



NASA SBIR 2011 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, cognitive 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, and even greater emphasis is placed on these attributes as small satellites (e.g., micro and nano satellite) technology matures. Communication technologies enabling acquisition of range safety data from sensitive instruments is imperative. Innovative solutions centered on operational issues are needed in all of the aforementioned areas. 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/](https://www.spacecomm.nasa.gov/spacecomm/) [1],

<https://www.spacecomm.nasa.gov/spacecomm/programs/default.cfm> [2],

<https://www.spacecomm.nasa.gov/spacecomm/programs/technology/default.cfm> [3],

<https://www.spacecomm.nasa.gov/spacecomm/programs/technology/sbir/default.cfm> [4]). 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 or on-orbit testing. Please see the following for more details:

- NASA Office of the Chief Technologist: (<http://www.nasa.gov/offices/oct/home/index.html> [5], http://www.nasa.gov/offices/oct/game_changing_technology/small_satellite_subsystem_tech/index.html [6], http://www.nasa.gov/offices/oct/crosscutting_capability/index.html [7]).
- International Space Station payload opportunities: (http://www.nasa.gov/mission_pages/station/research/nlab/index.html [8], http://www.nasa.gov/mission_pages/station/research/experiments_category.html [9]).
- CoNNeCT (Communications, Navigation & Networking Reconfigurable Testbed): (<http://spaceflightsystems.grc.nasa.gov/SpaceOps/CoNNeCT/> [10]).
- Terrestrial analogs (Desert Rats, Haughton Field): (<http://science.ksc.nasa.gov/d-rats/> [11],

<http://ti.arc.nasa.gov/tech/asr/intelligent-robotics/haughton-field/> [12]).

- SMD Topic S4 for more details concerning requirements for Small Satellite flight opportunities. NOTE: Communications technologies relevant to space-based range are solicited for in Space Transportation Subtopic O2.03 - 21st Century Spaceport Ground System Technologies.

Sub Topics:

O1.01 Antenna Technology

Lead Center: GRC

Participating Center(s): GSFC, JPL, JSC, LaRC

NASA seeks advanced antenna systems and technologies to enable communications for future space operations, space science, Earth science and solar system exploration missions. These areas, in priority order, are:

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. Emerging novel technologies such as ferroelectrics, multiferroics and spintronics concepts leading to new antenna designs are desirable.

Smart, Reconfigurable Antennas

Smart antennas, reconfigurable in frequency, polarization and radiation pattern, are of interest for space and planetary exploration missions. In particular, antenna designs and proof-of-concepts leading to the reduction of the number of antennas needed to meet the communication requirements associated with rovers, pressurized surface vehicles, habitats, etc., are highly desired. In addition to the aforementioned reconfigurability requirements, specific antenna 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.

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 technology standardization across each NASA network (i.e., DSN, NEN, and SN), within the framework of the newly envisioned NASA integrated network architecture, at Ka-band frequencies and above, are highly desired.

Phased Array Antennas

High performance phased array antennas, i.e., with efficiencies at least 3X that of state-of-practice MMIC-based phased arrays, 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, extravehicular activities (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 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.

Large Aperture Deployable Antennas

Large aperture deployable antennas with surface root-mean-square (rms) quality better than $\lambda/40$ 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., ≤ 2). These large Gossamer-like antennas are required to provide high-capacity communication links with low fabrication costs from deep space (Mars and beyond). Concepts addressing antenna adaptive beam correction with pointing control are also of interest.

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: 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 Deliverables: 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.

O1.02 Reconfigurable/Reprogrammable Communication Systems

Lead Center: GRC

Participating Center(s): AFRC, ARC, GSFC, JPL, JSC

NASA seeks novel approaches in reconfigurable, reprogrammable communication systems to enable the vision of space, exploration, science, and aeronautical flight systems. Advancements are required in communication systems to manage the demands of the harsh space environment on space electronics, maintain flexibility and adaptability to changing needs and requirements, and provide flexibility and survivability due to increased mission durations. NASA missions can have vastly different transceiver requirements ranging from 1's to 10's Mbps at UHF & S frequency bands while X & Ka frequency bands require 10's to 1000's of Mbps. Available mission resources also vary greatly depending on the science objective, operating environment, and spacecraft resources. For example, deep space missions are often power constrained; operating over large distances, and subsequently have lower data transmission rates when compared to near-Earth or near planetary satellites. These requirements and resource limitations are known prior to launch, which can be used to maximize transceiver efficiency while

minimizing resources consumed. Larger platforms such as vehicles or relay spacecraft may provide more resources but may also be expected to perform more complex functions or support multiple and simultaneous communication links to a diverse set of assets.

This solicitation seeks advancements in reconfigurable transceiver and associated component technology with a goal of providing flexible, reconfigurable communications capability while minimizing on-board resources and cost. Technological domains of interest include the development of software defined radios or radio subsystems which demonstrate reconfigurability, flexibility, reduced power consumption of digital signal processing systems, increased performance and bandwidth, reduced software qualification cost, and error detection and mitigation technologies. Complex reconfigurable systems will provide multiple channel and multiple and simultaneous waveforms. Within these domains of interest, desired proposal focus areas to develop and/or demonstrate technologies are as follows:

- Software/firmware for the management of waveform and/or functional reconfiguration during simultaneous radio operation while adhering to the Space Telecommunications Radio System (STRS) is desired.
- Methods and tools for the development of software/firmware components that are portable across multiple platforms. Standards-based approaches are preferred.
- Dynamic/distributed on-board processing architectures that are scalable and designed to operate in space environments.
- Component technology advancements in bandwidth capacity and reduced resource consumption.
- Analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities.
- Novel techniques or processes to increase memory densities.
- Novel approaches to mitigate device susceptibility to radiation effects.

