing design and hardware (i.e., attach structures, case design) of the launch vehicle to minimize risk
- Has minimal impact to the vehicle external mold line and mass requirements, such that the aerodynamic flight environments, dynamic load environments, and thermal environments imposed are of similar or equivalent levels as compared to the vehicles as currently flown
- Is compatible with existing launch vehicle hardware
- Is compatible with current vehicle qualification environments
- Is compatible with vehicle mass requirements
- Facilitates manufacturing and production (support multiple and repeatable flights)
- Accommodates flight specific payload modifications.

Much of this information can be found on line on the Launch Provider's public websites:

- [http://www.spacex.com/Falcon1UsersGuide.pdf](http://www.spacex.com/Falcon1UsersGuide.pdf) [16]

Once awarded, NASA (LSP) will facilitate the development of a Non-Disclosure Agreement (NDA) between the
Phase I Deliverables (EAEPT):

A final report containing technology design concept(s) demonstrating technical feasibility including:

- Feasibility of concept
- A draft Systems Requirements Document (SRD)
- A detailed path towards Phase II level design maturity
- Detailed report presenting the results of Phase I analysis, modeling, etc.
- Expected TRL at end of Phase I is 3

Phase II Deliverables (EAEPT):

- Preliminary Design Review (PDR) and Critical Design Review (CDR) of the aforementioned platform for use on one of the existing ELVs within NASA’s fleet
- Expected TRL at end of Phase II is 5

O2.02 Propulsion Technologies

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

O2.03 Spaceport Enhancement & Improvements

Lead Center: GSFC
Participating Center(s): AFRC, GRC, KSC

The key operating characteristics for a Spaceport focus are interoperability, ease of use, flexibility, safety/environmental protection, and multiple concurrent operations. The long-term vision is to have "airport-like"
spaceport operations. Therefore, the development of effective spaceport technologies is of primary importance to NASA. These technologies will need to support both the existing and future vehicles and programs.

**Space-Based Telemetry**

NASA is seeking to reduce or eliminate the need for redundant range assets and deployed down-range assets that are currently used to provide for Line-of-Sight (LOS) Tracking Telemetry and Control (TT&C) with sub-orbital platforms and orbit-insertion launch vehicles.

There are varying applications for space-based transceivers, each necessitating a different set of requirements. The desired focus is very low size, weight, and power (SWaP), tactical grade, highly reliable, and easily reconfigurable transceivers capable of establishing and maintaining unbroken satellite communication links for telemetry and/or control. This technology will serve applications, which include low-cost sub-orbital missions, secondary communications systems for orbit insertion vehicles, low cost and size orbital payloads (typically LEO), and flight test articles. Durations will range from minutes to several weeks and the ability to operate on highly dynamic platforms is critical. High data rate links are highly desired, thus the use of NASA's TDRSS is emphasized, although other commercial satellite systems, which can provide nearly global and high data rate links can also be explored. Factors to address include:

- Advancements in software based radios and encoding techniques,
- Use of the latest semiconductor technologies (GaN or other),
- Advanced heat dissipation techniques,
- Immunity to corona breakdown,
- Ease of data interfacing.

RF power output requirements range from a few watts to as high as 100 W. Special consideration should be given to transceiver capability vs. packaging that would allow for customizable configurations depending on the target application.

**Range Weather**

NASA seeks innovative technologies to remotely measure electric fields aloft to reduce the threat of destruction of a launch vehicle by rocket triggered lightning. Potential candidate technologies include new algorithms to take advantage of existing dual-polarized Doppler five-cm weather radar capability, or entirely new technologies for the remote sensing of electric fields. The ability to economically measure the incremental ballistic wind velocities along the predicted trajectory of launch vehicles at remote and evolving launch ranges at altitude up to 100 kft via fixed and mobile LIDAR approaches is also highly desirable.

The above technologies are considered to be highly desirable for NASA's objectives and critical for the realization of true Spaceports.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and
show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: A final report containing optimal design for the technology concept including feasibility of concept, detailed path towards Phase II hardware and software demonstration, and detailed results of Phase I analysis, modeling, prototyping, and testing.

Phase II Deliverables: A working proof-of-concept demonstrated and delivered to NASA for testing and verification with a TRL of 4 to 6.

O2.04 Advanced Composite Tank and Materials Technologies

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

This subtopic includes two major technology areas:

1. Reusable, Reliable and Low Cost Composite Tanks
2. Advanced Material Integration Technology Development

Proposals will be accepted for either area.

Reusable, Reliable and Low Cost Composite Propellant Tanks (RRLCCPT)

The objective of this subtopic is to help dramatically reduce the cost to low Earth orbit by advancing the technology involved in composite propellant tanks and advanced composite material development. The ability for launch vehicles to combine the significant weight savings of composite tanks with airline like operations could be possible if these tanks are also reusable, reliable, and need little to no maintenance between flights.

Purpose and Current State-of-the-Art: Composite tanks offer significant weight savings, but there are significant shortfalls in terms of reusability, especially when using cryogenic fluids. This lack of reusability severely hampers adoption of this enabling technology in future reusable vehicle. This subtopic will also address emerging composite tank technologies, specifically in the areas of testing and verification pertaining to damage tolerance, safe-life and checkout.

General Operational Needs and Requirements/ Performance Metrics:
Airline-like Operations

Government and commercial reusable launch vehicles are only economically viable if they can achieve high flight rates of dozens of flights per year or more per vehicle. These flight rates themselves are only possible if something akin to airline like operations becomes possible for spaceflight.

Reusability and Reliability

Reusable, reliable, and low cost composite tanks that need little to no maintenance between flights and minimal check-out are required for economic and operational sustainability. These developments can:

- Ease operability of the tank diagnostics
- Enable tank prognostics
- Enable tanks to handle high pressure cycles and loads without leaking or developing structural failure
- Promote ease of manufacture, and by more than one American company
- Promote ease of repair without returning tanks to the manufacturer's facility
- Promote rapid certification/recertification techniques to meet expected FAA commercial RLV requirements

Data and Technology Development

Of specific concern and interest are safe-life and damage tolerance testing. There is much scrutiny regarding the manner and degree of testing in these areas, specifically after some number of pressure cycles. Also of concern is the effect of temperature on and during cycling and material compatibility. Due to the limited amount of flight and long term performance data there is little to base future design on when the desire is heritage similarity. Thus, development in regards to these specific metrics (safe-life and damage tolerance testing) would be most beneficial to both short and long term missions.

The outcome of this portion of the SBIR is expected to be technologies and data that make possible composite propellant tanks that have improved reliability and performance that will enable a high degree of reusability. Data should show that proper material, manufacturing processes and design are used to produce a vessel that performs well under long-term use in a cryogenic condition. The vessel would minimize microcracking, should be damage tolerant and repairable, and have mounting capabilities.

For the proposed technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware demonstration and testing. Delivery of a demonstration unit for NASA testing at the completion of the Phase II contract is also required.

Phase I Deliverables (RRLCCPT): Final report containing:
Optimal design and feasibility of concept,

Detailed path towards Phase II demonstration,

Detailed results of Phase I analysis, modeling, prototyping and development testing

Material coupon data and a prototype sub-scale tank

Desired deliverables at the end of Phase I should be at TRL 3-4

Phase II Deliverables (RRLCCPT): By the end of Phase II, working proof-of-concept technologies, including features and demonstration of long term, high cycle performance at cryogenic temperatures, demonstrated and delivered to NASA for testing and verification.

Deliverables expected at the end of Phase II should be at TRL 5-6.

Advanced Material Integration Technology Development (AMITD)

Advanced materials including ceramic composites and metallic materials, will require technologies that will allow joining of these materials, specifically the development of advanced joining and integration technologies with enhanced temperature and performance capability. Typical materials are carbon and silicon carbide based composites and super alloys. The quality of joined sub-elements should also be evaluated nondestructively to assess the integrity and quality of the joints. Material systems may be similar or dissimilar in nature (composite to metals or composite to composites).

Purpose and Current State-of-the-Art: Currently the most commonly used fabrication approaches (CMC, CVI and PIP) have severe limitations in terms of size and shape of CMC components that can be manufactured with appropriate property attributes and a reasonable cost. Therefore, current design considerations for the manufacturing of large CMC components and structures will be utilizing technologies for joining/attaching smaller-sized components with simpler geometries and dissimilar material systems.

General Operational Needs and Requirements: Ceramic joining and integration is an enabling technology for the successful implementation of CMC's in a wide variety of high temperature applications. Among the various alternatives available to overcome the limitations of the many fabrication technologies for the manufacture of large CMC components and structures of complex shape, the joining of smaller components with simple geometry appears to be the most promising and practical. Application of simple equipments for curing and during the high temperature joining process is critical. Requirements include, but are not limited to:

- Materials to be joined are silicon carbide or carbon-based matrix fiber reinforced composites to a similar CMC or high temperature metallic alloy
Proposed joining approach should be robust and able to produce joints with tailorable microstructures

Thermo-mechanical properties of the joint interlayer should be tailorable and close to those of the base materials

Proposed technologies are expected to be easy to apply in a manufacturing environment at high technology readiness levels

For CMC-CMC joining, the joint interlayer material should be able to yield ceramic interlayers with temperature capability similar or better than the substrate materials with low porosity

Performance Metrics: The temperature capability of the ceramic joints in joined CMC should be similar to that of the CMC substrate materials. The chemical composition of the joints should not alter the stress rupture, creep, high temperature mechanical strength, and stiffness of the overall system in any significant manner. The environmental stability, time dependent mechanical properties, and performance of the joints should not be significantly different than the substrate materials.

For the proposed technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II sub-element and subcomponent development and testing. Delivery of a subcomponent demonstration unit for NASA testing at the completion of the Phase II contract is also required.

Phase I Deliverables (AMITD): Develop and demonstrate a robust joining concept, understand common test methods for joint testing, and assess the interfacial microstructure and mechanical properties of joints. Assess high temperature durability of joints and effect of joint design on thermo mechanical performance.

Desired deliverables at the end of Phase I should be at TRL 3-4.

Phase II Deliverables (AMITD): Produce and test additional joint prototypes (sub-elements and subcomponents) under representative flight conditions to include anticipated temperatures, heat fluxes, thermal gradients, and environmental effects. Full macro-structural and micro-structural material characterization of joints before and after testing will be required to assess life-limiting failure mechanisms and joint reliability. Provide joined CMC subcomponents or segmented structures with a method to non-destructively evaluate the joint quality.

Deliverables expected at the end of Phase II should be at TRL 5.

O2.05 Reusable, Reliable, Low Cost Thermal Protection Systems
Lead Center: ARC
Participating Center(s): AFRC
As NASA enables commercial space access, there is a critical need for reusable, reliable, low-cost thermal protection systems (TPS). New material and computational technologies offer the potential of more durable and operable TPS for space transportation vehicles that can tolerate high temperatures while improving operability and reducing maintenance time and costs.

This subtopic requests innovative proposals in the following areas:

- Technologies and systems offering a factor of two or greater reduction in maintenance time and costs
  - Reusable space transportation vehicles being developed for Earth to orbit access and return,
  - In-space transportation systems using aero-braking and aero-capture, and
  - On-demand payload and crew return systems

- Multi-use and reusable TPS concepts applicable for insulated composite and metallic vehicle structures
  - With improved robustness
  - Reduced and/or automated inspection, repair and recertification,
  - While remaining weight competitive to current flight proven TPS

- TPS non-destructive evaluation techniques and new health management approaches and strategies
- Rapid TPS inspection, repair, and flight certifications techniques
- Designs and concepts for new TPS attachment methods,
- Designs for gaps and joints
- TPS designs for control surfaces and interfaces

Phase I Deliverables: Phase I deliverables include a final report detailing optimal design for the technology concept, including a feasibility assessment and summary of analysis, modeling and any prototype development and testing. For concepts that show good feasibility, the final report should also contain a plan for Phase II development and demonstration.

Desired deliverables at the end of Phase I should be at TRL 2-3.

Phase II Deliverables: Phase II deliverables include a working proof-of-concept available for NASA inspection and testing if applicable. Opportunities and plans should be identified and summarized for potential commercialization.
Deliverables expected at the end of Phase II should be at TRL 4-5 (minimum).

Processing and Operations Topic O3

The Space Operations Mission Directorate (SOMD) is responsible for providing mission critical space exploration services to both NASA customers and to other partners within the U.S. and throughout the world: from flying out the Space Shuttle, to assembling and operating the International Space Station; ensuring safe and reliable access to space; maintaining secure and dependable communications between platforms across the solar system; and ensuring the health and safety of our Nation's astronauts. Each of the activities includes both ground-based and in-flight processing and operations tasks. Support that ensures these tasks are accomplished efficiently and accurately enables successful missions and healthy crews.

This topic area, while focused on operational space flight activities, is broad in scope. NASA is seeking technologies that range from addressing how better to improve and lower costs related to ground and flight assets to how best maximize and extend the life of the International Space Station. A typical approach would include:

- Phase I: Research to identify and evaluate candidate technology applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Bench or lab-level demonstrations are desirable.
- Phase II: Emphasis should be placed on developing and demonstrating the technology under simulated flight conditions.

The proposal shall outline a path showing how the technology could be developed into space-worthy systems.

The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract and, if possible, demonstrate earth based uses or benefits.

Sub Topics:

**O3.01 Mission Operations**

Lead Center: ARC
Participating Center(s): JPL
The objective is to develop advanced capability software systems for mission operations in support of NASA’s Space Communications Infrastructure. The current infrastructure for NASA Space Communications provides services for near-Earth spacecraft and deep space planetary missions. The infrastructure assets include the Deep Space Network (DSN), the Ground Network (GN), and the Space Network (SN).

NASA seeks automation technologies that will facilitate scheduling of oversubscribed communications resources. These capabilities should focus on the development of user interfaces and algorithms for the integration of diagnostic and situational awareness tools; and planning, scheduling, and resource optimization tools supporting:

- Increased numbers of missions and customers
- Increased number and complexity of constraints
- Decreased operations budgets
- Scheduling algorithms should be fault-tolerant

Current State-of-the-Art: Diagnosis software tools and resource optimization tools are mature independent software technologies, however the integration of the two is less mature. The challenge is to develop integrated software tools that can leverage the strengths of each class of tool. Diagnosis tools must inform the resource optimization algorithms of the active portions of the system, while the resource optimization tools must inform the diagnosis tools of the current plan in order to facilitate tracking of system state.

User Interfaces: Diagnosis software user interfaces rely on displaying diagnostic information either in fault tree form or spatially highlighting portions of schematics, which are suspect. On the other hand, planning/scheduling/resource optimization tools rely on the display of temporal information in Gantt charts, and other timeline-based methods. An integrated user interface would require the integration of the spatial and temporal information into a single display to facilitate the ease of use and understanding of the integrated tools.

Diagnosis and Situational Awareness: Space Communication Networks are complex systems made up of both physical and wireless connections. When faults occur in the network, isolating the faults in real-time is critical in order to maintain network capability. Model-based diagnostic systems are capable of modeling the connectivity of the system as well as propagating both nominal and off-nominal flow of information in the network. These systems can accurately characterize the state of the system in order to provide situational awareness for both humans as well as intelligent assistant and resource optimization tools. The utilization of the current state of the network is critical to reschedule resources that have failed or degraded.

Planning and Scheduling Tools for Resource Optimization: The goal of schedule optimization is to produce allocations that yield the best objectives. These may include maximizing DSN utilization, minimizing loss of desired tracking time, and optimizing project satisfaction. Each project may have their own definition of satisfaction such as maximal science data returned, maximal tracking time, best allocation of the day/week, etc. The difficulty is that we may not satisfy all of these objectives during the optimization process. Obviously, optimal solution for one objective may produce worse results for the other objectives. One possible solution is to map all of these objectives to an overall system goal. This mapping is normally non-linear. Technology needs to be developed for this non-linear mapping for scoring in addition to regular optimization approaches.

Areas of Interest: Integrated diagnosis and resource optimization tools are useful in different phases in the design and development of space communication networks. In early pre-planning phases of mission operations such tools...
are useful for: procedure development, contingency development, and other preparatory tasks. During the operations phase, such tools are useful for telemetry analysis; fault diagnosis, state determination and situational assessment; plan, procedure, and rules revisions and execution; decision-making; commanding; fault responses; and data management among others.