STRS Architecture documentation is available at the following link:

(<http://spaceflight systems.grc.nasa.gov/SpaceOps/CoNNeCT/> [10]).

The above URL also provides an overview of the Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT) flight program. The reconfigurable radios developed for this system represent the state-of-the-art in technology for space flight communication systems and may be used as a reference for the focus areas above. See also subtopic O1.06 - CoNNeCT Experiments for additional information.

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 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: 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 Deliverables: 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.

O1.03 Game Changing Technologies

Lead Center: GRC

Participating Center(s): ARC, JSC

NASA seeks revolutionary, highly innovative, game changing communications technologies that have the potential to enable order of magnitude performance improvements for space operations, exploration systems, and/or science mission applications. Research is geared towards far-term research focused in (but not limited to) the following areas:

- Develop novel techniques for size, weight, and power (SWAP) of communications systems by addressing digital processing and logic implementation tradeoffs, dynamic power management, hardware and software partitioning. Address high-speed, high resolution, low power consumption, and radiation tolerance (e.g., SiGe) to support near Earth and deep space mission environments. Investigate and demonstrate novel technologies to alleviate the demanding requirements (3- to- 5X improvement in sampling rate/resolution over state-of-the-art) on analog to digital converters (ADCs) and digital signal processors (DSPs).
- Develop technologies to evolve NASA communication networking and radio capabilities to autonomously sense and adapt to their environment, detect and repair problems and learn as they operate. Nodes will be dynamically aware of state and configuration of other nodes and adapt accordingly. Communications and navigation subsystems on future missions will interpret their situation on their own, understand their options, and select the best means to communicate or navigate.
- High-performance, multifunctional, nano-structured materials are of interest for applications in human spaceflight and exploration. These materials (notably single wall carbon nanotubes) exhibit extraordinary mechanical, electrical, and thermal properties at the nanoscale and possess exceptionally high surface area. The development of nano-scale communication devices and systems including nano-antennas, nano-transceivers, etc. are of interest for nano-spacecraft applications.
- Quantum entanglement, quantum key distribution or innovative breakthroughs in quantum information physics. Address proposed 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. Significant development is needed in high flux single photon sources and entangled pair sources for highly efficient, free space communications.

- Small spacecraft, due to their limited surface area, are typically power constrained, limiting small spacecraft communications systems to low-bandwidth architectures. Technologies and architectures, which can exploit commercial or other terrestrial communication infrastructures to enable novel smallsat missions to enable a wider variety of space missions are desired. Address how existing communications architectures can be adapted and utilized to provide routine, low cost, high bandwidth communications capabilities for spacecraft to ground, and spacecraft to spacecraft applications.
- Ultra wide-band (UWB) technology is sought to support robotic localization of surface assets. Whether two-way ranging (time -of-flight) or time-difference of arrival, the ability to synchronize the receivers determine the localization accuracy. Efficient Media Access Control (MAC) and networking protocols are paramount to ensure power efficiency and scalability. Integrating communications and positioning in an ad hoc network can indeed enable situational awareness, keeping track of location and relative position to other astronauts, robots, and vehicles at any time through visual and/or audio cues. Because initial synchronization or signal acquisition for Impulse Radio Ultra-Wide Band (IR-UWB) using equivalent-time sampling takes a long time especially for low pulse repetition rate systems, precise timing and coherent reception demand more power consumption and complexity than non-coherent IR-UWB. To maintain clock stability, most IR-UWB systems do not power down the receivers during operation. Narrower pulse width spreads the RF energy over a wider bandwidth but generation of precise low jitter (
- Develop methods for use of neutrinos for communications, timing, and ranging. Neutrinos are small, near light speed particles with no electric charge. Since neutrinos travel through most matter, they could be used for extreme long-distance signaling. Detection of neutrinos currently require massive underground liquid detectors. Highly innovative concepts, methods, techniques to enable neutrino based communication, ranging, timing, are sought.

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.

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. Within these domains of interest, desired proposal focus areas to develop and/or demonstrate technologies are as follows:

Isolation Platforms

Compact, lightweight, space qualifiable vibration isolation platforms for payloads massing between 3 and 50 kg that require less than 15 W of power and mass less than 3 kg that will attenuate an integrated angular disturbance of 150 micro-radians from 0.01 Hz to 500 Hz to less than 0.5 micro-radians 1-sigma.

Laser Transmitters

Space-qualifiable, greater than 20% DC to optical efficiency, 0.2 to 16 nanosecond pulse-width 1550-nm laser transmitter for pulse-position modulated data with from 16 to 320 slots per symbol, less than 35 picosecond pulse rise and fall times, near transform limited spectral width, single polarization output with at least 20 dB polarization extinction ratio, amplitude extinction ratio greater than 38 dB, average power of 5 to 20 Watt, massing less than 500 grams per Watt. 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.

Photon Counting Near-Infrared Detectors Arrays for Ground Receivers

Hexagonal close packed kilo-pixel arrays sensitive to 1000 to 1650 nm wavelength range with single photon detection efficiencies greater than 60% and single photon detection jitters less than 40 picoseconds 1-sigma, active diameter greater than 15 microns/pixel, and 1 dB saturation rates of at least 10 mega-photons (detected) per pixel and dark count rates of less than 1 MHz/square-mm.

Photon Counting Near-Infrared Detectors Arrays for Flight Receivers

For the 1000 to 1600 nm wavelength range with single photon detection efficiencies greater than 40% and 1dB saturation rates of at least 1 mega-photons/pixel and operational temperatures above 220K and dark count rates of

Ground-Based Telescope Assembly

Telescope/photon-buckets with primary mirror diameter ~2.5-m, f-number of ~1.1 and Cassegrain focus to be used as optical communication receiver/transmitter optics at 1000-1600nm. Maximum image spot size of ~20 micro-radian, and field-of-view of a~50 micro-radian. Telescope shall be positioned with a two-axis gimbal capable of 0.25 milli-radian pointing. Desired manufacturing cost for combined telescope, gimbal and dome in quantity (tens) of approximately \$2 M each.