NASA seeks proposals to develop the following capabilities in support of human situational awareness:

- Methods for acquiring, evaluating, and displaying telemetric information, so as to provide users with flexibility and easy access to desired information in desired format.
- Methods to determine situational information from multiple data sources, possibly noisy and incomplete, and present those to the user;
- Methods to track actions of other users or systems, including automated systems, and keep user aware of the situation.
- Methods to track user intent and provide the appropriate situational information;
- Methods for controlling the degree of automated/manual control, and tools for transitioning control between user and automation with minimal loss of context and situational awareness.
- Methods for creating, validating, evaluating, and revising model-based diagnostics models, taking into account collaborative aspects and reference materials required to build models (architecture diagrams/schematics, sensor definitions, fault modes, configurations and other reference materials).
- Techniques for checking or simulating model-based diagnostic models, in order to acquire a level of trust or assurance that the model is correct with respect to the configuration of the network.
- Methods for creating, validating, evaluating, and revising operations plans, taking into account collaborative aspects, complex flight rules, resource limitations and need for one-time constraints and exceptions.
- Techniques for checking or simulating plans, procedures, sequences and other combinations of commands and actions, in order to acquire a level of trust or assurance that the combination is correct and will satisfy desired safety and operations properties in actual execution
- Methods to change the planning/scheduling optimization functions to incorporate high priority requests.

Performance metrics: Measures of performance will compare human generated results vs. human/computer results for nominal and off-nominal network conditions. Experiments should be run on simulated communications test-bed(s), which can seed failures of different classes at different points in time.

Schedule quality will be determined by a number of factors including: (1) level of up time on the network, (2) degree of priority allocation (higher priority items scheduled first), (3) degree of contiguity allocation (items are scheduled as a group) and (4) other factors.

For the proposed technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware demonstration and testing. Delivery of a demonstration unit for NASA testing at the completion of the Phase II contract is also required.

Phase I Deliverables: Propose demonstration of integrated fault diagnosis/resource optimization tool on a number of communication asset allocation problem sets (involving dozens of missions, communications assets, and operational constraints). End Phase deliverable (TRL 4-5) would include a detailed rationale for technology return-on-investment (ROI) based on knowledge of current and future operations flows.
Phase II Deliverables: A demonstration of the integrated fault diagnosis/resource optimization tool with fault diagnosis/situational awareness system on actual or surrogate communication asset scheduling datasets. Deliverables (TRL 6) would include software system, use cases and evidence of utility of deployment of developed technology.

**O3.02 ISS Utilization**

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

NASA is investigating the near- and mid-term development of highly-desirable systems and technologies that provide innovative ways either to leverage existing ISS facilities for new scientific payloads or, to provide on orbit analysis to enhance capabilities and reduce sample return requirements.

Current utilization of the ISS is limited by available upmass, downmass, and crew time as well as by the capabilities of the interfaces and hardware already developed. Innovative interfaces between existing hardware and systems which are common to ground research could facilitate both increased, and faster, payload development.

Desired capabilities include, but are not limited to, the below examples.

- **Enabling additional cell and molecular biology culture techniques.** Providing innovative hardware to allow for safe, contained transfer of cells from container to container within the Microgravity Sciences Glove Box (MSG) would permit new types of studies on ISS. On orbit analysis techniques that would reduce or remove the need for downmass - such as a system for gene array tests, or kits for DNA extractions for long term storage - are also examples of hardware possibilities that would extend and enable additional research.

- **Providing compact Dynamic Light Scattering (DLS) hardware.** Development of a compact robust DLS instrument based on diode lasers and photo detectors capable of providing significant power and weight savings would make it possible to measure the diffusion coefficient of experimental systems using the Light Microscopy Module (LMM). This peer-reviewed science was considered a decade ago but not developed due to technology limitations. It should now be possible to measure diffusion coefficients from which the molecular temperature of the location being viewed could be deduced for known particles and solvents using the Stokes-Einstein equation. Innovative additions of a local oscillator used in conjunction with analog detectors could mitigate errors introduced by stray light.

- **Providing compact laser tweezers and supporting software.** Development of a compact robust Holographic Laser Tweezers (LT) instrument based on the recent developments of holographic techniques could expand the types of experiments conducted on orbit. This peer-reviewed science was previously considered but not developed because of the size and technology limitations of a decade ago. LT holds open the possibility of performing scientific experiments that manipulate groups of particles that evolve uniquely in space when gravitational sedimentation and jamming no longer exist. Any new LT and its corresponding control software should allow for tracking of particle positions in 3D (before the concentration becomes too high) and impart rotational forces. Being able to accurately track the position of particles while measuring the forces on them is important for laying the foundations of colloidal engineering. Novel self-calibration methods could be added to commercially available designs to further enhance the instrument and its capabilities. The instrument would need to meet the size and volume limitations of the Light Microscopy...
Module (LMM).

- Providing additional on-orbit analytical tools. Providing flight qualified hardware that is similar to commonly used tools in biological laboratories could allow for an increased capacity of on-orbit analysis thereby reducing the number of samples which must be returned to Earth. Examples of tools that will reduce downmass or expand on-orbit analysis include: sample handling tools; mass measurement devices; a (micro)plate reader; a mass spectrometer; non-cryogenic sample preservation systems; autonomous in-situ bioanalytical technologies; centrifuges for analysis and for providing fractional-g environments; microbial and cell detection and identification systems; and fluidics and microfluidics systems to allow autonomous on-orbit experimentation and high throughput screening.

- Providing Nanorack compatible inserts to enable additional life science payloads. Development of 1, 2 and/or 4 cube design biological payload hardware for use with the ISS Nanorack platform would decrease the need for development of multiple control racks and reduce development time of future payload experiments.

- Enabling additional payloads. Innovative methods for further subdividing payloads lockers would allow for numerous pico-payloads. Developing multi-generational or multi-use habitats would reduce the upmass and downmass required to conduct biological experiments on ISS.

The existing hardware suite and interfaces available on ISS may be found at: [http://www.nasa.gov/mission_pages/station/science/experiments/Discipline.html](http://www.nasa.gov/mission_pages/station/science/experiments/Discipline.html)

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Written report detailing evidence of demonstrated technology (TRL 5 or 6) in the laboratory or in a relevant environment and stating the future path toward hardware and software demonstration on orbit.

Phase II Deliverables: Hardware and/or software prototype that can be demonstrated on orbit (TRL 7).

O3.03 ISS Life Extension and Operational Enhancements

Lead Center: JSC

Participating Center(s): ARC, GSFC

NASA is exploring a wide range of both critical and highly desirable technologies that would, in the mid-term, aid in ISS life extension or provide operational enhancements.

Potential areas of investigation include the following:

- Providing detection technologies for leakage from modules and fluid systems.
• Enhanced on-orbit maintenance capabilities such as corrosion detection and re-mediation.
• MMOD detection, MMOD damage detection, evaluation and recovery.
• Methods for re-lubrication of rotating parts.
• Technologies that can isolate and resolve issues without crew interaction or that can perform nominal crew housekeeping activities such as self-cleaning air inlet filters and surfaces are highly desirable and could improve efficiency enough to allow more crew time for operation of scientific payloads.

Technologies to aid in life extension or operational enhancements of the ISS are not limited to the above examples and other areas will be considered for award.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Written report detailing evidence of technology feasibility in the laboratory (TRL 2-4) or in a relevant environment and stating the future path toward hardware and software demonstration on orbit.

Phase II Deliverables: Hardware and/or software prototype that can be demonstrated, preferably on orbit (TRL 4-6).

O3.04 Vehicle Integration and Ground Processing

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

This subtopic seeks to create new and innovative technology solutions, which improve safety and lower the life cycle costs of assembly, test, integration and processing of the ground and flight assets at our nation’s spaceports and propulsion test facilities.

Current State of the Art: The propulsion testing and launch vehicle processing activities at NASA account for a large portion of the life cycle costs of today’s space programs. The technologies in use today at these facilities date back to the beginnings of manned space flight. A majority of the test infrastructure at Stennis Space Center and launch processing facilities at Kennedy Space Center indeed go back to the Apollo era and early shuttle design days of the 1960’s and early 70’s. Technology solutions typically take 3-6 years from inception in the SBIR Phase I program to having a direct impact on the processing activity. NASA needs to invest in these vehicle integration and ground-processing technology needs now to be in place for the NASA heavy launch vehicle concepts of the future.

Propellant servicing operation for both propulsion testing and launch operations are in need of technology advancement to make these operations safer and more cost efficient. The hardware and practices in use today do indeed date back to 1960’s investments. Technology solutions are needed to increase visibility into processes real-time (smart instrumentation), more efficient cryogenic propellant storage solutions, a new generation of cryogenic couplings to allow cold mate and de-mate operations without ice or frost buildup, and to
reduce our usage of massive amounts of gaseous helium (a scarce, non-renewable global resource).

Changes in environmental regulations have had a tremendous negative impact on the coatings used to protect our NASA test and launch infrastructure. Many of the coatings used in the last 10 years are no longer available due to changes in the environmental law banning the use of certain chemicals. KSC and SSC are located in some of the worst corrosion environments in the country. At KSC, the addition of the acidic exhaust plumes from solid rocket motors, make these conditions even worse. New advancements in coatings and materials are needed to reduce the infrastructure maintenance costs of these facilities.

Due to the lightweight, high strength properties, composite materials are being sought more often to solve weight reduction efforts on future launch vehicles. New materials mean new problems for the ground operations team charged with insuring these vehicles are safe to fly. New inspection tools are needed to confirm structural integrity during the processing flow after field repairs or accidental contact.

The following areas are of particular interest:

**Propellant Servicing Technologies**

Technologies for advanced, energy efficient cryogenic fluid storage, transfer and propellant servicing of launch vehicles and propulsion test facilities. These efforts include:

- Cost effective technology solutions to support helium facility supply infrastructure and helium conservation initiatives to reduce/eliminate helium usage during LH2 and LO2 system operations and recover/re-purify helium from large volume waste streams;
- Techniques and technologies to reduce parasitic heat loads in large cryogenic storage tank structural design to enable more economical zero boil-off storage concepts;
- Advances in smart instrumentation for in-situ fluid flow analysis and process control, surviving and operating under cryogenic and launch conditions to enable real-time monitoring of propellant servicing processes and high efficiency purging operations of cryogenic systems; and
- Non-frosting/icing quick-disconnect development to support cryogenic propellant servicing operations.

**Control of Material Degradation**

Technologies are needed for the prediction, prevention, detection and mitigation of corrosion/erosion in spaceport and propulsion test facility infrastructure and ground support equipment including steel refractory concrete. Material solutions must meet current and emerging environmental restrictions and endure today’s corrosive and highly acidic launch environments. These needs include:

- Methodology to predict long-term corrosion protection performance of coatings for steel operating in a marine environment;
- Damage responsive coatings with corrosion inhibitors;
- Replacement options for poor-performing refractory concrete exhibiting low temperature cure characteristics or means of providing large area coverage with modular units that can be cured off site;
- Protective coatings for non-painted surfaces;
- Innovations in thermal spray metallic coatings equipment and alloys;
- Non-chrome protective coatings/sealants for aluminum alloys; and
- New environmentally friendly protective coating options to replace products lost due to EPA regulation changes.

**Spaceport Processing Evaluation/Inspection Tools**

Technologies in support of defect detection in composite materials; methods for determining structural integrity of composite materials and bonded assemblies; and non-intrusive inspection of Composite Overwrapped Pressure Vessels (COPV), Orion heat shield and other composite systems. Technologies must support identifying composite material defects, evaluating material integrity, damage inspection and/or acceptance testing of composite systems. Technology solutions are also desired for in-situ evaluation of refractory concrete as installed in the flame trenches associated with propulsion test and launch pad infrastructure. Provide solutions that reduce inspection times, provide higher confidence in system reliability, increase safety and lower life cycle costs.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

**Phase I Deliverables:** Demonstration of technical feasibility (TRL 2-4).

**Phase II Deliverables:** Demonstration of technology (TRL 4-6)

The technology in this subtopic may also be applicable to Topic O2, Space Transportation.

**O3.05 Advanced Motion Imaging**

**Lead Center:** MSFC

**Participating Center(s):** JSC

Digital motion imaging technologies provide great improvements over analog systems, but also present significant challenges, including radiation damage to sensor systems and components. Cameras and sensors need to survive operations on orbit for years without debilitating radiation damage that degrades image quality and performance.

The focus of this subtopic is the development of components, systems, and core technologies that advance the capabilities to capture process and distribute high-resolution digital motion imagery.

**Current State of the Art:** HDTV cameras flown on the Space Shuttle and the International Space Station have proven to be highly susceptible to damage from ionizing radiation. This damage is manifested by bad pixels that
eventually render the camera useless after short periods of on-orbit use, usually less than one year. In addition, upmass and downmass constraints make the use of large format motion picture film cameras impractical, so a digital equivalent is needed for large venue documentary film productions, such as IMAX films. Areas of interest in the near term are for space environment, radiation tolerant, HDTV and digital cinema cameras and sensors. Mid and Long term goals include radiation tolerant reprogrammable encoders and improved distribution systems for video data signals. These systems are highly desired by the human spaceflight programs.

Technologies are sought that provide high resolution, progressively scanned motion imagery with limited or mitigated radiation damage to sensors, are viable for astronaut hand-held applications or external spacecraft use, and that provide imagery that meets standards commonly used by digital television or digital cinema production facilities. Commercial HDTV cameras used for internal hand-held use have generally been small and light (5'' x 6'' x 11'', between 2 and 3 pounds), run off rechargeable batteries, and utilize standard lens mounts. Future cameras for exterior applications ideally would be smaller and more modular in design (no larger than 4'' x 5'' x 7'' and 2.5 pounds). The critical technology need is the radiation tolerance of the sensor, not the size, weight and mass of the camera that results from such a sensor.

While commercial HDTV and Digital Cinema cameras for use on Earth are mature technologies, there are no flight-proven radiation tolerant HDTV and Digital Cinema cameras and sensors currently available. Commercial cameras flown on the Shuttle and ISS thus far do function, but degrade within a year on orbit. While hard to classify, the current TRL for these cameras within the context of spaceflight operations could be considered to be a 5 or 6. The ultimate goal is to develop radiation-hardened camera sensors capable of surviving three or more years in space.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Deliverables for Phase I will include detailed designs and development plans with plausible data and rationale that demonstrates why the designs and plans should mitigate radiation effects on the sensors.

Phase II Deliverables: Deliverables for Phase II will include developmental hardware suitable for testing in a lab or space flight environment (TRL 6) as well as a test plan, relevant data, and define expected lifespan of the sensors.

O3.06 Advanced Acoustic Monitoring Technologies

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

This subtopic addresses acoustic monitoring technologies for current International Space Station (ISS) and future long duration spaceflight missions.
Specifically, this subtopic calls for proposals to develop and demonstrate acoustic sensor technology enabling real-time, remotely performed measuring and monitoring of sound pressure levels and noise exposure levels in long-duration space vehicles. These technologies are the building blocks towards a network of continuously monitored, real-time acoustic sensors providing sound pressure level information as a function of frequency and/or time at multiple locations. Additionally, these technologies shall provide:

- Typical sound level meter,
- Typical acoustic dosimeter processing and analysis functionality,
- Capability for hazard level alerting.

Current State of the Art: Acoustic monitoring is currently being performed on the ISS using a hand-held sound level meter (SLM) that is moved to 60 different locations where a 15 second measurement is performed. Each SLM survey session takes 2 hours of crew time, and the survey is performed once every 2 months, thus reduced crew time needed will be an important benefit.

Because of the length of the survey, only a portion of the ISS can be measured during a single session. Similarly, acoustic dosimetry at fixed locations is performed once every 2 months, but only at three locations for each session because of crew-time and hardware limitations. Advanced acoustic monitoring technology will provide the capability to allow for more frequent and directed acoustic measurements and will allow nighttime measurements. These benefits will permit more precise trending, environmental monitoring and will provide a better validation of acoustic models, i.e., we will be able to isolate the impacts of various operations or pieces of hardware.

Areas of interest: Current automated acoustic monitoring methods used in ground-based systems perform measurements in isolated areas, e.g., around airports. However, the technology employed is large and heavy, using conventional data acquisition boards, transducers, and transmitters.

NASA seeks proposals for acoustic monitors for spaceflight vehicle applications that:

- Are miniaturized,
- Are lightweight,
- Integrate data acquisition, sampling, and processing into the sensor
- Transmit the processed data wirelessly,
- Low-power consumption
- Can be a part of a multi-sensor system

The functional SLM goal is to provide average sound pressure level measurements over a short time duration (e.g. 20 seconds) as a function of frequency. The functionality required includes:

- Type II measurement accuracy over the octave band frequency range from 63 Hz to 20 kHz,
- Dynamic range of 90 dB or better,
• 1/3 octave band frequency representation,
• Narrow band frequency representation with selectable frequency resolution.