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

01.05 Long Range Space RF Telecommunications

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC

This subtopic seeks to develop innovative long-range RF telecommunications technologies supporting the needs of space missions.

Purpose (based on NASA needs) and current state-of-the-art

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

Technologies of interest

This subtopic seeks innovative technologies in the following areas:

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- Ultra-small, light-weight, low-cost, low-power, modular deep-space transceivers, transponders and components, incorporating MMICs, MEMs 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 DC-to-RF-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 mass and cost of reliable vacuum electronics amplifier components (e.g., TWTAs and Klystrons).
 - Ultra low-noise amplifiers (MMICs or hybrid, uncooled) for RF front-ends (
 - 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.

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 I (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.

O1.06 CoNNeCT Experiments

Lead Center: GRC

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

NASA has developed an on-orbit, reprogrammable, software defined radio-based (SDR) testbed facility aboard the International Space Station (ISS), to conduct a suite of experiments to advance technologies, reduce risk, and enable future mission capabilities. The Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT) provides SBIR recipients and through other mechanisms NASA, large business, other Government agencies, and academic partners the opportunity to develop and field communications, navigation, and networking

technologies in the laboratory and space environment based on reconfigurable, software defined radio platforms. Each SDR is compliant with the Space Telecommunications Radio System (STRS) Architecture, NASA's common architecture for SDRs. The Testbed is installed on the truss of ISS and communicates with both NASA's Space Network via Tracking Data Relay Satellite System (TDRSS) at S-band and Ka-band and direct to/from ground systems at S-band. One SDR is capable of receiving L-band at the GPS frequencies of L1, L2, and L5.

NASA seeks innovative software experiments to run aboard CoNNeCT to demonstrate and enable future mission capability using the reconfigurable features of the software defined radios. Experiment software/firmware can run in the flight SDRs, the flight avionics computer, and on a corresponding ground SDR at the Space Network, White Sands Complex. Unique experimenter ground hardware equipment may also be used.

Experimenters will be provided with appropriate documentation (e.g., flight SDR, avionics, ground SDR) to aid their experiment application development, and may be provided access to the ground-based and flight SDRs to prepare and conduct their experiment. Access to the ground and flight system will be provided on a best effort basis and will be based on their relative priority with other approved experiments. Please note that selection for award does not guarantee flight opportunities on the ISS.

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

- Demonstration of mission applicability of SDR.
- Aspects of reconfiguration.
 - Unique/efficient use of processor, FPGA, DSP resources.
 - Inter-process communications.
- Spectrum efficient technologies.
- Space internetworking.
 - Disruption Tolerant Networking.
- Position, navigation and timing (PNT) technology.
- Technologies/waveforms for formation flying.
- High data rate communications.
- Uplink antenna arraying technologies.
- Multi-access communication.
- RF sensing applications (science emulation).

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- Cognitive applications.

Experimenters using ground or flight systems will be required to meet certain pre-conditions for flight including:

- Provide software/firmware deliverables suitable for flight (i.e., NASA Class C flight software).
- Document development and build environment and tools for waveform/applications.
- Provide appropriate documentation (e.g., experimenter requirements, waveform/software user's guide, ICD's) throughout the development and code deliverable process.
- Software/firmware deliverables compliant to the Space Telecommunications Radio System (STRS) Architecture, Release 1.02.1.
- Verification of performance on ground based system prior to operation on the flight system.

Methods and tools for the development of software/firmware components that is portable across multiple platforms and standards-based approaches are preferred.

Documentation for both the CoNNeCT system and STRS Architecture may be found at the following link:

(<http://spaceflight systems.grc.nasa.gov/SpaceOps/CoNNeCT/> [10]).

These documents will provide an overview of the CoNNeCT flight and ground systems, ground development and test facilities, and experiment flow. Documentation providing additional detail on the flight SDRs, hardware suite, development tools, and interfaces will be made available to successful SBIR award recipients. Note that certain documentation available to SBIR award recipients is restricted by export controls and available to U.S. citizens only.

For all above technologies, Phase I will provide experimenters time to develop and advance waveform/application architectures and designs along with detailed experiment plans. The subtopic will seek to leverage more mature waveform developments to reduce development risk in subsequent phases. The experiment plan will show a path toward Phase II software/firmware completion, ground verification process, and delivering a software/firmware and documentation package for NASA space demonstration aboard the flight SDR. Phase II will allow experimenters to complete the waveform development and demonstrate technical feasibility and basic operation of key algorithms on CoNNeCT ground-based SDR platforms and conduct their flight system experiment. Opportunities and plans should also be identified and summarized for potential commercialization.

Phase I Deliverables:

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- Experiment Reference Design Mission Document.
 - Waveform/application architecture and detailed design document, including plan/approach for STRS compliance.
 - Experiment Plan.
 - Demonstrate simulation or model of key waveform/application functions.
 - Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 3-4).

Phase II Deliverables:

- Experiment Requirements Document.
- Simulation or model of waveform application.
- Demonstration of waveform/application in the laboratory on CoNNeCT breadboards or engineering models.
- Software/firmware application source and binary code and documentation. Source/binary code will be run on engineering models and/or demonstrated on-orbit in flight system (at TRL-5-7) SDRs.

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 Nano/Small Sat Launch Vehicle Technology

Lead Center: KSC

Participating Center(s): ARC

The space transportation industry is in need of low-cost, reliable, on-demand, routine space access. Both government and private entities are pursuing various small launch systems and architectures aimed at addressing this market need. Significant technical risk and cost exists in new system development and operations - reducing incentive for private capital investment in this still-nascent industry. Public and private sector goals are aligned in reducing these risks and enabling the development of small launch systems capable of reliably delivering payloads to low Earth orbit. The Nano/Micro Launch Vehicle (NMLV) will provide the nation with a new, small payload access to space capability. The primary objective is to develop a capability to place nano and micro satellites weighing up to approximately 20 kilograms into a reference orbit defined as circular, 450 kilometer altitude, from various inclinations ranging from 0 to 98 degrees.