The following SLM functionality is desired:

• Type I measurement accuracy over the octave band frequency range from 63 Hz to 20 kHz,
• Octave band noise floor of 10 dB re 20 micropascals
• Fractional octave (1/1, 1/3, 1/12) band frequency representation.

The functional Acoustic Dosimeter goal is to provide noise exposure levels and data logging, i.e., log of sound levels as a function of time. The functionality required includes:

• Type III accuracy over the audible frequency range,
• Logging of A-weighted Overall Sound Pressure Levels every 30 seconds for a period of 24-hours,
• Dynamic range of 90 dB or better.

The following Acoustic Dosimeter functionality is desired:

• Noise floor of 30 dB re 20 micropascals.

The goal for the hazard level alert functionality is to provide continuous acoustic monitoring with logic that sends a signal (to trigger a non-auditory alert) if hazardous noise levels of 85 dBA and above are detected. This is a new crew-health related function that will reduce the crew’s risk for exposure to high noise levels, and will protect the crew in the case of an off-nominal noise event. The functionality desired includes:

• Perform continuous acoustic data sampling
• Send an electronic signal if noise levels are 85 dBA or above

The following hazard level alert functionality is desired:

• Pre-trigger capability so onset of hazardous noise is measured.

The technology from this SBIR subtopic is highly desired for use on ISS and for future long duration space missions for the long-term.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software
package for NASA testing at the completion of the Phase II contract. For Phase II, a demonstration in the JSC Acoustics and Noise Control Lab (ANCL) is being requested so that testing can be performed in the ISS Acoustic Mockup. As a result, an SBIR testing facility waiver will be needed.

Potential Phase III activities are envisioned to be a demonstration of the sensor’s capability on board ISS as a Station Detailed Test Objective (SDTO)

Phase I Deliverables:

- Sensor preliminary design
- Breadboard microphone transducer (proof of concept)
- Test data showing acoustic performance of breadboard sensor
- Forward plan for sensor development, including plans for in-situ calibration
- The expected TRL at the end of Phase I is 3-5

Phase II Deliverables:

- Sensor design in flight-like package
- Test data showing acoustic performance of flight-like sensor
- Demonstration of multiple sensors in ground facility (NASA JSC ANCL)
- The expected TRL at the end of Phase II should be 6.

O3.07 Cryogenic Fluid Management Technologies

Lead Center: KSC

The ultimate objective of this Cryogenic Fluid Management (CFM) Technologies solicitation is to demonstrate a variety of critical CFM technologies in a micro-gravity space environment via a deployable or non-deployable test bed.

The initial phase (Phase I) will identify and develop prototype experiments that could be integrated into a universal platform for demonstration of these experiments in their relevant micro-gravity environment.

The second phase (Phase II) of this solicitation would develop a universal and innovative test bed platform that could be launched as a secondary payload on an expendable launch vehicle.
State of the art: CFM technologies are, for the most part, limited to ground tests that do not provide a complete and accurate demonstration of the technologies in their true operational environment. This increases risk in the development of emerging technologies for future applications in the areas of space based propellant depots, low gravity descent and ascent operations, and future space or planetary based architectures.

Areas of interest:

The purpose of these experiments would be to allow testing of:

- Designs for fluid and propellant transfer plumbing
- Multi-layer insulation (MLI) designs
- Various mass gauging designs
- Thermal control and boil-off control designs in a true micro-gravity space environment

Sample technologies in current queue at NASA centers that require testing in such type of platform include:

- Vapor Cooling
- Orientation
- Para-ortho $\text{H}_2$ conversion
- Fluid Transfer Coupling
- Thermodynamic Vent System
- Automated Rendezvous and Docking
- Thick MLI blanket
- Broad area cooling (vapor cooled, active cooled)
- Sun Shield
- Mass gauge
  - Radio Frequency (RF)
  - Pressure Volume Temperature (PVT)
  - Level Sensor (Cryo-Tracker)

- Instrumentation
  - Cryo tracker
  - Mass flow rate (fill, vent)
  - Tank pressure
  - Temperature (liquid, vent, tank wall, transfer lines, structure)
  - System acceleration

- Liquid Acquisition Device (LAD)
- Settling
- Propulsion ($\text{H}_2$/O$_2$ thruster, solar thermal)
  - $\text{H}_2$/O$_2$ thruster
  - Solar thermal
• Propellant Positional Device (PPD) (magnetic, screen)
• Cryo-Cooler
• Mixing (Vehicle maneuvers (roll), pumps)
• Structural interface (conic, struts)

The identification and design of critical CFM components that could be utilized in future exploration architectures in the space environment are being solicited for this platform. The technologies and future development of the platform supporting them would allow demonstration and proof of concepts for the designs and hardware necessary for mechanisms such as fluid transfers in propellant depots and in planetary spacecraft prior to the actual full development, design, fabrication, and launch of hardware. These CFM technologies and platform would provide a simple, low cost and innovative method to prove technologies and could avoid large and costly design modifications or possible multiple launch requirements for future space based architectures.

A viable option for the low cost approach involves launching as a secondary payload on launch vehicles currently in use such as an Atlas V or Delta IV. Such launch vehicles hold a high level of design maturity, contributing to a huge savings in development costs. In addition, through riding as a secondary payload, a majority of the launch costs could be absorbed by the primary mission. In a typical launch vehicle configuration, the secondary payload is attached to a launch vehicle’s second stage propellant tank beneath the primary payload. After separation of the primary payload, the platform would either deploy and operate as a free flying spacecraft and perform the various CFM demonstrations, or could remain attached to the propellant tank to prove fluid transfer capabilities, along with additional experiments. A third option is to utilize the residual propellants from the launch vehicle to fill a tank on the platform, which would subsequently deploy to perform various additional demonstrations.

The platform would be processed and integrated in the typical fashion of spacecrafts launched today. A platform that remains completely passive (non-operational and containing no commodities) until separation of the primary payload greatly reduces ground-processing requirements. Individual experiments could also be integrated with the platform prior to integration to the launch vehicle to further reduce operational complexities.

The second phase of the project would design a platform so as to encompass additional requirements such as:

• The capability to support and integrate multiple CFM technology experiments per mission
• Demonstrating innovative, fluid transfer designs
• MLI designs
• Various mass gauging designs
• Thermal control and boil-off control designs
• Validation of CFD propellant models
• Testing of propellant management devices
• Mixing pumps
• Thermodynamic vapor cooling systems
• Environmental thermal shielding designs

Design of the platform would need to ensure that it does not impose additional risk to the mission success of the primary payload and is capable of remaining completely passive and inert until the primary payload is successfully deployed. This includes launching with empty tank(s), lines, etc., and maintaining the ability for residual cryogenic propellants to be transferred from the launch vehicle upper stage to the proposed secondary payload upon completion of the primary mission.
Optional configurations could include multiple tanks with self-contained fluids, however the use of residuals, with innovative propellant transfer lines, from an upper stage promotes cost savings in both the propellant commodities, pressurization systems required for pre-launch processing, limit hazard and safety concerns for the primary mission, and the passive nature reduces the complexities added in the analyses and operations required for integration with the launch vehicle and primary mission.

The platform, itself, would contain tank to tank fluid transfer capabilities, avionics, thermal control systems, telemetry capabilities and, if deployable, an attitude control system. The platform design would be capable of interfacing with the launch vehicle separation system and avionics. Additional potential experiments and uses include validation of CFD propellant models, testing of propellant management devices, mixing pumps, thermodynamic vapor cooling systems, and environmental thermal shielding designs.

Performance metrics: A platform that is capable of remaining passive and inert through completion of the primary mission on an EELV. The platform shall be capable of supporting at a minimum of four CFM demonstrations per mission. The designs for the experiments are to be such that they are capable of demonstrating CFM technologies supporting the operational requirements of future space based architectures in cryogenic temperature ranges.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware demonstration and delivering a demonstration unit for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Demonstration of technical feasibility (TRL 3-4).

Phase II Deliverables: Prototype design and demonstration of innovative technology testing platform, capable of integrating multiple CFM experiments (TRL 4-6). A ready to launch version of this as an EELV secondary payload performing demonstrations of CFM technologies is highly desired.

Navigation Topic O4

NASA is seeking innovative research in the areas of positioning, navigation, and timing (PNT) that have relevance
to Space Communications and Navigation programs and goals, as described at http://www.spacecomm.nasa.gov [17]. NASA’s Space Communication and Navigation Office considers the three elements of PNT to represent distinct, constituent capabilities: (1) positioning, by which we mean accurate and precise determination of an asset’s location and orientation referenced to a coordinate system; (2) navigation, by which we mean determining an asset’s current and/or desired absolute or relative position and velocity state, and applying corrections to course, orientation, and velocity to attain achieve the desired state; and (3) timing, by which we mean an asset’s acquiring from a standard, maintaining within user-defined parameters, and transferring where required, an accurate and precise representation of time. This year, NASA seeks PNT technologies in three focus areas: metric tracking of launch vehicles, on-orbit PNT sensors and components, and flight dynamics technologies and software. Some of the subtopics in this topic could result in products that may be included in a future small satellite flight opportunity. Please see the SMD Topic S4 for more details as to the requirements for flight opportunities.

Sub Topics:

O4.01 Metric Tracking of Launch Vehicles

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

Launch vehicles can exhibit high dynamics during flight and there can be external interference on the GPS frequency. The goal of this subtopic is to have a highly reliable way of tracking vehicles from launch to orbit utilizing GPS and/or inertial measurement unit.

Areas of interest:

Metric Tracking Hardware

Metric tracking of launch vehicles requires the development of accurate and stable integrated metric tracking and inertial measurement units. The focus is on technologies that enable and advance development of low Size, Weight, and Power (SWaP), tactical grade, integrated metric tracking units that provide accurate and stable positioning, attitude, and inertial measurements on highly dynamic platforms. Factors to address include:

- Ultra-tight coupling of rate sensors, accelerometers, and attitude-determining GPS receivers that will provide very high frequency integrated metric solutions,
- The ability to reliably function on spin-stabilized rockets (up to 7 rev/s), during sudden jerk and acceleration maneuvers, and in high vibration environments,
- Advancements in MEMs-based rate sensors and accelerometers, algorithm techniques and Kalman filtering, high bandwidth and low noise outputs, phased-based attitude determination, single aperture systems, quick Time to First Fix and reacquisition.

Use of GPS and Ability to Mitigate Interference Signals

NASA seeks innovative technologies to increase the accuracy of the L1 C/A navigation solution by combining the pseudo ranges and phases of the L1 C/A signals, and use of the L2 and L5 carriers. Factors to consider:

- GPS signal degradation can be obtained by differencing the available carrier phase and pseudo range
measurements and then removing these differences from the navigation solution.

- Jamming of GPS signals are a concern during the tracking of launch vehicles.

- Technologies are sought that combine spatial processing of signals from multiple antennas with temporal processing techniques to mitigate intentional interference signals (jamming) received by the GPS receiver. The coordinated response of adaptive pattern control (beam and null steering) and digital excision of certain interfering signal components can minimize strong jamming signals. Adaptive nulling minimizes interfering signals by the optimal control of the GPS antenna pattern (null steering).

Proposals can either address a single subject as described above or a combination of subjects.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I (to reach TRL 3) and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract (to reach TRL 5).

Phase I Deliverables:

- Midterm Technical Report

- Final Phase I Technical Feasibility Report with a Phase II Integration Path. Proof-of-concept bench top demonstration preferred.

Phase II Deliverables:

- Final Phase II Technical Report

- Demonstration hardware/software/field test.


Lead Center: GSFC

Participating Center(s): GRC, JPL, JSC

This solicitation seeks proposals that will serve NASA's ever-evolving set of near-Earth and interplanetary missions that require precise determination of spacecraft position and velocity in order to achieve mission success. While the definition of "precise" depends upon the mission context, typical scenarios have required meter-level or better position accuracies, and sub-millimeter-level per sec or better velocity accuracies. This solicitation is
primarily focused on NASA's needs in four focused areas identified below.

Proposals are encouraged that leverage the following NASA developed state-of-the-art capabilities:

- GEONS ([http://techtransfer.gsfc.nasa.gov/ft_tech_geons.shtm](http://techtransfer.gsfc.nasa.gov/ft_tech_geons.shtm)[18])
- Navigator ([http://techtransfer.gsfc.nasa.gov/ft_tech_gps_navigator.shtm](http://techtransfer.gsfc.nasa.gov/ft_tech_gps_navigator.shtm)[19])
- Electra ([http://descanso.jpl.nasa.gov/Monograph/series9_chapter.cfm](http://descanso.jpl.nasa.gov/Monograph/series9_chapter.cfm)[21])

NASA is not interested in funding efforts that seek to "re-invent the wheel" by duplicating the many investments that NASA and others have already made in establishing the current state-of-the-art.

General Operational Needs, Requirements and Performance Metrics:

**Onboard Near-Earth Navigation Systems**

NASA seeks proposals for development of a commercially viable transceiver with embedded orbit determination software providing enhanced accuracy and integrity for autonomous onboard GPS- based and TDRSS-based navigation, along with time-transfer in near-Earth space via augmentation messages broadcast by TDRSS. The augmentation message should include information on the TDRS orbits, status, and health that could be provided by future TDRS, and should provide information on the GPS constellation based on NASA's TDRSS Augmentation for Satellites Signal (TASS). Proposers are advised that NASA's GEONS and GIPSY orbit determination software packages already support the capability to ingest TASS messages.

**Onboard Deep-Space Navigation Systems**

NASA seeks proposals to develop an onboard autonomous navigation and time-transfer system for reduction of DSN tracking requirements. Such a system should provide accuracy comparable to delta differenced one-way ranging (DDOR) solutions anywhere in the inner solar system, and exceed DDOR solution accuracy beyond the orbit of Jupiter. Proposers are advised that NASA's GEONS and DS-1 navigation software packages already support the capability to ingest many one way forward Doppler, optical sensor observation, and accelerometer data types.

**Technologies Supporting Improved TDRSS-based Navigation**

NASA seeks proposals providing improvements in TDRS orbit knowledge, TDRSS radiometric tracking, ground-based orbit determination, and Ground Terminal improvements that improve navigation accuracy for TDRS users. Methods for improving TDRS orbit knowledge should exploit the possible future availability of accelerometer data collected onboard future TDRS. The goal is navigation and communications integrated into a single processor.
Navigation Payload Technology for Lunar Relay Satellites

NASA seeks lunar relay navigation payload technologies that can:

- Transmit accurate spread spectrum signals (emphasizing the stability of the frequency reference yielding accurate timing and chipping rate of the PN code and a low noise carrier)
- Receive same in return (either in coherent mode (the relay transmits and receives using the same frequency reference) or non-coherent mode (where the accurate frequency reference is on one end of link, either the transmit side or the receive side)).

This relay navigation payload should be capable of receiving a satellite-to-satellite link with similar signal properties. The relay navigation payload has to measure the range (two-way), pseudo-range (one-way), and both one-way and two-way Doppler. The relay navigation payload must be able to de-commutate data received from Earth and lunar bases to maintain time synchronization with a master time source, use the data onboard to either slave its frequency reference or to update its reference, and turn-around the data to modulate onto the user data stream.

Additionally, the relay navigation payload must have:

- ‘Reasonable fidelity’ autonomous filtered navigation capability to fuse all data types listed above as well as antenna gimbal angles, accelerometer data, and rendezvous radar data, to estimate the lunar relay state
- Output data rates of 1 Hz for the states of multiple satellites and comprehensive fault detection and correction data
- State outputs that can be modulated on transmitted data streams
- TASS-like broadcast beacon capability for navigation. The data on the beacon can originate either at a base location (earth, moon), the relay, or another asset with which the relay communicates.
- Dissemination of time and navigation data for the local environment

Proposals can either address a single subject as described above or a combination of subjects.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I (to reach TRL 3) and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract (to reach TRL 5).
Phase I Deliverables:

- Midterm Technical Report
- Final Phase I Technical Feasibility Report with a Phase II Integration Path. Proof-of-concept bench top demonstration preferred.

Phase II Deliverables:

- Final Phase II Technical Report
- Demonstration hardware/software/field test.

O4.03 Flight Dynamics Software and Technologies

Lead Center: GRC
Participating Center(s): GSFC, JPL

NASA is beginning to invest in re-engineering its suite of tools and facilities that provide navigation and mission design services for design and operations of mid-term and long-term near-Earth and interplanetary missions. This solicitation seeks proposals that will develop the highly desired flight dynamics technologies and software that support these efforts.