This SBIR subtopic seeks commercial solution in the areas of nano and micro spacecraft launch vehicle technologies.

This subtopic will particularly focus on higher risk entrepreneurial projects for dedicated nano and micro spacecraft launch vehicles. This subtopic seeks proposals including, but not limited to, the following areas:

- Sub-orbital booster conceptual designs of system/architectures capable of reducing the mission costs associated with the launching of small payloads to LEO.
- Sub-orbital booster technologies traceable to an orbital capable Nano/Micro Launch Vehicle (NMLV)*, whereby specific technologies are identified for Phase II development and test.

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: Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product.

Also required are for all technologies are performance predictions, cost objectives, and development and demonstration plans for the Nano/Micro Launch Vehicle (NMLV). Formulate and deliver a verification matrix of measurements to be performed in Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

The report shall also provide options for commercialization opportunities after Phase II.

Phase II Deliverables: Working engineering model of proposed Phase I components or technologies, along with full report on development and measurements, including populated verification matrix from Phase I. The prototype hardware shall emphasize launch cost reduction technologies, and possess sufficient design information to fabricate, integrate, and operate the selected high-risk component(s) for demonstration. Refinement of the sub-orbital booster design is required as knowledge is gained through the critical component development process. Exit

TRL 5-6 is expected at the end of Phase II

*The NMLV would be a smaller vehicle than the Pegasus launch vehicle which is considered a Small Launch Vehicle (SLV).

O2.02 Propulsion Technologies

Lead Center: GRC

Participating Center(s): AFRC, ARC, MSFC

Current launch to orbit vehicles, both expendable and reusable, require months of preparation for flight. Although there are available (in-production) practical propulsion options for such a vehicle, the costs for outfitting the booster stage are in the hundreds of millions of dollars. If reusable, additional months are required to verify all components and systems before re-flight. These costs severely limit what missions NASA can perform. The propulsion systems are a major focus during this time, yet aircraft engines are checked and certified for re-flight in less than an hour. While rocket engines actually have many similarities to aircraft engines, there are several factors that drive the complexity and therefore the cost of rocket engines. These include toxic propellants that require special protections for personnel and the environment, cryogenic propellants that require complex tank fill operations and costly specialized ground support equipment, high combustion chamber temperatures for increased performance and thrust, and high combustion chamber pressures for increased performance and reduced engine size and weight.

To move more toward low cost access to space, the above barriers to low-cost propulsion systems must be addressed and overcome. Of primary focus are non-toxic propellant combinations that provide adequate performance without requiring excessive specialized handling equipment and procedures, and engines that provide reliable and adequate performance without needing to push the far limits of temperature and pressure environments. Component technologies that move toward these top-level goals that are of interest include:

- Ablative materials and manufacturing techniques that increase capability while reducing production time and cost.
- Innovative chamber cooling concepts that reduce manufacturing complexity, reduce pressure drop, and minimize performance losses caused by cooling.
- Development of non-toxic propellants and technologies that enable their use such as catalysts, compatible materials, feed/storage systems, etc.
- Low-cost nozzle materials, manufacturing techniques, and coatings to reduce the amount of active cooling required.
- Ignition concepts that require low part count and/or low energy to be used as either primary or redundant ignition sources.
- Manufacturing techniques that lower the cost of manufacturing complex components such as injectors and coolant channels. Examples include, but are not limited to, development and demonstration of rapid

prototype techniques for metallic parts, power metallurgy techniques for the manufacture of geometrically complex parts, and application of nanotechnology for near net shape manufacturing.

- Sensors, instruments, and algorithms to diagnose the health of the engine valves, injector, igniter, chamber, coolant channels, etc. without requiring hours of manual inspections.

Specified target metrics include:

- A cost target of
- Reduced ground support equipment.
- Increased performance margin (e.g., operating temperature % of material limit, operating stress % of component limit, etc.).

These are critical technology improvements that are required in the next 3 - 8 years. Projects are required to demonstrate the component or technology to a TRL level of 5 - 6 in order to allow for infusion into low-cost earth-to-orbit propulsion systems. The NASA Office of Chief Technologist has developed Technology Roadmaps that identify technology gaps and needs to enable certain future missions. This subtopic calls for technologies that are discussed in more detail in the Technology Area 1 (Launch Propulsion Systems) and Technology Area 13 (Ground & Launch Systems Processing) roadmaps. These are available for viewing at (<http://www.nasa.gov/offices/oct/home/roadmaps/index.html> [13]). Proposals should reference specific elements from these and other relevant roadmaps and explain how the proposed technology will address identified technology gaps and needs.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase II 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: Lab-scale component or technology demonstrations and reports of target metric performance.

Phase II Deliverables: Subscale component or technology demonstrations and reports of target metric performance. Opportunities and plans should also be identified and summarized for potential commercialization.

O2.03 21st Century Spaceport Ground Systems Technologies

Lead Center: KSC

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

This subtopic seeks innovative solutions that will allow spaceport launch service providers to operate in an efficient,

low cost manner and increases capabilities associated with integration, checkout, and preparations required to configure and ready space systems for launch. The goal is a set of technologies, processes, and strategic concepts that can be collectively used to facilitate launch vehicle processing by reducing complexity, turn-around times, and mission risk while implementing novel concepts for the processing of launch vehicles.

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. Additional key operating characteristics for a spaceport focus are interoperability, ease of use, flexibility, safety/environmental protection, support multiple concurrent operations, and the de-coupling of pre-launch processing from other users on the range.