Proposals that leverage state-of-the-art capabilities already developed by NASA are especially encouraged, such as:

- General Mission Analysis Tool (http://sourceforge.net/projects/gmat/ [23])
- GPS-Inferred Positioning System and Orbit Analysis Simulation Software (http://gipsy.jpl.nasa.gov/orms/goa/ [24])
- Optimal Trajectories by Implicit Simulation (http://otis.grc.nasa.gov/ [25])
Proposers who contemplate licensing NASA technologies are highly encouraged to coordinate with the appropriate NASA technology transfer offices prior to submission of their proposals.

Areas of interest: In the context of this solicitation, flight dynamics technologies and software are algorithms and software that may be used in ground support facilities, or onboard a spacecraft, so as to provide Position, Navigation, and Timing (PNT) services that reduce the need for ground tracking and ground navigation support. Flight dynamics technologies and software also provide critical support to pre-flight mission design, planning, and analysis activities.

This solicitation is primarily focused on NASA’s operational needs in the following focused areas:

- Applications of cutting-edge estimation techniques, such as, but not limited to, sigma-point and particle filters, to spaceflight navigation problems.
- Applications of estimation techniques that have an expanded state vector (beyond position and velocity components) to monitor non-Gaussian state noise processes and/or non-Gaussian measurement noise processes.
- Applications of estimation techniques that combine measurements from multiple sensor suites in a highly coupled manner to improve upon the overall system accuracy.
- Addition of novel estimation techniques to existing NASA mission design software that is either freely available via NASA Open Source Agreements, or that is licensed by the proposer.
- Applications of advanced dynamical theories to space mission design and analysis, especially in the context of unstable orbital trajectories in the vicinity of small bodies and libration points.
- Addition of novel measurement technologies to existing NASA onboard navigation software that is licensed by the proposer.
- Addition of orbit determination capabilities to existing NASA mission design software that is either freely available via NASA Open Source Agreements, or that is licensed by the proposer.

Technologies and software should support a broad range of spaceflight customers. Technologies and software specifically focused on a particular mission’s or mission set’s needs, for example rendezvous and docking, or formation flying, are the subject of other solicitations by the relevant sponsoring organizations and should not be submitted in response to this solicitation.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I (to reach TRL 3) and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract (to reach TRL 5).

Phase I Deliverables:
Antenna Technology Topic O1.01
NASA seeks advanced antenna technologies in the following areas: phased array antennas; ground-based uplink antenna array designs; large aperture deployable antennas; novel materials for next generation antennas; smart, reconfigurable antennas; and antenna concepts for harsh environments.

Phased Array Antennas
High performance phased array antennas are needed for high-data rate communication at Ka-Band frequencies and above as well as for remote sensing applications. Communications applications include: planetary exploration, landers, probes, rovers, EVA, suborbital vehicles, sounding rockets, balloons, unmanned aerial vehicles (UAV’s), TDRSS communication, and expendable launch vehicles (ELV’s). Also of interest are multi-band phased array antennas (e.g., X- and Ka-band) and RF/optical shared aperture dual use antennas, which can dynamically reconfigure active elements in order to operate in either band as required in order to maximize flexibility, efficiency and minimize the mass of hardware delivered to space. Phased array antennas for space-based range applications to accommodate dynamic maneuvers are also of interest. The arrays are required to be aerodynamic or conformal in shape for sounding rockets, UAV’s, and expendable platforms and must be able to withstand the launch environment. Potential remote sensing applications include: radiometers, passive radar interferometer platforms, and synthetic aperture radar (SAR) platforms for planetary science.

Ground-based Uplink Antenna Array Designs
NASA is considering arrays of ground-based antennas to increase capacity and system flexibility, to reduce reliance on large antennas and high operating costs, and eliminate single point of failure of large antennas. A large number of smaller antennas arrayed together results in a scalable, evolvable system, which enables a flexible schedule and support for more simultaneous missions. A significant challenge is the implementation of an array for transmitting (uplinking), which may or may not use the same antennas that are used for receiving. Arraying concepts that can enable a single network (i.e., DSN, NEN, and SN) at Ka-band frequencies and above are highly desired.
Large Aperture Deployable Antennas
Large aperture deployable antennas with surface root-mean-square (rms) quality better than \( ?/40 \) at Ka-Band frequencies and above, are desired. In addition, these antennas should significantly reduce stowage volume (packaging efficiencies as high as 50:1), provide high deployment reliability, and significantly reduced mass density (i.e., \(?1kg/m^2\)). These large Gossamer-like antennas are required to provide high-capacity communication links with low fabrication costs from deep space (Mars and beyond). Applicability to Ka-Band or higher frequencies is required. Concepts addressing antenna adaptive beam correction with pointing control are also of interest.

Novel Materials for Next Generation Antennas
NASA is interested in exploiting novel materials approaches for next generation antennas. For example, “smart” materials such as shape memory polymers or ionic polymer metal composites to permit active shape control or beam correction are of interest. Artificial electromagnetic media for phase velocity control and impedance tuning to improve the efficiency and bandwidth of electrically small antennas is of interest. Ferroelectric based technologies as well as multiferoics and spintronics concepts leading to new antenna designs are desirable.

Smart, Reconfigurable Antennas
Smart, reconfigurable antennas for applications in planetary operations are of interest. The characteristics to consider include the frequency, polarization, and the radiation pattern. Low-cost approaches are encouraged to reduce the number of antenna apertures needed to meet the requirements associated with rovers, pressurized surface vehicles, habitats, etc. for planetary surface exploration. Desirable features include multi-beam operation to support connectivity to different communication nodes on planetary surfaces, or in support of communication links for satellite relays around planetary orbits. Innovative receiver front-ends or technologies that allow for the DSP to move closer to the antenna terminal furthering the impact of the aforementioned, revolutionary “game-changing” antenna technology concepts are highly desirable.

Antenna Concepts for Harsh Environments
Novel, “Game Changing”, robust antenna concepts that can perform optimally and reliably in harsh environments such as those imposed by the Lunar regolith/dust and Martian dust are highly desirable.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: A final report containing optimal design for the technology concept including feasibility of concept, and a detailed path towards Phase II hardware demonstration. The report shall also provide options for commercialization opportunities after Phase II.

Phase II Deliverables: A working proof-of-concept demonstrated and delivered to NASA for testing and verification. Exit TRL 5 is expected at the end of Phase II.

Sub Topics:
Reconfigurable/Reprogrammable Communication Systems Topic O1.02
This solicitation seeks advancements in reconfigurable transceiver and associated component technology. The goal of the subtopic is to provide flexible, reconfigurable communications capability while minimizing on-board resources and cost. Areas of interest to develop and/or demonstrate are as follows:

- Software/firmware for the management of waveform or functional reconfiguration. Simultaneous operation while reconfiguration takes place and an adherence to the Space Telecommunications Radio System (STRS) v 1.02.1 document is desired, which will soon be publicly available at [https://www.spacecomm.nasa.gov/spacecomm/default.cfm](https://www.spacecomm.nasa.gov/spacecomm/default.cfm) [9]
  - Goal: Simultaneous operation while reconfiguration takes place.
  - Goal: STRS compliance
- Methods and tools for the development of software/firmware components that are portable across multiple platforms. Standards-based approaches are preferred.
  - Goal: Tool chain and/or development processes that result in 80% portability between 2 standards-based SDR platforms.
- Dynamic/distributed on-board processing architectures that are scalable and are designed to operate in...
various space environments.
  - Goal: 10x processing capability increase for fixed SWaP.

- Component technology advancements in bandwidth capacity and reduced resource consumption.
  - Goal: 5x bandwidth processing increase, 2x decrease in resource consumption.

- Analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities.
  - Goal: 3x increase in sampling resolution capabilities.

- Novel techniques or processes to increase memory densities.
  - Goal: 5x increase in memory per unit volume.

- Novel approaches to mitigate device susceptibility to radiation effects.
  - Goal: Target payload class SEU and latch-up mitigation techniques to achieve requirements for various class payloads in the desired space environment at lowest SWaP cost.

NASA also seeks to populate a repository for STRS compliant waveforms. These waveforms may be field or ported to available STRS-compliant SDRs. The description of STRS-compliance is available in the STRS 1.02.1 document, soon to be publicly available at https://www.spacecomm.nasa.gov/spacecomm/default.cfm. [9]

Note that NASA not only seeks reconfigurable/reprogrammable communication systems for flight applications, but also for the additional capabilities reconfigurable/reprogrammable systems may add to R&D and interoperability test labs. NASA centers have varying roles, capabilities, and R&D interests/priorities. Therefore, this year’s call will also take into consideration how the products from O1.03 (Phase I, II, and III) will contribute to the current administration’s vision for NASA and its commercial and international partners, and where these products may be relevant within our collection of terrestrial labs and/or flight systems.

The advancement of component technology for reconfigurable/reprogrammable communications systems is highly desirable for the insertion of these systems into space missions. Further adoption of reconfigurable/reprogrammable communications systems allow NASA science and human space flight missions to reduce risk and evolve as future requirements mature. These component technologies address either the reduction of size, weight, and power of these systems, or the costs associated with development.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: The Phase I deliverable consists of a report detailing the technical feasibility of the innovation and it’s contribution to the advancement of the state-of-the-art. The Phase I technology is expected to result in the component technology developed to TRL 2-3.

Phase II Deliverables: The Phase II deliverable consists of a demonstration of hardware and/or software prototype(s) with the intent of integration or testing in a relevant NASA laboratory, with a corresponding report detailing operating instructions for the component technology. The Phase II technology is expected to result in the component technology developed to TRL 5-6.

Sub Topics:
  - Game Changing Technologies Topic O1.03

NASA seeks revolutionary, highly innovative, game changing technologies that have the potential to enable order of magnitude performance improvements for space communications and navigation. Fundamental, strategic R&D is a critical element in developing innovative and superior technologies for space communication and navigation systems by addressing deficiencies in the current space communications network infrastructure to enhance performance, improve efficiency and reduce cost.

Research is geared towards emphasizing research and space technologies that are far-term focused in (but not limited to) the following areas:

- Low SWAP Transceivers: Develop novel techniques to reduce the size, weight, and power (SWAP) requirements for communications transceivers and software-defined radios for space missions. Address SWAP challenges by addressing digital processing and logic implementation tradeoffs, static vs. dynamic power, voltage and frequency scaling, hardware and software partitioning such that operational modes are effectively managed. Use of open, interoperable standards is encouraged.

- Ka-band RF Devices and Components: Investigate novel RF (especially Ka-band) communications
technologies and innovative approaches for high bandwidth, Ka-band devices and components (transceivers, modulators, highly efficient amplifiers, etc.). Approaches to significantly reducing size, mass, and power requirements for these components are paramount as well.

- **High Performance Ultra Low-Power ADCs and DACs:** The high power consumption and lack of flexibility to reconfigure on-the-fly make off-the-shelf analog-to-digital converters (ADCs) devices ill-suited for digital radio applications. To enable next-generation radios and support the ever-increasing user demands of high resolution (6 GSPS) and input bandwidths (2.5 GHz), breakthroughs in high-speed, low power ADCs are needed. Assume dynamically adjustable resolution up to 16 bits and on-board ultra-low jitter clock circuit to enhance spectral power distribution. A deep sleep mode feature is highly desirable to conserve power. Currently, state-of-the-art high rate digital-to-analog converters (DACs) are power prohibitive. To increase robustness, spectral efficiency, and compactness, NASA seeks to develop complementary DACs. For example, at a scant total power budget of 4 watts, ADCs and DACs will facilitate breakthroughs in S-band digital transceivers with fewer parts, smaller form factors, and greater design flexibility.

- **Nanotechnology:** High-performance, multi-functional, nano-structured materials for communications applications. Single wall carbon nano-tubes exhibit extraordinary mechanical, electrical, and thermal properties at the nano-scale level and possess exceptionally high surface area to volume ratio. The development of nano-scale communication devices and systems including nano-antennas, nano-transceivers, etc. are of interest for nano-spacecraft applications.

- **Quantum Entanglement:** Innovative breakthroughs in quantum information physics has sparked interest to specifically address this phenomenon and the critical unknowns relevant to revolutionary improvements in communicating data, information or knowledge. Methods or techniques that demonstrate extremely novel means of effectively packaging, storing, encrypting, and/or transferring information are sought.

- **RF MEMS Integrated Components:** RF micro-electromechanical systems (MEMS) offer exceptional RF performance and power characteristics that can lead to dramatic advantages for novel radio applications. Such as wireless filter banks, switching matrices, and instrumentation. Although low-power, high efficiency charge pumps can be integrated into advanced communication systems that employ novel MEMS devices (e.g. switches or varactors) or circuits (e.g. tunable filters or power amplifiers), there are some long-term challenges with power handling and non-linear behavior for power levels of 1 Watt. Because high-Q varactors and filters are not well understood, NASA seeks to advance revolutionary MEMS devices and architectures that are immune to bias noise.

- **Trans-Horizon Communications:** Innovative approaches to use of medium to high frequency (300 KHz-30MHz) bands for applications benefiting future surface landing missions. Concepts, studies, development of key technologies are needed to perform non-line-of-sight communication for potential use on the surfaces of celestial bodies. For example, the lunar exosphere may have the ability to support such communications, if fully understood. Modulation and coding techniques, antennas, solid-state amplifiers, digital baseband circuitry, etc. are required to be developed and/or validated to enable over the horizon communication and communications into craters for robotic and human missions. Range of communications on the order of 10-20 kilometers at a data rate of 128 kbps is envisioned to support many of these types of surface communications links.

- **Navigation:** In adopting any proposed game-changing technologies, the capability for provision of high-quality metric tracking observables for orbit determination and other tracking services must be considered. Proposers should recognize that NASA may not be able to adopt certain game-changers in communications and navigation technology if they do not support at least NASA’s current needs for metric tracking data services. Proposals in this area should document any potential performance enhancements, and especially any foreseeable compatibility issues associated with metric tracking data services.

- **Low-Power High Stability Reference Sources:** Highly stable clocks and oscillators play a pivotal role in a myriad of space communications and navigation applications. Atomic (cesium) clocks used today have time measurement accuracies on the order of 2 nanoseconds per day. New research (optical, quantum) into improving time measurement accuracy, size, reliability for space communications and navigation are of interest. Highly stable clock sources for wireless communications devices can improve network synchronization and channel selection to enhance security and anti-jamming capabilities.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

**Phase I Deliverables:** Deliverables expected at the end of Phase I include trade studies, conceptual designs, simulations, analyses, reports, etc. at TRL 1-2.
Phase II Deliverables: Demonstrate performance of technique or product through simulations and models, hardware or software prototypes. It is expected that at the end of the Phase II award period, the resulting deliverables/products will be at or above TRL 3.

Sub Topics:

Long Range Optical Telecommunications Topic O1.04

This subtopic seeks innovative technologies for long range Optical Telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

Systems and technologies relating to acquisition, tracking and sub-micro-radian pointing of the optical communications beam under typical deep-space ranges (to 40 AU) and spacecraft micro-vibration environments, as follows:

- **Small lightweight two-axis gimbals:** Flight qualifiable, less than 2 kg in mass capable to actuating payload mass of approximately 3 kg at rates up to 5 degrees/second, less than 30 micro-radian jitter, 30 micro-radian rms error and blind-pointing accuracy of less than 35 micro-radian. Proposals should come up with innovative pragmatic designs that can be flown in space.

- **Photon counting Si, InGaAs, and HgCdTe detectors and arrays:** For the 1000 to 1600 nm wavelength range with single photon detection efficiencies greater than 60% and output jitters less than 20 pico-second, active area greater than 20 microns/pixel, and 1 dB saturation rates of at least 100 mega-photons (detected) per pixel and dark count rates of less than 1 MHz/square-mm.

- **Single-photon-sensitive, high-bandwidth, linear mode photo-detectors:** With high bandwidth (>1GHz), high gain (>1000), low-noise (<1kcps), large diameter (200 micron), HgCdTe avalanche photodiode and/or (small diameter) arrays for optical detection at 1060 nm or 1550 nm.

- **Uncooled photon counting imagers:** With >1024 x 1024 formats, ultra low dark count rates and visible to near-IR sensitivity.

- **Ultra-low fixed pattern non-uniformity NIR imagers:** With large format (1024x1024), non-uniformity of less than 0.1%, low noise (<1e- read, <1ke/pix/s dark) and high (>0.7) quantum efficiency.

- **Radiation hard photon counting detectors and arrays:** For the 1000 to 1600 nm wavelength range with single photon detection efficiencies greater than 40% and 1dB saturation rates of at least 30 mega-photons/pixel and operational temperatures above 220K and dark count rates of <10 MHz/mm. Radiation levels at least 300 krad (unprotected).