Specific areas of interest:

- End-to-End Command and Control Services.
- Technologies and Capabilities that enable flexible and adaptable control by integrating enterprise capabilities with remote and distributed control functions while simultaneously maintaining security and safety for critical operation.
- Communications Services and RF/Optical Services to enable virtual distributed teams for control, engineering, safety analysis and support.
- Technologies and Capabilities that enable multi-government teams to operate existing or new assets in the most cost efficient manner. In addition technologies or capabilities that would move existing government provided capabilities and provide a path to commercialization in the future.
- Preventative and condition based maintenance along with self-healing capabilities for ground systems.
- Technologies and Capabilities that reduce required work content, through an automated understanding of when and if maintenance work needed to be performed, in addition, capabilities that reduce cost or provide additional mission assurance capabilities at comparable or reduced cost.
- De-coupled pre-launch processing where the strategy for de-coupling involves the spaceport's capacity, configurability and Space-Based capabilities.
- Technologies and Capabilities that reduce the amount of ground operations that must be coordinated with other Range users, which would enable every user on the Range to believe they are the only user of the range throughout the ground flow.
- Spaceport and Range technologies and capabilities that increase launch attempts per day and/or consecutive days across the entire Florida Launch and Range Complex.
- Technologies and Capabilities that provide, localized, accurate forecasting of weather in support of Ground Operations.
- Improve security and control of range hazard areas.
- Technologies and Capabilities that improve the security of the range while reducing the cost to perform and monitor the Range volume.
- Innovative systems for payload recovery techniques with advancements in the areas of Mid-Air Retrieval

(MAR) systems and guided payload recovery systems (such as a guided parafoil system).

- Technologies and Capabilities that allow in-flight recovery of small vehicles and payloads. In addition, Technologies and Capabilities that significantly reduce the cost of recovery operations.

Priority will be given to innovative solutions that:

- Enable low-cost concepts that reduce operations and life cycle costs.
- Demonstrate a transition path into spaceport operations.
- Can achieve high-fidelity ground-based demonstrations within the next 4 years; longer-term development proposals will be accepted, but will be considered at a lower priority for funding.

Research should be conducted to convincingly prove technical feasibility during Phase I, with clear pathways to demonstrating and delivering functional prototypes, meeting all objectives, 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 model of proposed product, along with full report of development and measurements, shall emphasize cost reduction and efficiency technologies, and include a populated verification matrix from Phase II (TRL 5). Opportunities and plans should also be identified and summarized for potential commercialization.

O2.04 Advanced Tank Technology Development

Lead Center: MSFC

Participating Center(s): JSC

The objective of this subtopic is to dramatically reduce the cost of achieving low Earth orbit by advancing the technology required for spaceflight propellant tank development. The ability for launch vehicles to combine the significant weight savings of composite tanks and composite overwrap pressure vessels (COPVs) with airline like operations could be possible if these tanks are reusable, reliable, and need little to no maintenance between flights.

Composite and composite overwrap tanks offer significant weight savings, however, 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 designs. This subtopic seeks to mature such emerging technologies pertaining to high performance, light-weight tanks and pressure vessels suitable for cryogenic and

non-cryogenic temperatures at high pressures; seeks to develop technologies that extend life and/or decrease cost while being mindful of permeability, damage tolerance, safe-life and checkout issues; and seek out seal and joint development, increasing tank robustness and life while not increasing weight or cost; all against the current state-of-the-art capabilities and technologies.

Areas of interest to develop and/or demonstrate are as follows:

- **Material Development:** New composite material development specifically for cryogenic use demonstrating cycling, reparability, and knowledge of permeability and damage tolerance. Data should clearly show materials and processes used in producing a vessel that performs well under long-term use in a cryogenic condition. Vessel performance and cycling should be analyzed at and during operational conditions (i.e., cryogenic conditions) to verify material integrity. The vessel would minimize micro cracking, should be damage tolerant and repairable, and have mounting capabilities. Permeability of the material should be addressed and evaluated against current material usage and limitations.
- **Reusability and Reliability:** Reusable, reliable, and low cost tanks that need little to no maintenance between flights and minimal check-out are required for economic and operational sustainability. These innovative propellant tank (either cryogenic or non-cryogenic) 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 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 during cycling and on material integrity. 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.

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: Desired deliverables at the end of Phase I should be at TRL 3-4. Final report containing:

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- 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.

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

O2.05 Advanced Propulsion Testing Technologies

Lead Center: SSC

The aim of this subtopic is to develop new technologies to reduce cost and schedule, improve reliability and quality, and increase safety of Rocket Propulsion Testing. To this end, proposals for technology development will be accepted for any of the following four subject areas:

- Critical Vacuum Sensing.
- Helium Recovery.
- Robust Components.
- Advanced Propulsion Test Data Management.

Critical Vacuum Sensing Technology

Develop new innovative methods for remotely and automatically locating and quantifying vacuum leaks in large vacuum chambers subject to harsh environmental conditions. A new test stand, A3, is being built at SSC to test rocket engines at altitude conditions. Information on A3 Test Stand can be found at the following URLs:

- <http://sscfreedom.ssc.nasa.gov/etd/ETDTestFacilitiesA3.asp> [14].
- http://www.tulane.edu/~sse/FORUM_2010/pdfs/e1.pdf [15].
- http://www.nasa.gov/centers/stennis/pdf/436170main_A-3%20Test%20Stand%20FS-2010-03-00093.pdf [16].

To simulate altitude during rocket engine testing, A3 test stand produces a vacuum of 0.15psia inside a large, 40 ft diameter, rocket engine test chamber using 27 chemical steam generators and a 2-stage diffuser/ejector system. If vacuum leaks occur, the desired simulated altitude may not be achievable thus any leaks must be located and repaired. However, personnel access to the vacuum test chamber during operation is restricted due to the hazardous nature of its operation. This makes locating vacuum leaks difficult, if not impossible. Therefore, automated remote detection and location of areas of air in-leakage is required. Due to the unique nature of this test facility, innovation in these technologies is necessary. Performance metrics include accuracy and sensitivity in detecting leaks in the harsh operational environment with high levels of noise and vibration while not producing false leak indications, as well as robust design for the harsh environment.