- **Isolation platforms:** Compact, lightweight, low power, broad bandwidth (0.1 Hz -3 kHz) disturbance rejection.

- **Laser transmitters:** Space qualifiable, greater than 20% wall plug efficiency, lightweight, 20-500 pico-second pulse-width (10 to >100 MHz PRF), tunable (~0.2 nm) pulsed 1064-nm or 1550-nm laser transmitter fiber or planar-waveguide MOPA sources with greater than 1 kW of peak power per pulse (over the entire pulse-repetition rate), with Stimulated Brillouin Scattering suppression and >10 W of average power, near transform limited spectral width, and less than 10 pico-second pulse rise and fall times. Also of interest for the laser transmitter are: robust and compact packaging with radiation tolerant electronics inherent in the design, and high speed electrical interface to support output of pulse position modulation encoding of sub nanosecond pulses and inputs such as Spacewire, Firewire or Gigabit Ethernet. Detailed description of approaches to achieve the stated efficiency is a must.

- **Low-cost ground-based telescope assembly:** With diameter greater than 2-m, primary mirror with f-number of ~1.1 and Cassegrain focus to be used as optical communication receiver optics. Maximum RMS surface figure error of 1-wave at 1000 nm wavelength. Telescope shall be positioned with a two-axis gimbal capable of 0.25mrad pointing. Combined telescope, gimbal and dome shall be manufacturable in quantity (tens) for ~$3 M each.

- **Daytime atmospheric compensation techniques:** Capable of removing all significant atmospheric turbulence distortions (tilt and higher-order components) on an uplink laser beam; and/or for a 2-m diameter downlink receiver telescope. Also of interest are technologies to actively compensate for the static and dynamic (gravity sag and thermal) aberrations of 2-m diameter telescopes with a surface figure of 10’s of waves (down to less than 1-wave at 1000 nm).

Research should be conducted to convincingly prove technical feasibility during Phase I, with clear pathways to demonstrating and delivering functional hardware, meeting all objectives and specifications, in Phase II.
Phase I Deliverables:

- Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 3-4)
- Verification matrix of measurements to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

Phase II Deliverables:

- Working brassboard model of proposed product, along with full report of development and measurements, including populated verification matrix from phase II (TRL 5).
- Opportunities and plans should also be identified and summarized for potential commercialization.

Sub Topics:

**Long Range Space RF Telecommunications Topic O1.05**

This solicitation seeks to develop innovative long-range RF telecommunications technologies supporting the needs of space missions. The ultimate objective is to maximize aggregate mission data return per unit mass, unit volume, unit cost and unit power consumed by the spacecraft telecommunications subsystem.

In the future, spacecraft with increasingly capable instruments producing large quantities of data will be visiting the moon and the planets. To support the communication needs of these missions and maximize the data return to Earth, innovative long-range telecommunications technologies that maximize power efficiency, transmitted power density and data rate, while minimizing size, mass and power are required.

The current state-of-the-art in long-range RF space telecommunications is 6 Mbps from Mars using microwave communications systems (X-Band and Ka-Band) with output power levels in the low tens of Watts and DC-to-RF efficiencies in the range of 10-25%.

This solicitation seeks proposals in the following areas:

- Ultra-small, light-weight, low-cost, low-power, modular deep-space transceivers, transponders and components, incorporating MMICs and Bi-CMOS circuits;
- MMIC modulators with drivers to provide a wide range of linear phase modulation (greater than 2.5 rad), high-data rate (10 - 200 Mbps) BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (26 GHz, 32 GHz and 38 GHz);
- High-efficiency (> 60%), low mass Solid-State Power Amplifiers (SSPAs), of both medium output power (10 W-50 W) and high-output power (150 W-1 KW), using power combining and/or wide band-gap semiconductors at X-band (8.4 GHz) and Ka-band (26 GHz, 32 GHz and 38 GHz);
- Utilization of nano-materials and/or other novel materials and techniques for improving the power efficiency or reducing the cost of reliable vacuum electronics amplifier components (e.g., TWTAs and Klystrons);
- Ultra low-noise amplifiers (MMICs or hybrid) for RF front-ends (< 50 K noise temperature);
- MEMS-based integrated RF subsystems that reduce the size and mass of space transceivers and transponders. Frequencies of interest include UHF, X- and Ka-Band. Of particular interest is Ka-band from 25.5 - 27 GHz and 31.5 - 34 GHz.
- Ultra low mass, high gain, high efficiency spacecraft antennas using advanced light materials and structures.
- Novel, hybrid spacecraft antenna designs that can act as efficient reflectors/concentrators of both RF (X- and Ka-Band) and optical (1550 nm) electromagnetic waves.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Feasibility study, including simulations and measurements, proving the proposed approach to
develop a given product (TRL 3-4). Verification matrix of measurements to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

Phase II Deliverables: Working engineering model of proposed product, along with full report of development and measurements, including populated verification matrix from Phase II (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.

Sub Topics:
Space Networking Topic O1.06

NASA’s Space Communications and Navigation Program (SCaN) is integrating its current agency networks: Deep Space Network (DSN), Space Network (SN), TDRSS spacecraft, Near Earth Network (NEN), and future Exploration Destination networks into a single Integrated Architecture circa 2018. Technologies must be adaptable to a variety of network operating environments ranging from the long-latency limited bandwidths of deep space communications to near Earth environments with traffic flow over global partner assets and the future internet. It is also important to note that NASA systems include ground-to-ground segments in addition to space-to-ground links. Solutions must keep in mind the “big picture” and be capable of seamlessly integrating with future ground systems.

Emerging space communications environments are expected to be shaped in various ways: small mobile mission clusters; traditional large spacecraft and launch vehicles; complexities of commercial and international partnering on the network and user sides; increasing threats to US space communications and navigation assets; and NASA’s need for 40% reduction in network operating costs.

NASA seeks space-networking technologies, which add network intelligence and learning capabilities to increase network efficiency; provide tailored user services; reduce network operating costs through automation; and increase security and resiliency.

Several technologies with promise to meet some of these challenges are listed below with their purpose current state-of-art, and performance metrics desired. Proposals should focus on one or two of these technologies, or for the more complex topics, single implementation aspects.

- **Dynamic traffic prioritization** provides a means to quickly isolate different types of traffic schemes across the space network. Current technologies allow for such features in the ground environment and the study should leverage those techniques as appropriate. The proposed approach should identify what is necessary for prioritization to be leveraged across multiple space organizations. It should also identify how decisions may impact the performance of different types of data streams.

- **Adaptive autonomous network management** is to enable smart network elements to make decisions within a predetermined playbook based upon awareness of local network conditions, policies and network end-to-end-objectives. Examples such as automated uplink/downlink scheduling have been demonstrated and are in operational use in limited circumstances. The concept is to shorten the time between a particular network anomaly and the resulting response by mission control allowing for more efficient utilization of the network. Studies must show how the shortened control loop yields better efficiency and how both conditions and automated responses are relayed back to a human operator.

- **Cognitive networking with learning** is to enable intelligent network elements to reason about reconfiguration decisions [at any layer in the protocol stack] even in unexpected conditions [whether to make decisions autonomously or to offer quantitative support to human operators] based upon situational awareness of network conditions and statistical learning about network behavior and consequences of prior interventions. Software defined and cognitive radios have been demonstrated for terrestrial use and are progressing towards broader cognitive network applications with limited and specific terrestrial demonstrations. Cognitive networking with learning is currently at the forefront of the state-of-the-art, with a multiplicity of approaches being developed for diverse applications such as Future Internet, mobile wireless, and tactical communications. Bidders are encouraged to narrow their focus to specific implementation issues in the domain and focus on adaptation for SCaN space networks. Desired performance metrics are relevant analytical estimates of potential benefits and feature cost-benefit.

- **Enhanced security and trust management services** for missions that have limited computational and power resources. Contact should not be assumed to be continuous and approaches should leverage proven security techniques where appropriate and provide a means to authenticate between assets and to provide a means to securely update network information (i.e. route injection). It will be important to identify how the proposed approach mitigates particular security risks while also remaining efficient in the space environment.
Novel techniques for position determination, timing, and route computation are to provide essential services for missions that venture beyond GPS coverage and SCaN infrastructure particularly for missions limited in equipage they can carry or in the face of intentional service disruption. Human missions develop positional uncertainty at a rate of 10 km/hr due to random accelerations. Early lunar missions like LRO are without timing service. Route computation requirements emerge with formation flight, delta-V sensitive libration point and planetary highway orbits, and robotic surface exploration. [Metrics: convergence time, overhead (number of bytes used by routing algorithm to reach steady state)].

For more information on NASA’s future space communication plans, please see the Space Communications and Navigation website at https://www.spacecomm.nasa.gov/ [10]

Performance metrics are listed by technology above.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Phase I report will analytically demonstrate technical feasibility of one or more space networking technologies identified above by characterizing:

- Technical requirements flow-down from generic objectives and summary of state-of-the-art to SCaN network-specific requirements on key performance metrics
- Identification of specific technical challenges to implementation for SCaN networks.
- Analysis of at least three alternative approaches to obtain this performance for SCaN networks.
- Assessment of cost-benefit of each (e.g. risk, complexity, added overhead)
- Selection of software or hardware concept and emphasis topics for further investigation.
- Plan for Phase II resolution of issues or uncertainties and hardware and software demonstration.
- Target TRL 3 at the end of Phase I efforts.

Phase II Deliverables: Phase II report will document:

- Updates to the technical requirements flow-down, identified technical challenges, and selected hardware or software concept based upon further investigation in Phase II.
- Analytical or experimental investigations undertaken to resolve issues and further definition of the selected approach.
- Design and test approach selected for hardware or software demonstration with detailed description of assumptions and parameters.
- Conclusions based upon test results and recommendations for further investigation including any plans for commercialization or further development.
- Target TRL of 5 at the end of Phase II efforts.

Sub Topics:
Secondary/Auxiliary Payload-to-Launch Vehicle Interface Technologies Topic O2.01
This subtopic includes two major technology areas:

1. Small payload standard interface technologies (SPSIT)
2. Entry and ascent experimental platform technologies (EAEPT)

Proposals will be accepted for either area.
Many expendable launch vehicle (ELV) launches do so with excess capacity. The utilization of specific excess volumes within a launch system must be accomplished at a low cost with minimal to no additional risk to the primary payload or launch vehicle. This subtopic seeks to develop commercial solutions that will allow and encourage new enabling launch capabilities and standardization of key payload-to-launch vehicle processes and interface standards with the goal of producing a low cost, low risk platform or process for integrating secondary or auxiliary payloads on existing NASA ELV launches.

The goal is to develop new launch vehicle capabilities such as adapters/platforms, processes, and/or avionics interface standards that can be collectively used to:

- Minimize integration tasks and/or duration of integration efforts to install secondary/auxiliary payloads onto NASA ELV launches
- Facilitate secondary/auxiliary spacecraft and subsystem design while reducing testing duration and complexity
- Impose no additional risk to the primary mission
- Enable novel mission concepts for secondary/auxiliary payloads

**Small Payload Standard Interface Technologies**

Currently, the Poly-Picosatellite Orbital Deployer (PPOD) provides a cost-efficient standard interface and deployment system for CubeSats in the 1 to 3 kg mass range. In addition, the Evolved ELV (EELV) Secondary Payload Adapter (ESPA) provides a standard structural interface for secondary payloads up to 180 kg and is designed for interface into Atlas V and Delta IV launch vehicles. A smaller version of the ESPA ring has been conceptualized for smaller launch vehicles. Both the ESPA and the small ESPA are most cost effective when they accommodate 6 payloads. In addition, for the most part, the avionics and electrical power interfaces are unique to each launch vehicle fleet. This subtopic seeks to develop commercial solutions that could allow the cost effective launch of one or more secondary/auxiliary payloads via an interface (structural, avionics and electrical) that is standard or expandable/upgradable to be compatible with the maximum number of domestic launch vehicles. NASA currently has Pegasus XL, Taurus XL, Falcon 1, Falcon 9, Atlas V and Delta IV on contract.

A significant fraction of mission costs are typically unique designs and approaches to perform relatively routine functions such as launch accommodations and subsystem-to-subsystem interface and communications. By standardizing many of these approaches, spacecraft and payload developers can design their systems with an expectation of a predictable, low-cost integration flow. Launch service providers can mitigate mission risk through the use of predictable and proven interfaces standardized to streamline analytical/physical integration processes and test flows.

This subtopic will focus on new interfaces for payloads in the mass range of 3 to 180 kg, which can be grouped as needed for any modularization concepts. A range of 11 to 100 kg has been specifically identified as a region where critical technology demonstrations and new space technologies could use affordable orbital launch opportunities to increase their TRL, potentially reducing their overall cost and risk to development. Enabling affordable launch capabilities in these ranges could also allow scientific and educational spacecraft (s/c) developers the ability to design to a specific mass range that will result in on-orbit research.
The technologies in this subtopic are highly desirable because although adapters that could support most missions exist, having multiple systems across multiple launch vehicles fleets will contribute to higher integration costs. Standards amongst the s/c and adapter community will reduce integration cost and therefore the per-kilogram cost-to-orbit.

Areas of interest (SPSIT):

- Launch adapters and systems and associated spacecraft standards
- Standardized spacecraft and/or payload integration test flows, processes and qualification techniques
- Standardized electrical interfaces, sometimes known as plug and play electrical power and data bus standards for streamlined subsystem integration.

The critical requirement for all areas of interest identified above is that the design, integration or implementation shall not increase base line risk to the primary spacecraft or the launch vehicle mission success. Implementation of the above enables support for any upcoming missions needing the capability to demonstrate new technology on-orbit by using a standard interface or process.

Phase I Deliverables (SPSIT):

- Assessments of current and future spacecraft/mission/space technologies in the mass ranges will identify current adapter systems, processes and determine the TRL for each system within 3 year timeframe from award date
- Develop draft standards for both spacecraft, adapter, integration process and avionics interfaces

At the completion of phase I, the goal is to have achieved a TRL 3 or better for the adapter systems and processes

Phase II Deliverables (SPSIT):

- Finalize standards within the mass range
- Complete adapter hardware designs
- "Plug-n-play" avionics standards hardware/software
- Conduct PDR and CDR of new technologies
Finalize standards for the integration process

Higher TRL levels at the completion of Phase II will increase the likelihood of a path for infusion into NASA missions.

Entry and Ascent Experimental Platform Technologies

Current launch capabilities for aerodynamic and hypersonic research are limited to either high cost launches as a primary payload on a launch vehicle, or small packages (typical sounding rocket payload volume and mass ~ 10 ft³, 300 lbm). Sounding rockets that provide the technology testing capabilities are also limited in the altitude and the speeds they can achieve. Therefore, the conceptual design for a new platform is being sought to fill the technology-testing gap. For example, if the vehicle configuration had spare solid rocket motor capacity, this experimental platform could launch as a secondary payload, by occupying the location of a solid rocket motor on a launch vehicle such as the Atlas V or Delta IV.

The new experimental platform would provide expanded testing capabilities to accommodate payloads with larger (2-10 times) size and weight, obtaining greater altitudes and speeds than currently provided using sounding rockets. The platform would provide an affordable way to demonstrate and test new technologies through hypersonic, intra-atmospheric, and reentry phases. The launch vehicle can be any vehicle used by NASA (currently, Pegasus XL, Taurus XL, Falcon 1, Falcon 9, Atlas V and Delta IV are on contract) and must be integrated onto the first stage of a vehicle per the areas of interest listed in Areas of interest section below.

Usage of this experimental platform could support development of a number of advanced technologies through flight-testing in representative environments, where their TRL could be validated and advanced. Such technologies could then be considered viable options for atmospheric entry and ascent technologies for governmental and commercial applications.

Technologies that could be tested in this experimental platform include but are not limited to:

- Thermal protection materials,
- Guidance, navigation and control,
- Vehicle configuration concepts for investigation of both ascent and entry designs for earth, lunar, and Mars space vehicles under supersonic and hypersonic conditions

Objective (EAEPT): Design a cost effective experimental platform with associated payload interface that minimizes the impact to the primary payload and launch vehicle's processing and certification for flight.

Areas of interest (EAEPT): NASA seeks platform designs incorporating the following characteristics:
• Ability to integrate with the launch vehicle late in the mission integration phase,

• Ability to fly a dummy payload(s) (in case the secondary payload does not meet the launch readiness date),

• Mo required mission unique interfaces with the launch vehicle (electrical, environmental control, etc.)