Helium Recovery Technology

Helium is a rare and nonrenewable resource with many properties critical to the commercial, military, and fundamental scientific research sectors. NASA consumes approximately 1 million pounds of helium each year, primarily for purging of cryogenic propellant systems in which the helium is discharged to atmosphere and lost. The goal of this subtopic thrust area is to develop innovative helium recovery technologies that economically dissociate helium from large volumes of mixtures of helium, air, and hydrogen purge discharge, and pressurize the reclaimed helium for storage and reuse. The total cost of recovering and reusing helium, from both capital and energy expenditure, should be less than procuring the same amount of helium from traditional sources. Also, particular emphasis is placed on portability (i.e., not a fixed installation) and speed of separation (near-real-time) that accommodates a single system servicing numerous distinct sources of helium, air, and hydrogen mixtures developed over the range of rocket propulsion testing and ground and flight operations and the temporal transient nature of production of these mixtures.

Robust Component Technologies

Rocket propulsion test hardware as well as ground and flight launch operations hardware regularly experience large and rapid changes in pressures, temperatures, vibration, and fluid flow rates while demanding high precision control and reliability. Typical ranges in these parameters are pressures from vacuum all the way up to 10,000 psi, working fluids at ambient temperature all the way down to -420F, vibration environments in the 100's of G RMS acceleration. These parameters can span their entire range in milliseconds. State of the art propulsion system testing hardware has evolved over time as better materials and experience in hardware interactions with these environments have progressed. Innovation in component performance diagnostics technology is required to continue the current progression in hardware operational reliability, cost, and weight optimization. Accordingly, the goal of this subtopic thrust area is to develop innovative in situ hardware performance measurement and diagnostics technology along with the accompanying data acquisition and management systems required for utilization the new technologies.

Advanced Propulsion Test Data Management Capability

Substantial advances in data capture and storage technologies have exponentially increased real and near-real time data availability in rocket propulsion testing. Effective utilization of this increase in data availability requires evolution of data management technologies, methods, and concepts that will enable greater and more effective real-time access, manipulation, and application in the control and quality of propulsion systems testing. Recent initiatives in development of hardware-in-the-loop technologies, merging measured and simulation data in real time feedback with propulsion test hardware have demonstrated the feasibility and utility of this technology. The goal of this subtopic thrust area is to develop innovative ways to take advantage of increased propulsion test data availability utilizing high performance hardware such as GPU based computer systems along with innovation in algorithms and software to implement new data management technologies, methods, and concepts.

In these subject areas, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward hardware and/or software development as appropriate, which occurs during Phase II and culminates in a proof-of-concept system.

Phase I Deliverables: A final report describing optimal design for the technology concept including feasibility, trade studies, detailed results of Phase I analysis, modeling, prototyping, and testing as applicable. The report should also contain a detailed path towards Phase II hardware and/or software proof-of-concept system. The technology concept at the end of Phase I should be at a TRL of 3-4.

Phase II Deliverables: A working proof-of-concept system successfully demonstrated in a relevant environment and delivered to NASA for testing and verification. The technology at the end of Phase II should be at a TRL of 6-7.

Processing and Operations Topic O3

The Space Operations Mission Directorate (SOMD) provides 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. Activities include ground-based and in-flight processing and operations tasks, along with support that ensures these tasks are accomplished efficiently and accurately enables successful missions and healthy crews. This topic area, while largely focused on operational space flight activities, is broad in scope. NASA is seeking technologies that address how to improve and lower costs related to ground and flight assets, and maximize and extend the life of the International Space Station. A typical flight focused 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. For ground processing and operations tasks, the proposal shall outline a path showing how the technology could be developed into ground or flight systems. The contract shall 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 Remotely Operated Mobile Sensing Technologies for inside ISS

Lead Center: ARC

Participating Center(s): JPL

This subtopic seeks proposals to develop technologies that advance capabilities for space telepresence and mission operations situation awareness, fault diagnosis, isolation, and recovery onboard the ISS using an onboard free-flyer as a mobile sensor platform. In order to increase productivity and reduce risks on long-missions on spacecraft, such as the ISS, leading toward human exploration, commercialization, and colonization of space, ground personnel have a need to remotely command a wide-variety of sensors on mobile platforms to collect data from a variety of positions within spacecraft. The sensors include, but are not limited to, those capable of performing imaging, identifying inventory, and measuring electromagnetic radiation, temperature, acoustics, atmospheric properties, and chemical concentrations. To increase crew productivity, it is highly desirable that the mobile platform be capable of being deployed by ground command, move to the commanded location, collect data, and then return to its storage dock where it is recharged all without requiring crew assistance.

This subtopic solicitation calls for developing a variety of software and hardware technologies that would enable a free-flyer to operate in multiple modules inside ISS including but not limited to:

- Free-flyer localization capability without engineering environment.
- Collision avoidance capability.
- Adjustable autonomous control software that supports safe operation with low-bandwidth, intermittent command communication loop with varying latencies > 10 sec.
- EXPRESS rack-based auto-docking, recharging, refueling, deployment mechanism with matching free-flyer mechanism.
- Quiet propulsion capability meeting ISS noise limit requirements (
- Vision-based object identification capability.
- RFID-based inventory identification capability.

Proposals may address any one or a combination of the above or related subjects.