• Does not impose additional risk on the success of the primary mission

• Enables maximum use of the existing design and hardware (i.e., attach structures, case design) of the launch vehicle to minimize risk

• Has minimal impact to the vehicle external mold line and mass requirements, such that the aerodynamic flight environments, dynamic load environments, and thermal environments imposed are of similar or equivalent levels as compared to the vehicles as currently flown

• Is compatible with existing launch vehicle hardware

• Is compatible with current vehicle qualification environments

• Is compatible with vehicle mass requirements

• Facilitates manufacturing and production (support multiple and repeatable flights)

• Accommodates flight specific payload modifications.

Much of this information can be found on line on the Launch Provider's public websites:


• [http://www.spacex.com/Falcon1UsersGuide.pdf](http://www.spacex.com/Falcon1UsersGuide.pdf) [16]

Once awarded, NASA (LSP) will facilitate the development of a Non-Disclosure Agreement (NDA) between the small business and launch provider.

Phase I Deliverables (EAEPT):
A final report containing technology design concept(s) demonstrating technical feasibility including:

- Feasibility of concept
- A draft Systems Requirements Document (SRD)
- A detailed path towards Phase II level design maturity
- Detailed report presenting the results of Phase I analysis, modeling, etc.
- Expected TRL at end of Phase I is 3

Phase II Deliverables (EAEPT):

- Preliminary Design Review (PDR) and Critical Design Review (CDR) of the aforementioned platform for use on one of the existing ELVs within NASA's fleet
- Expected TRL at end of Phase II is 5

Sub Topics:
- Propulsion Technologies Topic O2.02

Sub Topics:
- Spaceport Enhancement & Improvements Topic O2.03

The key operating characteristics for a Spaceport focus are interoperability, ease of use, flexibility, safety/environmental protection, and multiple concurrent operations. The long-term vision is to have “airport-like” spaceport operations. Therefore, the development of effective spaceport technologies is of primary importance to NASA. These technologies will need to support both the existing and future vehicles and programs.

**Space-Based Telemetry**

NASA is seeking to reduce or eliminate the need for redundant range assets and deployed down-range assets that are currently used to provide for Line-of-Sight (LOS) Tracking Telemetry and Control (TT&C) with sub-orbital platforms and orbit-insertion launch vehicles.

There are varying applications for space-based transceivers, each necessitating a different set of requirements. The desired focus is very low size, weight, and power (SWaP), tactical grade, highly reliable, and easily reconfigurable transceivers capable of establishing and maintaining unbroken satellite communication links for telemetry and/or control. This technology will serve applications, which include low-cost sub-orbital missions, secondary communications systems for orbit insertion vehicles, low cost and size orbital payloads (typically LEO), and flight test articles. Durations will range from minutes to several weeks and the ability to operate on highly
dynamic platforms is critical. High data rate links are highly desired, thus the use of NASA’s TDRSS is emphasized, although other commercial satellite systems, which can provide nearly global and high data rate links can also be explored. Factors to address include:

- Advancements in software based radios and encoding techniques,
- Use of the latest semiconductor technologies (GaN or other),
- Advanced heat dissipation techniques,
- Immunity to corona breakdown,
- Ease of data interfacing.

RF power output requirements range from a few watts to as high as 100 W. Special consideration should be given to transceiver capability vs. packaging that would allow for customizable configurations depending on the target application.

**Range Weather**

NASA seeks innovative technologies to remotely measure electric fields aloft to reduce the threat of destruction of a launch vehicle by rocket triggered lightning. Potential candidate technologies include new algorithms to take advantage of existing dual-polarized Doppler five-cm weather radar capability, or entirely new technologies for the remote sensing of electric fields. The ability to economically measure the incremental ballistic wind velocities along the predicted trajectory of launch vehicles at remote and evolving launch ranges at altitude up to 100 kft via fixed and mobile LIDAR approaches is also highly desirable.

The above technologies are considered to be highly desirable for NASA’s objectives and critical for the realization of true Spaceports.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: A final report containing optimal design for the technology concept including feasibility of concept, detailed path towards Phase II hardware and software demonstration, and detailed results of Phase I analysis, modeling, prototyping, and testing.

Phase II Deliverables: A working proof-of-concept demonstrated and delivered to NASA for testing and verification with a TRL of 4 to 6.
Sub Topics:
Advanced Composite Tank and Materials Technologies Topic O2.04
This subtopic includes two major technology areas:

(1) Reusable, Reliable and Low Cost Composite Tanks
(2) Advanced Material Integration Technology Development

Proposals will be accepted for either area.

Reusable, Reliable and Low Cost Composite Propellant Tanks (RRLCCPT)

The objective of this subtopic is to help dramatically reduce the cost to low Earth orbit by advancing the technology involved in composite propellant tanks and advanced composite material development. The ability for launch vehicles to combine the significant weight savings of composite tanks with airline like operations could be possible if these tanks are also reusable, reliable, and need little to no maintenance between flights.

Purpose and Current State-of-the-Art: Composite tanks offer significant weight savings, but there are significant shortfalls in terms of reusability, especially when using cryogenic fluids. This lack of reusability severely hampers adoption of this enabling technology in future reusable vehicle. This subtopic will also address emerging composite tank technologies, specifically in the areas of testing and verification pertaining to damage tolerance, safe-life and checkout.

General Operational Needs and Requirements/ Performance Metrics:

Airline-like Operations
Government and commercial reusable launch vehicles are only economically viable if they can achieve high flight rates of dozens of flights per year or more per vehicle. These flight rates themselves are only possible if something akin to airline like operations becomes possible for spaceflight.

Reusability and Reliability
Reusable, reliable, and low cost composite tanks that need little to no maintenance between flights and minimal check-out are required for economic and operational sustainability. These developments can:

- Ease operability of the tank diagnostics
- Enable tank prognostics
• Enable tanks to handle high pressure cycles and loads without leaking or developing structural failure
• Promote ease of manufacture, and by more than one American company
• Promote ease of repair without returning tanks to the manufacturer's facility
• Promote rapid certification/recertification techniques to meet expected FAA commercial RLV requirements

Data and Technology Development

Of specific concern and interest are safe-life and damage tolerance testing. There is much scrutiny regarding the manner and degree of testing in these areas, specifically after some number of pressure cycles. Also of concern is the effect of temperature on and during cycling and material compatibility. Due to the limited amount of flight and long term performance data there is little to base future design on when the desire is heritage similarity. Thus, development in regards to these specific metrics (safe-life and damage tolerance testing) would be most beneficial to both short and long term missions.

The outcome of this portion of the SBIR is expected to be technologies and data that make possible composite propellant tanks that have improved reliability and performance that will enable a high degree of reusability. Data should show that proper material, manufacturing processes and design are used to produce a vessel that performs well under long-term use in a cryogenic condition. The vessel would minimize microcracking, should be damage tolerant and repairable, and have mounting capabilities.

For the proposed technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware demonstration and testing. Delivery of a demonstration unit for NASA testing at the completion of the Phase II contract is also required.

Phase I Deliverables (RRLCCPT): Final report containing:

• Optimal design and feasibility of concept,
• Detailed path towards Phase II demonstration,
• Detailed results of Phase I analysis, modeling, prototyping and development testing
• Material coupon data and a prototype sub-scale tank

Desired deliverables at the end of Phase I should be at TRL 3-4

Phase II Deliverables (RRLCCPT): By the end of Phase II, working proof-of-concept technologies, including features and demonstration of long term, high cycle performance at cryogenic temperatures, demonstrated and delivered to NASA for testing and verification.
Deliverables expected at the end of Phase II should be at TRL 5-6.

**Advanced Material Integration Technology Development (AMITD)**

Advanced materials including ceramic composites and metallic materials, will require technologies that will allow joining of these materials, specifically the development of advanced joining and integration technologies with enhanced temperature and performance capability. Typical materials are carbon and silicon carbide based composites and super alloys. The quality of joined sub-elements should also be evaluated nondestructively to assess the integrity and quality of the joints. Material systems may be similar or dissimilar in nature (composite to metals or composite to composites).

Purpose and Current State-of-the-Art: Currently the most commonly used fabrication approaches (CMC, CVI and PIP) have severe limitations in terms of size and shape of CMC components that can be manufactured with appropriate property attributes and a reasonable cost. Therefore, current design considerations for the manufacturing of large CMC components and structures will be utilizing technologies for joining/attaching smaller-sized components with simpler geometries and dissimilar material systems.

General Operational Needs and Requirements: Ceramic joining and integration is an enabling technology for the successful implementation of CMC’s in a wide variety of high temperature applications. Among the various alternatives available to overcome the limitations of the many fabrication technologies for the manufacture of large CMC components and structures of complex shape, the joining of smaller components with simple geometry appears to be the most promising and practical. Application of simple equipments for curing and during the high temperature joining process is critical. Requirements include, but are not limited to:

- Materials to be joined are silicon carbide or carbon-based matrix fiber reinforced composites to a similar CMC or high temperature metallic alloy
- Proposed joining approach should be robust and able to produce joints with tailorable microstructures
- Thermo-mechanical properties of the joint interlayer should be tailorable and close to those of the base materials
- Proposed technologies are expected to be easy to apply in a manufacturing environment at high technology readiness levels
- For CMC-CMC joining, the joint interlayer material should be able to yield ceramic interlayers with temperature capability similar or better than the substrate materials with low porosity

Performance Metrics: The temperature capability of the ceramic joints in joined CMC should be similar to that of the CMC substrate materials. The chemical composition of the joints should not alter the stress rupture, creep, high temperature mechanical strength, and stiffness of the overall system in any significant manner. The environmental stability, time dependent mechanical properties, and performance of the joints should not be significantly different than the substrate materials.

For the proposed technologies, research should be conducted to demonstrate technical feasibility during Phase I.
and show a path toward Phase II sub-element and subcomponent development and testing. Delivery of a subcomponent demonstration unit for NASA testing at the completion of the Phase II contract is also required.

Phase I Deliverables (AMITD): Develop and demonstrate a robust joining concept, understand common test methods for joint testing, and assess the interfacial microstructure and mechanical properties of joints. Assess high temperature durability of joints and effect of joint design on thermo mechanical performance.

Desired deliverables at the end of Phase I should be at TRL 3-4.

Phase II Deliverables (AMITD): Produce and test additional joint prototypes (sub-elements and subcomponents) under representative flight conditions to include anticipated temperatures, heat fluxes, thermal gradients, and environmental effects. Full macro-structural and micro-structural material characterization of joints before and after testing will be required to assess life-limiting failure mechanisms and joint reliability. Provide joined CMC subcomponents or segmented structures with a method to non-destructively evaluate the joint quality.

Deliverables expected at the end of Phase II should be at TRL 5.

Sub Topics:
Reusable, Reliable, Low Cost Thermal Protection Systems Topic O2.05
As NASA enables commercial space access, there is a critical need for reusable, reliable, low-cost thermal protection systems (TPS). New material and computational technologies offer the potential of more durable and operable TPS for space transportation vehicles that can tolerate high temperatures while improving operability and reducing maintenance time and costs.

This subtopic requests innovative proposals in the following areas:

- Technologies and systems offering a factor of two or greater reduction in maintenance time and costs
  - Reusable space transportation vehicles being developed for Earth to orbit access and return,
  - In-space transportation systems using aero-braking and aero-capture, and
  - On-demand payload and crew return systems

- Multi-use and reusable TPS concepts applicable for insulated composite and metallic vehicle structures
  - With improved robustness
- Reduced and/or automated inspection, repair and recertification,
- While remaining weight competitive to current flight proven TPS

- TPS non-destructive evaluation techniques and new health management approaches and strategies
- Rapid TPS inspection, repair, and flight certifications techniques
- Designs and concepts for new TPS attachment methods,
- Designs for gaps and joints
- TPS designs for control surfaces and interfaces

Phase I Deliverables: Phase I deliverables include a final report detailing optimal design for the technology concept, including a feasibility assessment and summary of analysis, modeling and any prototype development and testing. For concepts that show good feasibility, the final report should also contain a plan for Phase II development and demonstration.

Desired deliverables at the end of Phase I should be at TRL 2-3.

Phase II Deliverables: Phase II deliverables include a working proof-of-concept available for NASA inspection and testing if applicable. Opportunities and plans should be identified and summarized for potential commercialization.

Deliverables expected at the end of Phase II should be at TRL 4-5 (minimum).

Sub Topics:
Mission Operations Topic O3.01
The objective is to develop advanced capability software systems for mission operations in support of NASA's Space Communications Infrastructure. The current infrastructure for NASA Space Communications provides services for near-Earth spacecraft and deep space planetary missions. The infrastructure assets include the Deep Space Network (DSN), the Ground Network (GN), and the Space Network (SN).
NASA seeks automation technologies that will facilitate scheduling of oversubscribed communications resources. These capabilities should focus on the development of user interfaces and algorithms for the integration of diagnostic and situational awareness tools; and planning, scheduling, and resource optimization tools supporting:

- Increased numbers of missions and customers
- Increased number and complexity of constraints
- Decreased operations budgets
- Scheduling algorithms should be fault-tolerant

Current State-of-the-Art: Diagnosis software tools and resource optimization tools are mature independent software technologies, however the integration of the two is less mature. The challenge is to develop integrated software tools that can leverage the strengths of each class of tool. Diagnosis tools must inform the resource optimization algorithms of the active portions of the system, while the resource optimization tools must inform the diagnosis tools of the current plan in order to facilitate tracking of system state.

User Interfaces: Diagnosis software user interfaces rely on displaying diagnostic information either in fault tree form or spatially highlighting portions of schematics, which are suspect. On the other hand, planning/scheduling/resource optimization tools rely on the display of temporal information in Gantt charts, and other timeline-based methods. An integrated user interface would require the integration of the spatial and temporal information into a single display to facilitate the ease of use and understanding of the integrated tools.

Diagnosis and Situational Awareness: Space Communication Networks are complex systems made up of both physical and wireless connections. When faults occur in the network, isolating the faults in real-time is critical in order to maintain network capability. Model-based diagnostic systems are capable of modeling the connectivity of the system as well as propagating both nominal and off-nominal flow of information in the network. These systems can accurately characterize the state of the system in order to provide situational awareness for both humans as well as intelligent assistant and resource optimization tools. The utilization of the current state of the network is critical to reschedule resources that have failed or degraded.

Planning and Scheduling Tools for Resource Optimization: The goal of schedule optimization is to produce allocations that yield the best objectives. These may include maximizing DSN utilization, minimizing loss of desired tracking time, and optimizing project satisfaction. Each project may have their own definition of satisfaction such as maximal science data returned, maximal tracking time, best allocation of the day/week, etc. The difficulty is that we may not satisfy all of these objectives during the optimization process. Obviously, optimal solution for one objective may produce worse results for the other objectives. One possible solution is to map all of these objectives to an overall system goal. This mapping is normally non-linear. Technology needs to be developed for this non-linear mapping for scoring in addition to regular optimization approaches.

Areas of Interest: Integrated diagnosis and resource optimization tools are useful in different phases in the design and development of space communication networks. In early pre-planning phases of mission operations such tools are useful for: procedure development, contingency development, and other preparatory tasks. During the operations phase, such tools are useful for telemetry analysis; fault diagnosis, state determination and situational assessment; plan, procedure, and rules revisions and execution; decision-making; commanding; fault responses; and data management among others.
NASA seeks proposals to develop the following capabilities in support of human situational awareness:

- Methods for acquiring, evaluating, and displaying telemetric information, so as to provide users with flexibility and easy access to desired information in desired format.
- Methods to determine situational information from multiple data sources, possibly noisy and incomplete, and present those to the user;
- Methods to track actions of other users or systems, including automated systems, and keep user aware of the situation.
- Methods to track user intent and provide the appropriate situational information;
- Methods for controlling the degree of automated/manual control, and tools for transitioning control between user and automation with minimal loss of context and situational awareness.
- Methods for creating, validating, evaluating, and revising model-based diagnostics models, taking into account collaborative aspects and reference materials required to build models (architecture diagrams/schematics, sensor definitions, fault modes, configurations and other reference materials).
- Techniques for checking or simulating model-based diagnostic models, in order to acquire a level of trust or assurance that the model is correct with respect to the configuration of the network.
- Methods for creating, validating, evaluating, and revising operations plans, taking into account collaborative aspects, complex flight rules, resource limitations and need for one-time constraints and exceptions.
- Techniques for checking or simulating plans, procedures, sequences and other combinations of commands and actions, in order to acquire a level of trust or assurance that the combination is correct and will satisfy desired safety and operations properties in actual execution
- Methods to change the planning/scheduling optimization functions to incorporate high priority requests.