Three SPHERES satellites have operated inside ISS since 2006. In addition to performing dozens of experiments, these satellites demonstrate that mobile platforms in the form of free-flyers can be operated on ISS. However, these satellites have not been operated by ground personnel and their current design is inadequate to meet the needs described above for several reasons, e.g., the satellites require crew assistance to operate, require that batteries and CO₂ cartridges (propellant) be replaced by crew between test sessions, and are confined to a work area bounded by external beacons used by the satellites to localize themselves within their workspace, approximately 2x2x2 meters. However, the SPHERES satellites may be useful in demonstrating technologies called for by this subtopic. Proposals are encouraged that leverage the SPHERES satellites operating onboard ISS

and SPHERES engineering units at the NASA Ames Research Center. More information on SPHERES is at:

- http://www.nasa.gov/mission_pages/station/research/experiments/SPHERES.html [17].
- <http://ssl.mit.edu/spheres> [18].

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:

- Midterm Technical Report.
- Final Phase I Technical Report with a feasibility study including: simulations and measurements demonstrating the approach used to develop and test the prototype, constraints on other systems, concept of operations, verification matrix of measurements with pass/fail ranges for each quantity to be verified at the end of Phase II, and the Phase II integration path.
- Proof-of-concept simulation and/or bench top demonstration (TRL 3-4).

Phase II Deliverables:

- Midterm Technical Report.
- Final Phase II Technical Report with specifications including: design, development approach, tests to verify the prototype, verification matrix of measurements with pass/fail ranges for each quantity verified, constraints on other systems, and operations guide. Opportunities and plans for potential commercialization should also be included.
- Fully-functional engineering prototype of proposed product (TRL 5-6).

O3.02 ISS Utilization

Lead Center: JSC

Participating Center(s): ARC, GRC, KSC

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 now make it possible to measure the diffusion coefficient of experimental systems using the Light Microscopy Module (LMM) on the International Space Station (ISS). The light scattering instrument (laser, detector, optics) to be mounted on a Leica DM/RXA microscope camera port should be about the size of a 40mm diameter tube around 60mm long) with associated support electronics (including the correlator) being able to fit into a volume of about 30mm x 100mm x 100mm, or less. The intensity dynamic range should be able to cover between 10^{-10} to 10^{-7} Watts. The relaxation time range should be capable to spanning 200nsec to 50sec. This peer-reviewed science was considered a decade ago but not developed due to technology limitations. It is now possible to meet the required performance criteria (with the above size and power requirements) to measure diffusion coefficients. From the measured diffusion coefficient, particle size can be extracted, or the temperature determined for the location being viewed (e.g., in a capillary cell with a temperature gradient along it) can be deduced (for known particles and solvents) using the Stokes-Einstein equation.
- Providing compact laser tweezers and supporting software. Development of a compact robust Holographic Laser Tweezers (LT) instrument and associated control scripts for use with a microscope on the International Space Station (ISS) based on the recent developments of holographic techniques. This could expand the types of experiments conducted on orbit. The laser tweezers that would mount on a Leica DM/RXA microscope should be less than ~100mm on a side and the associated control electronics should be less than ~150mm on a side. This technology should now be robust side it is solid-state and no longer requires gimbaled mirrors. 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 to better than one micron 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. Because of its use on space station, the instrument should be self-calibrating. 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 and material science 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; an atomic force microscope (for biological and

material science samples), 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/research/experiments_category.html [9].

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 Demonstration & Development of Improved Exploration Technologies

Lead Center: JSC

Participating Center(s): ARC

The focus of this subtopic is on technologies and techniques that may advance the state of the art of spacecraft systems by utilizing the International Space Station as a technology test bed.

Successful proposals will address using the long duration, microgravity and extreme vacuum environment available on the ISS to demonstrate component or system characteristics that extend beyond the current state of the art by:

- Increasing capability/operating time including overall operational availability.

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- Reducing logistics and maintenance efforts.
 - Reducing operational efforts, minimizing crew interaction with both systems and the ground.
 - Reducing known spacecraft/spaceflight technical risks and needs.
 - Providing information on the long-term space environment needed in the development of future spacecraft technologies through model development, simulations or ground testing verified by on orbit operational data.

While selection for award does not guarantee flight opportunities, the proposed demonstrations should focus on increasing the TRL in the following technology areas of interest:

- Propulsion (in-space and novel, electromagnetic and/or very high specific impulse systems).
- Power and energy storage.
- Robotics tele-robotics and autonomous (RTA) Systems.
- Human health, life support and habitation systems.
- Science instruments, observatories and sensor systems.
- Nanotechnology.
- Materials, structures, mechanical systems and manufacturing.
- Thermal management systems including novel heat radiation techniques.
- Spacecraft (including ISS) plasma and contamination in-situ diagnostics.
- Environmental control systems, including improved carbon dioxide removal.

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: 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 Deliverables: 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.

03.04 Vehicle Integration and Ground Processing

Lead Center: KSC

Participating Center(s): SSC

This subtopic seeks to create new and innovative technology solutions to 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. The following areas are of particular interest:

Control of Material Degradation

Technologies are needed to reduce costs due to material degradation of materials in spaceport and propulsion test facility infrastructure and ground support equipment, Material solutions must meet current and emerging environmental restrictions and endure today's corrosive and highly acidic launch environments. These needs include:

- New environmentally friendly technologies for paint removal and surface preparation that can be applied to large structures. New technologies must achieve better performance than conventional abrasive blasting techniques by reducing the cost of collecting and/or processing waste while keeping blasting rates the same or better than conventional technologies. These technologies must work for inorganic zinc coating.
- New environmentally friendly technologies for prevention/reduction of microbial corrosion in steel piping systems utilizing brackish or untreated water.
- Sub-scale or laboratory tests that can be used to evaluate the suitability of refractory concrete for use in launch pad and rocket test facilities flame deflectors. Proposed tests must show that they are relevant to full scale blast effects.
- Innovative refractory material application methods to ensure field applications have the same properties (strength, density, performance, etc...) as small scale test coupons.