Performance metrics: Measures of performance will compare human generated results vs. human/computer results for nominal and off-nominal network conditions. Experiments should be run on simulated communications test-bed(s), which can seed failures of different classes at different points in time.

Schedule quality will be determined by a number of factors including: (1) level of up time on the network, (2) degree of priority allocation (higher priority items scheduled first), (3) degree of contiguity allocation (items are scheduled as a group) and (4) other factors.

For the proposed technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware demonstration and testing. Delivery of a demonstration unit for NASA testing at the completion of the Phase II contract is also required.

Phase I Deliverables: Propose demonstration of integrated fault diagnosis/resource optimization tool on a number of communication asset allocation problem sets (involving dozens of missions, communications assets, and operational constraints). End Phase deliverable (TRL 4-5) would include a detailed rationale for technology return-on-investment (ROI) based on knowledge of current and future operations flows.

Phase II Deliverables: A demonstration of the integrated fault diagnosis/resource optimization tool with fault diagnosis/situational awareness system on actual or surrogate communication asset scheduling datasets. Deliverables (TRL 6) would include software system, use cases and evidence of utility of deployment of developed technology.
NASA is investigating the near- and mid-term development of highly-desirable systems and technologies that provide innovative ways either to leverage existing ISS facilities for new scientific payloads or, to provide on orbit analysis to enhance capabilities and reduce sample return requirements.

Current utilization of the ISS is limited by available upmass, downmass, and crew time as well as by the capabilities of the interfaces and hardware already developed. Innovative interfaces between existing hardware and systems which are common to ground research could facilitate both increased, and faster, payload development.

Desired capabilities include, but are not limited to, the below examples.

- Enabling additional cell and molecular biology culture techniques. Providing innovative hardware to allow for safe, contained transfer of cells from container to container within the Microgravity Sciences Glove Box (MSG) would permit new types of studies on ISS. On orbit analysis techniques that would reduce or remove the need for downmass - such as a system for gene array tests, or kits for DNA extractions for long term storage - are also examples of hardware possibilities that would extend and enable additional research.
- Providing compact Dynamic Light Scattering (DLS) hardware. Development of a compact robust DLS instrument based on diode lasers and photo detectors capable of providing significant power and weight savings would make it possible to measure the diffusion coefficient of experimental systems using the Light Microscopy Module (LMM). This peer-reviewed science was considered a decade ago but not developed due to technology limitations. It should now be possible to measure diffusion coefficients from which the molecular temperature of the location being viewed could be deduced for known particles and solvents using the Stokes-Einstein equation. Innovative additions of a local oscillator used in conjunction with analog detectors could mitigate errors introduced by stray light.
- Providing compact laser tweezers and supporting software. Development of a compact robust Holographic Laser Tweezers (LT) instrument based on the recent developments of holographic techniques could expand the types of experiments conducted on orbit. This peer-reviewed science was previously considered but not developed because of the size and technology limitations of a decade ago. LT holds open the possibility of performing scientific experiments that manipulate groups of particles that evolve uniquely in space when gravitational sedimentation and jamming no longer exist. Any new LT and its corresponding control software should allow for tracking of particle positions in 3D (before the concentration becomes too high) and impart rotational forces. Being able to accurately track the position of particles while measuring the forces on them is important for laying the foundations of colloidal engineering. Novel self-calibration methods could be added to commercially available designs to further enhance the instrument and its capabilities. The instrument would need to meet the size and volume limitations of the Light Microscopy Module (LMM).
- Providing additional on-orbit analytical tools. Providing flight qualified hardware that is similar to commonly used tools in biological laboratories could allow for an increased capacity of on-orbit analysis thereby reducing the number of samples which must be returned to Earth. Examples of tools that will reduce downmass or expand on-orbit analysis include: sample handling tools; mass measurement devices; a (micro)plate reader; a mass spectrometer; non-cryogenic sample preservation systems; autonomous in-situ bioanalytical technologies; centrifuges for analysis and for providing fractional-g environments; microbial and cell detection and identification systems; and fluidics and microfluidics systems to allow autonomous on-orbit experimentation and high throughput screening.
- Providing Nanorack compatible inserts to enable additional life science payloads. Development of 1, 2 and/or 4 cube design biological payload hardware for use with the ISS Nanorack platform would decrease the need for development of multiple control racks and reduce development time of future payload
Enabling additional payloads. Innovative methods for further subdividing payloads lockers would allow for numerous pico-payloads. Developing multi-generational or multi-use habitats would reduce the upmass and downmass required to conduct biological experiments on ISS.

The existing hardware suite and interfaces available on ISS may be found at: http://www.nasa.gov/mission_pages/station/science/experiments/Discipline.html [6]

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Written report detailing evidence of demonstrated technology (TRL 5 or 6) in the laboratory or in a relevant environment and stating the future path toward hardware and software demonstration on orbit.

Phase II Deliverables: Hardware and/or software prototype that can be demonstrated on orbit (TRL 7).

Sub Topics:
ISS Life Extension and Operational Enhancements Topic O3.03
NASA is exploring a wide range of both critical and highly desirable technologies that would, in the mid-term, aid in ISS life extension or provide operational enhancements.

Potential areas of investigation include the following:

- Providing detection technologies for leakage from modules and fluid systems.
- Enhanced on-orbit maintenance capabilities such as corrosion detection and re-mediation.
- MMOD detection, MMOD damage detection, evaluation and recovery.
- Methods for re-lubrication of rotating parts.
- Technologies that can isolate and resolve issues without crew interaction or that can perform nominal crew housekeeping activities such as self-cleaning air inlet filters and surfaces are highly desirable and could improve efficiency enough to allow more crew time for operation of scientific payloads.

Technologies to aid in life extension or operational enhancements of the ISS are not limited to the above examples and other areas will be considered for award.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.
Phase I Deliverables: Written report detailing evidence of technology feasibility in the laboratory (TRL 2-4) or in a relevant environment and stating the future path toward hardware and software demonstration on orbit.

Phase II Deliverables: Hardware and/or software prototype that can be demonstrated, preferably on orbit (TRL 4-6).

Sub Topics:

Vehicle Integration and Ground Processing Topic O3.04
This subtopic seeks to create new and innovative technology solutions, which improve safety and lower the life cycle costs of assembly, test, integration and processing of the ground and flight assets at our nation’s spaceports and propulsion test facilities.

Current State of the Art: The propulsion testing and launch vehicle processing activities at NASA account for a large portion of the life cycle costs of today’s space programs. The technologies in use today at these facilities date back to the beginnings of manned space flight. A majority of the test infrastructure at Stennis Space Center and launch processing facilities at Kennedy Space Center indeed go back to the Apollo era and early shuttle design days of the 1960’s and early 70’s. Technology solutions typically take 3-6 years from inception in the SBIR Phase I program to having a direct impact on the processing activity. NASA needs to invest in these vehicle integration and ground-processing technology needs now to be in place for the NASA heavy launch vehicle concepts of the future.

Propellant servicing operation for both propulsion testing and launch operations are in need of technology advancement to make these operations safer and more cost efficient. The hardware and practices in use today do indeed date back to 1960’s investments. Technology solutions are needed to increase visibility into processes real-time (smart instrumentation), more efficient cryogenic propellant storage solutions, a new generation of cryogenic couplings to allow cold mate and de-mate operations without ice or frost buildup, and to reduce our usage of massive amounts of gaseous helium (a scarce, non-renewable global resource).

Changes in environmental regulations have had a tremendous negative impact on the coatings used to protect our NASA test and launch infrastructure. Many of the coatings used in the last 10 years are no longer available due to changes in the environmental law banning the use of certain chemicals. KSC and SSC are located in some of the worst corrosion environments in the country. At KSC, the addition of the acidic exhaust plumes from solid rocket motors, make these conditions even worse. New advancements in coatings and materials are needed to reduce the infrastructure maintenance costs of these facilities.

Due to the lightweight, high strength properties, composite materials are being sought more often to solve weight reduction efforts on future launch vehicles. New materials mean new problems for the ground operations team charged with insuring these vehicles are safe to fly. New inspection tools are needed to confirm structural integrity during the processing flow after field repairs or accidental contact.

The following areas are of particular interest:
Propellant Servicing Technologies

Technologies for advanced, energy efficient cryogenic fluid storage, transfer and propellant servicing of launch vehicles and propulsion test facilities. These efforts include:

- Cost effective technology solutions to support helium facility supply infrastructure and helium conservation initiatives to reduce/eliminate helium usage during LH2 and LO2 system operations and recover/re-purify helium from large volume waste streams;
- Techniques and technologies to reduce parasitic heat loads in large cryogenic storage tank structural design to enable more economical zero boil-off storage concepts;
- Advances in smart instrumentation for in-situ fluid flow analysis and process control, surviving and operating under cryogenic and launch conditions to enable real-time monitoring of propellant servicing processes and high efficiency purging operations of cryogenic systems; and
- Non-frosting/icing quick-disconnect development to support cryogenic propellant servicing operations.

Control of Material Degradation

Technologies are needed for the prediction, prevention, detection and mitigation of corrosion/erosion in spaceport and propulsion test facility infrastructure and ground support equipment including steel refractory concrete. Material solutions must meet current and emerging environmental restrictions and endure today’s corrosive and highly acidic launch environments. These needs include:

- Methodology to predict long-term corrosion protection performance of coatings for steel operating in a marine environment;
- Damage responsive coatings with corrosion inhibitors;
- Replacement options for poor-performing refractory concrete exhibiting low temperature cure characteristics or means of providing large area coverage with modular units that can be cured off site;
- Protective coatings for non-painted surfaces;
- Innovations in thermal spray metallic coatings equipment and alloys;
- Non-chrome protective coatings/sealants for aluminum alloys; and
- New environmentally friendly protective coating options to replace products lost due to EPA regulation changes.

Spaceport Processing Evaluation/Inspection Tools

Technologies in support of defect detection in composite materials; methods for determining structural integrity of composite materials and bonded assemblies; and non-intrusive inspection of Composite Overwrapped Pressure Vessels (COPV), Orion heat shield and other composite systems. Technologies must support identifying composite material defects, evaluating material integrity, damage inspection and/or acceptance testing of composite systems. Technology solutions are also desired for in-situ evaluation of refractory concrete as installed in the flame trenches associated with propulsion test and launch pad infrastructure. Provide solutions that reduce inspection times, provide higher confidence in system reliability, increase safety and lower life cycle costs.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.
Phase I Deliverables: Demonstration of technical feasibility (TRL 2-4).

Phase II Deliverables: Demonstration of technology (TRL 4-6)

The technology in this subtopic may also be applicable to Topic O2, Space Transportation.

Sub Topics:
  Advanced Motion Imaging Topic O3.05
Digital motion imaging technologies provide great improvements over analog systems, but also present significant challenges, including radiation damage to sensor systems and components. Cameras and sensors need to survive operations on orbit for years without debilitating radiation damage that degrades image quality and performance.

The focus of this subtopic is the development of components, systems, and core technologies that advance the capabilities to capture process and distribute high-resolution digital motion imagery.

Current State of the Art: HDTV cameras flown on the Space Shuttle and the International Space Station have proven to be highly susceptible to damage from ionizing radiation. This damage is manifested by bad pixels that eventually render the camera useless after short periods of on-orbit use, usually less than one year. In addition, upmass and downmass constraints make the use of large format motion picture film cameras impractical, so a digital equivalent is needed for large venue documentary film productions, such as IMAX films. Areas of interest in the near term are for space environment, radiation tolerant, HDTV and digital cinema cameras and sensors. Mid and Long term goals include radiation tolerant reprogrammable encoders and improved distribution systems for video data signals. These systems are highly desired by the human spaceflight programs.

Technologies are sought that provide high resolution, progressively scanned motion imagery with limited or mitigated radiation damage to sensors, are viable for astronaut hand-held applications or external spacecraft use, and that provide imagery that meets standards commonly used by digital television or digital cinema production facilities. Commercial HDTV cameras used for internal hand-held use have generally been small and light (5" x 6" x 11", between 2 and 3 pounds), run off rechargeable batteries, and utilize standard lens mounts. Future cameras for exterior applications ideally would be smaller and more modular in design (no larger than 4" x 5" x 7" and 2.5 pounds). The critical technology need is the radiation tolerance of the sensor, not the size, weight and mass of the camera that results from such a sensor.

While commercial HDTV and Digital Cinema cameras for use on Earth are mature technologies, there are no flight-proven radiation tolerant HDTV and Digital Cinema cameras and sensors currently available. Commercial cameras flown on the Shuttle and ISS thus far do function, but degrade within a year on orbit. While hard to classify, the current TRL for these cameras within the context of spaceflight operations could be considered to be a 5 or 6. The ultimate goal is to develop radiation-hardened camera sensors capable of surviving three or more years in space.
For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Deliverables for Phase I will include detailed designs and development plans with plausible data and rationale that demonstrates why the designs and plans should mitigate radiation effects on the sensors.

Phase II Deliverables: Deliverables for Phase II will include developmental hardware suitable for testing in a lab or space flight environment (TRL 6) as well as a test plan, relevant data, and define expected lifespan of the sensors.

Sub Topics:
Advanced Acoustic Monitoring Technologies Topic O3.06
This subtopic addresses acoustic monitoring technologies for current International Space Station (ISS) and future long duration spaceflight missions.

Specifically, this subtopic calls for proposals to develop and demonstrate acoustic sensor technology enabling real-time, remotely performed measuring and monitoring of sound pressure levels and noise exposure levels in long-duration space vehicles. These technologies are the building blocks towards a network of continuously monitored, real-time acoustic sensors providing sound pressure level information as a function of frequency and/or time at multiple locations. Additionally, these technologies shall provide:

- Typical sound level meter,
- Typical acoustic dosimeter processing and analysis functionality,
- Capability for hazard level alerting.

Current State of the Art: Acoustic monitoring is currently being performed on the ISS using a hand-held sound level meter (SLM) that is moved to 60 different locations where a 15 second measurement is performed. Each SLM survey session takes 2 hours of crew time, and the survey is performed once every 2 months, thus reduced crew time needed will be an important benefit.

Because of the length of the survey, only a portion of the ISS can be measured during a single session. Similarly, acoustic dosimetry at fixed locations is performed once every 2 months, but only at three locations for each session because of crew-time and hardware limitations. Advanced acoustic monitoring technology will provide the capability to allow for more frequent and directed acoustic measurements and will allow nighttime measurements. These benefits will permit more precise trending, environmental monitoring and will provide a better validation of acoustic models, i.e., we will be able to isolate the impacts of various operations or pieces of hardware.

Areas of interest: Current automated acoustic monitoring methods used in ground-based systems perform
measurements in isolated areas, e.g., around airports. However, the technology employed is large and heavy, using conventional data acquisition boards, transducers, and transmitters.

NASA seeks proposals for acoustic monitors for spaceflight vehicle applications that:

- Are miniaturized,
- Are lightweight,
- Integrate data acquisition, sampling, and processing into the sensor
- Transmit the processed data wirelessly,
- Low-power consumption
- Can be a part of a multi-sensor system

The functional SLM goal is to provide average sound pressure level measurements over a short time duration (e.g. 20 seconds) as a function of frequency. The functionality required includes:

- Type II measurement accuracy over the octave band frequency range from 63 Hz to 20 kHz,
- Dynamic range of 90 dB or better,
- 1/3 octave band frequency representation,
- Narrow band frequency representation with selectable frequency resolution.

The following SLM functionality is desired:

- Type I measurement accuracy over the octave band frequency range from 63 Hz to 20 kHz,
- Octave band noise floor of 10 dB re 20 micropascals
- Fractional octave (1/1, 1/3, 1/12) band frequency representation.

The functional Acoustic Dosimeter goal is to provide noise exposure levels and data logging, i.e., log of sound levels as a function of time. The functionality required includes:

- Type III accuracy over the audible frequency range,
- Logging of A-weighted Overall Sound Pressure Levels every 30 seconds for a period of 24-hours,
- Dynamic range of 90 dB or better.

The following Acoustic Dosimeter functionality is desired:

- Noise floor of 30 dB re 20 micropascals.
The goal for the hazard level alert functionality is to provide continuous acoustic monitoring with logic that sends a signal (to trigger a non-auditory alert) if hazardous noise levels of 85 dBA and above are detected. This is a new crew-health related function that will reduce the crew’s risk for exposure to high noise levels, and will protect the crew in the case of an off-nominal noise event. The functionality desired includes:

- Perform continuous acoustic data sampling
- Send an electronic signal if noise levels are 85 dBA or above

The following hazard level alert functionality is desired:

- Pre-trigger capability so onset of hazardous noise is measured.