Spaceport Processing Evaluation/Inspection Tools

Innovative solutions are desired that reduce inspection times, provide higher confidence in system reliability, increase safety and lower life cycle costs. Technologies must support identifying composite material defects, evaluating material integrity, damage inspection and/or acceptance testing of composite systems. These include:

- Technologies in support of defect detection in composite materials.
- Methods for determining structural integrity of composite materials and bonded assemblies.
- Non-intrusive inspection of Composite Overwrapped Pressure Vessels (COPV), Orion heat shield and other composite systems.

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- In-situ evaluation of refractory concrete as installed in the flame trenches associated with propulsion test and launch pad infrastructure.

Hypergolic Propellant Sensing Technologies

Technologies for leak detection and leak visualization for hypergolic propellants, such as:

- Novel, cost effective technology solutions to provide leak detection of hypergolic propellants at concentrations of 10ppb with minimal environmental sensitivity (i.e., humidity). Sensors and leak detection systems should provide quantitative data with minimum interferences, drift, and exposure and recovery time.
- Novel, cost effective technology solutions to provide leak detection of hypergolic propellants at concentrations of 1ppm with minimal environmental sensitivity (i.e., humidity). Sensors and leak detection systems should provide quantitative data with minimum interferences, drift, and exposure and recovery time.
- Technology to provide leak visualization of hypergolic propellants to support operations (propellant loading, pressurization, leak check).

Cold Gas Storage and Servicing of Launch Vehicle Systems

Storing high-pressure pneumatic gases in a chilled state increases the on board density of gasses used for pressurization during flight. Traditional solutions embed these 3000 - 6000 psig metallic tanks into the flight vehicles' main cryogenic propellant tanks. To achieve the lightest weight tanks, final pressurization takes place after the tanks are immersed to maximize strength gained by the lower temperatures. Under these conditions, it takes several hours to achieve thermal equilibrium with the host tank and maximize mass density of the compressed gas. Solutions are sought to reduce this time to less than 60 minutes to achieve thermal equilibrium of the compressed gas with the host liquid cryogen tank and maximize pneumatic gas mass on board the flight vehicle.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware or software demonstration and delivering a demonstration unit or 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)

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. Digital High Definition Television (HDTV) cameras flown on the Shuttle and International Space Station have shown higher susceptibility to ionizing radiation damage, manifested by visible "dead" pixels in the image. In order to practically deploy HDTV cameras, sensors and processors 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 without performance degradation from ionizing radiation that would require frequent upmass to orbit to replace components or systems.

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.

Domains of Interest

Domains of interest in the near term address needs for space environment, radiation tolerant, HDTV and digital cinema cameras and down-stream video processors. Mid and Long term goals include radiation tolerant, reprogrammable, highly bandwidth efficient encoders and improved distribution systems for video data signals. Current HDTV transmissions from the ISS require approximately 25 Mbps. Bitrates with equal or better video quality are desired at half that bit rate. These systems are highly desired by the human spaceflight programs.

Technologies of Interest

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 designs and development plans with plausible data and rationale that demonstrates why the designs and plans should mitigate radiation effects on the sensors, and a detailed path towards Phase II hardware demonstration. The report shall also provide options for commercialization opportunities after Phase II.

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 defined expected lifespan of the sensors.

03.06 Environmental Control Systems & Technologies for NR & Cubesats

Lead Center: ARC

A significant challenge faced by free-flying spacecraft and shared by ISS-bound experiment packages is the requirement for a controlled (or at least known) environment while the payload is awaiting launch on the launch vehicle or is in transit to the ISS. Due to the retirement of the Space Shuttle, NASA has a need for flight qualified, environmentally conditioned transportation systems compatible with new space launch systems capable of sustaining and extending the life of perishable materials and specimens until experiment packages can be installed and properly interfaced on-board ISS. This solicitation seeks to develop innovative environmental control technologies for the ground and space transportation of nanorack cubes and cubesats.

Cubesat integration timelines frequently call for passively mating to the launch vehicle or deployer system many weeks in advance of launch. The environment that the payload experiences plays a major role on the shelf life of certain materials and specimens within the spacecraft. Technologies capable of monitoring and extending the shelf life of perishable payloads are of interest to NASA as the environment in and around the launch vehicle is not always controlled in a manner favorable to a payload. Technologies can be either integrated directly into the Cubesat or external to the Cubesat.

Two applications for these technologies are sought:

- ISS Nanorack Transportation System.
 - This system will have the ability to maintain temperatures within relevant ranges for biological and/or perishable Nanorack payloads from time of experiment preparation at the payload processing facility until installation into the host facility on ISS. This also includes ground

transportation phases of the mission.

- The Transportation System will also provide a time history of relevant parameters ie temperature, relative humidity, vibration, etc, during the transportation periods up to payload installation on ISS.

- Cubesat applications.
 - Cubesat applications involve technologies that may be incorporated into the Cubesat spacecraft itself, or systems that can be used as adjuncts to monitor and control the environment in and around the Cubesat payload/spacecraft. These technologies can be passive and/or active in nature.
 - Cubesat applications will also provide a time history of relevant parameters ie temperature, relative humidity, etc during the dwell time on the pad while awaiting launch.

Innovative approaches to this problem will significantly increase the utility of Nanoracks modules and/or Cubesat spacecraft in that this technology will enable an expanded set of experiment types and mission scenarios. Such a capability may also be extended in support of ground control experiments where on-orbit environments must be duplicated in the lab.

Nanorack information can be found here: <http://nanoracks.com> [19].

Cubesat information can be found here: <http://cubesat.org/> [20].

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:

- Midterm Technical Report.
- Final Phase I Technical Report with a feasibility study including: simulations and measurements demonstrating the approach used to develop and test the prototype, constraints on other systems, concept of operations, verification matrix of measurements with pass/fail ranges for each quantity to be verified