The technology from this SBIR subtopic is highly desired for use on ISS and for future long duration space missions for the long-term.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract. For Phase II, a demonstration in the JSC Acoustics and Noise Control Lab (ANCL) is being requested so that testing can be performed in the ISS Acoustic Mockup. As a result, an SBIR testing facility waiver will be needed.

Potential Phase III activities are envisioned to be a demonstration of the sensor’s capability on board ISS as a Station Detailed Test Objective (SDTO)

Phase I Deliverables:

- Sensor preliminary design
- Breadboard microphone transducer (proof of concept)
- Test data showing acoustic performance of breadboard sensor
- Forward plan for sensor development, including plans for in-situ calibration
- The expected TRL at the end of Phase I is 3-5

Phase II Deliverables:

- Sensor design in flight-like package
- Test data showing acoustic performance of flight-like sensor
• Demonstration of multiple sensors in ground facility (NASA JSC ANCL)
• The expected TRL at the end of Phase II should be 6.

Sub Topics:
Cryogenic Fluid Management Technologies Topic O3.07
The ultimate objective of this Cryogenic Fluid Management (CFM) Technologies solicitation is to demonstrate a variety of critical CFM technologies in a micro-gravity space environment via a deployable or non-deployable test bed.

The initial phase (Phase I) will identify and develop prototype experiments that could be integrated into a universal platform for demonstration of these experiments in their relevant micro-gravity environment.

The second phase (Phase II) of this solicitation would develop a universal and innovative test bed platform that could be launched as a secondary payload on an expendable launch vehicle.

State of the art: CFM technologies are, for the most part, limited to ground tests that do not provide a complete and accurate demonstration of the technologies in their true operational environment. This increases risk in the development of emerging technologies for future applications in the areas of space based propellant depots, low gravity descent and ascent operations, and future space or planetary based architectures.

Areas of interest:

The purpose of these experiments would be to allow testing of:

• Designs for fluid and propellant transfer plumbing
• Multi-layer insulation (MLI) designs
• Various mass gauging designs
• Thermal control and boil-off control designs in a true micro-gravity space environment

Sample technologies in current queue at NASA centers that require testing in such type of platform include:

• Vapor Cooling
• Orientation
• Para-ortho H\textsubscript{2} conversion
• Fluid Transfer Coupling
• Thermodynamic Vent System
• Automated Rendezvous and Docking
• Thick MLI blanket
- Broad area cooling (vapor cooled, active cooled)
- Sun Shield
- Mass gauge
  - Radio Frequency (RF)
  - Pressure Volume Temperature (PVT)
  - Level Sensor (Cryo-Tracker)

- Instrumentation
  - Cryo tracker
  - Mass flow rate (fill, vent)
  - Tank pressure
  - Temperature (liquid, vent, tank wall, transfer lines, structure)
  - System acceleration

- Liquid Acquisition Device (LAD)
- Settling
- Propulsion (H₂/O₂ thruster, solar thermal)
  - H₂/O₂ thruster
  - Solar thermal

- Propellant Positional Device (PPD) (magnetic, screen)
- Cryo-Cooler
- Mixing (Vehicle maneuvers (roll), pumps)
- Structural interface (conic, struts)

The identification and design of critical CFM components that could be utilized in future exploration architectures in the space environment are being solicited for this platform. The technologies and future development of the platform supporting them would allow demonstration and proof of concepts for the designs and hardware necessary for mechanisms such as fluid transfers in propellant depots and in planetary spacecraft prior to the actual full development, design, fabrication, and launch of hardware. These CFM technologies and platform would provide a simple, low cost and innovative method to prove technologies and could avoid large and costly design modifications or possible multiple launch requirements for future space based architectures.

A viable option for the low cost approach involves launching as a secondary payload on launch vehicles currently in use such as an Atlas V or Delta IV. Such launch vehicles hold a high level of design maturity, contributing to a huge savings in development costs. In addition, through riding as a secondary payload, a majority of the launch costs could be absorbed by the primary mission. In a typical launch vehicle configuration, the secondary payload is attached to a launch vehicle's second stage propellant tank beneath the primary payload. After separation of the primary payload, the platform would either deploy and operate as a free flying spacecraft and perform the various CFM demonstrations, or could remain attached to the propellant tank to prove fluid transfer capabilities, along with additional experiments. A third option is to utilize the residual propellants from the launch vehicle to fill a receiver tank on the platform, which would subsequently deploy to perform various additional demonstrations.

The platform would be processed and integrated in the typical fashion of spacecrafts launched today. A platform that remains completely passive (non-operational and containing no commodities) until separation of the primary payload greatly reduces ground-processing requirements. Individual experiments could also be integrated with the platform prior to integration to the launch vehicle to further reduce operational complexities.
The second phase of the project would design a platform so as to encompass additional requirements such as:

- The capability to support and integrate multiple CFM technology experiments per mission
- Demonstrating innovative, fluid transfer designs
- MLI designs
- Various mass gauging designs
- Thermal control and boil-off control designs
- Validation of CFD propellant models
- Testing of propellant management devices
- Mixing pumps
- Thermodynamic vapor cooling systems
- Environmental thermal shielding designs

Design of the platform would need to ensure that it does not impose additional risk to the mission success of the primary payload and is capable of remaining completely passive and inert until the primary payload is successfully deployed. This includes launching with empty tank(s), lines, etc., and maintaining the ability for residual cryogenic propellants to be transferred from the launch vehicle upper stage to the proposed secondary payload upon completion of the primary mission.

Optional configurations could include multiple tanks with self-contained fluids, however the use of residuals, with innovative propellant transfer lines, from an upper stage promotes cost savings in both the propellant commodities, pressurization systems required for pre-launch processing, limit hazard and safety concerns for the primary mission, and the passive nature reduces the complexities added in the analyses and operations required for integration with the launch vehicle and primary mission.

The platform, itself, would contain tank to tank fluid transfer capabilities, avionics, thermal control systems, telemetry capabilities and, if deployable, an attitude control system. The platform design would be capable of interfacing with the launch vehicle separation system and avionics. Additional potential experiments and uses include validation of CFD propellant models, testing of propellant management devices, mixing pumps, thermodynamic vapor cooling systems, and environmental thermal shielding designs.

Performance metrics: A platform that is capable of remaining passive and inert through completion of the primary mission on an EELV. The platform shall be capable of supporting at a minimum of four CFM demonstrations per mission. The designs for the experiments are to be such that they are capable of demonstrating CFM technologies supporting the operational requirements of future space based architectures in cryogenic temperature ranges.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware demonstration and delivering a demonstration unit for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Demonstration of technical feasibility (TRL 3-4).
Phase II Deliverables: Prototype design and demonstration of innovative technology testing platform, capable of integrating multiple CFM experiments (TRL 4-6). A ready to launch version of this as an EELV secondary payload performing demonstrations of CFM technologies is highly desired.

Sub Topics:

Metric Tracking of Launch Vehicles Topic O4.01
Launch vehicles can exhibit high dynamics during flight and there can be external interference on the GPS frequency. The goal of this subtopic is to have a highly reliable way of tracking vehicles from launch to orbit utilizing GPS and/or inertial measurement unit.

Areas of interest:

Metric Tracking Hardware

Metric tracking of launch vehicles requires the development of accurate and stable integrated metric tracking and inertial measurement units. The focus is on technologies that enable and advance development of low Size, Weight, and Power (SWaP), tactical grade, integrated metric tracking units that provide accurate and stable positioning, attitude, and inertial measurements on highly dynamic platforms. Factors to address include:

- Ultra-tight coupling of rate sensors, accelerometers, and attitude-determining GPS receivers that will provide very high frequency integrated metric solutions,

- The ability to reliably function on spin-stabilized rockets (up to 7 rev/s), during sudden jerk and acceleration maneuvers, and in high vibration environments,

- Advancements in MEMs-based rate sensors and accelerometers, algorithm techniques and Kalman filtering, high bandwidth and low noise outputs, phased-based attitude determination, single aperture systems, quick Time to First Fix and reacquisition.

Use of GPS and Ability to Mitigate Interference Signals

NASA seeks innovative technologies to increase the accuracy of the L1 C/A navigation solution by combining the pseudo ranges and phases of the L1 C/A signals, and use of the L2 and L5 carriers. Factors to consider:
GPS signal degradation can be obtained by differencing the available carrier phase and pseudo range measurements and then removing these differences from the navigation solution.

Jamming of GPS signals are a concern during the tracking of launch vehicles.

Technologies are sought that combine spatial processing of signals from multiple antennas with temporal processing techniques to mitigate intentional interference signals (jamming) received by the GPS receiver. The coordinated response of adaptive pattern control (beam and null steering) and digital excision of certain interfering signal components can minimize strong jamming signals. Adaptive nulling minimizes interfering signals by the optimal control of the GPS antenna pattern (null steering).

Proposals can either address a single subject as described above or a combination of subjects.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I (to reach TRL 3) and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract (to reach TRL 5).

Phase I Deliverables:

- Midterm Technical Report
- Final Phase I Technical Feasibility Report with a Phase II Integration Path. Proof-of-concept bench top demonstration preferred.

Phase II Deliverables:

- Final Phase II Technical Report
- Demonstration hardware/software/field test.

Sub Topics:

On-Orbit PNT (Positioning, Navigation, and Timing) Sensors and Components Topic O4.02

This solicitation seeks proposals that will serve NASA's ever-evolving set of near-Earth and interplanetary missions that require precise determination of spacecraft position and velocity in order to achieve mission success. While the definition of "precise" depends upon the mission context, typical scenarios have required meter-level or better position accuracies, and sub-millimeter-level per sec or better velocity accuracies. This solicitation is primarily focused on NASA's needs in four focused areas identified below.
Proposals are encouraged that leverage the following NASA developed state-of-the-art capabilities:

- GEONS (http://techtransfer.gsfc.nasa.gov/ft_tech_geons.shtm [18])
- Navigator (http://techtransfer.gsfc.nasa.gov/ft_tech_gps_navigator.shtm [19])
- GIPSY (https://gipsy-oasis.jpl.nasa.gov/ [20])
- Electra (http://descanso.jpl.nasa.gov/Monograph/series9_chapter.cfm [21])
- Blackjack (http://www.jpl.nasa.gov/releases/2000/blackjackgps.html [22])

NASA is not interested in funding efforts that seek to "re-invent the wheel" by duplicating the many investments that NASA and others have already made in establishing the current state-of-the-art.

General Operational Needs, Requirements and Performance Metrics:

**Onboard Near-Earth Navigation Systems**

NASA seeks proposals for development of a commercially viable transceiver with embedded orbit determination software providing enhanced accuracy and integrity for autonomous onboard GPS-based and TDRSS-based navigation, along with time-transfer in near-Earth space via augmentation messages broadcast by TDRSS. The augmentation message should include information on the TDRS orbits, status, and health that could be provided by future TDRS, and should provide information on the GPS constellation based on NASA's TDRSS Augmentation for Satellites Signal (TASS). Proposers are advised that NASA's GEONS and GIPSY orbit determination software packages already support the capability to ingest TASS messages.

**Onboard Deep-Space Navigation Systems**

NASA seeks proposals to develop an onboard autonomous navigation and time-transfer system for reduction of DSN tracking requirements. Such a system should provide accuracy comparable to delta differenced one-way ranging (DDOR) solutions anywhere in the inner solar system, and exceed DDOR solution accuracy beyond the orbit of Jupiter. Proposers are advised that NASA's GEONS and DS-1 navigation software packages already support the capability to ingest many one way forward Doppler, optical sensor observation, and accelerometer data types.

**Technologies Supporting Improved TDRSS-based Navigation**

NASA seeks proposals providing improvements in TDRS orbit knowledge, TDRSS radiometric tracking, ground-based orbit determination, and Ground Terminal improvements that improve navigation accuracy for TDRS users. Methods for improving TDRS orbit knowledge should exploit the possible future availability of accelerometer data collected onboard future TDRS. The goal is navigation and communications integrated into a single processor.
Navigation Payload Technology for Lunar Relay Satellites

NASA seeks lunar relay navigation payload technologies that can:

- Transmit accurate spread spectrum signals (emphasizing the stability of the frequency reference yielding accurate timing and chipping rate of the PN code and a low noise carrier)
- Receive same in return (either in coherent mode (the relay transmits and receives using the same frequency reference) or non-coherent mode (where the accurate frequency reference is on one end of link, either the transmit side or the receive side)).

This relay navigation payload should be capable of receiving a satellite-to-satellite link with similar signal properties. The relay navigation payload has to measure the range (two-way), pseudo-range (one-way), and both one-way and two-way Doppler. The relay navigation payload must be able to de-commutate data received from Earth and lunar bases to maintain time synchronization with a master time source, use the data onboard to either slave its frequency reference or to update its reference, and turn-around the data to modulate onto the user data stream.

Additionally, the relay navigation payload must have:

- ‘Reasonable fidelity’ autonomous filtered navigation capability to fuse all data types listed above as well as antenna gimbal angles, accelerometer data, and rendezvous radar data, to estimate the lunar relay state
- Output data rates of 1 Hz for the states of multiple satellites and comprehensive fault detection and correction data
- State outputs that can be modulated on transmitted data streams
- TASS-like broadcast beacon capability for navigation. The data on the beacon can originate either at a base location (earth, moon), the relay, or another asset with which the relay communicates.
- Dissemination of time and navigation data for the local environment

Proposals can either address a single subject as described above or a combination of subjects.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I (to reach TRL 3) and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract (to reach TRL 5).
Phase I Deliverables:

- Midterm Technical Report
- Final Phase I Technical Feasibility Report with a Phase II Integration Path. Proof-of-concept bench top demonstration preferred.

Phase II Deliverables:

- Final Phase II Technical Report
- Demonstration hardware/software/field test.

Sub Topics:
Flight Dynamics Software and Technologies Topic O4.03
NASA is beginning to invest in re-engineering its suite of tools and facilities that provide navigation and mission design services for design and operations of mid-term and long-term near-Earth and interplanetary missions. This solicitation seeks proposals that will develop the highly desired flight dynamics technologies and software that support these efforts.

Proposals that leverage state-of-the-art capabilities already developed by NASA are especially encouraged, such as:

- General Mission Analysis Tool (http://sourceforge.net/projects/gmat/ [23])
- GPS-Inferred Positioning System and Orbit Analysis Simulation Software (http://gipsy.jpl.nasa.gov/orms/goa/ [24])
- Optimal Trajectories by Implicit Simulation (http://otis.grc.nasa.gov/ [25])

Proposers who contemplate licensing NASA technologies are highly encouraged to coordinate with the appropriate NASA technology transfer offices prior to submission of their proposals.

Areas of interest: In the context of this solicitation, flight dynamics technologies and software are algorithms and software that may be used in ground support facilities, or onboard a spacecraft, so as to provide Position,
Navigation, and Timing (PNT) services that reduce the need for ground tracking and ground navigation support. Flight dynamics technologies and software also provide critical support to pre-flight mission design, planning, and analysis activities.

This solicitation is primarily focused on NASA's operational needs in the following focused areas:

- Applications of cutting-edge estimation techniques, such as, but not limited to, sigma-point and particle filters, to spaceflight navigation problems.

- Applications of estimation techniques that have an expanded state vector (beyond position and velocity components) to monitor non-Gaussian state noise processes and/or non-Gaussian measurement noise processes.

- Applications of estimation techniques that combine measurements from multiple sensor suites in a highly coupled manner to improve upon the overall system accuracy.

- Addition of novel estimation techniques to existing NASA mission design software that is either freely available via NASA Open Source Agreements, or that is licensed by the proposer.

- Applications of advanced dynamical theories to space mission design and analysis, especially in the context of unstable orbital trajectories in the vicinity of small bodies and libration points.

- Addition of novel measurement technologies to existing NASA onboard navigation software that is licensed by the proposer.

- Addition of orbit determination capabilities to existing NASA mission design software that is either freely available via NASA Open Source Agreements, or that is licensed by the proposer.

Technologies and software should support a broad range of spaceflight customers. Technologies and software specifically focused on a particular mission's or mission set's needs, for example rendezvous and docking, or formation flying, are the subject of other solicitations by the relevant sponsoring organizations and should not be submitted in response to this solicitation.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I (to reach TRL 3) and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract (to reach TRL 5).

Phase I Deliverables:

- Midterm Technical Report

- Final Phase I Technical Feasibility Report with a Phase II Integration Path
Phase II Deliverables:

- Final Phase II Technical Report
- Algorithm Specification
- Delivery of software package
- Demonstration of software package

Sub Topics: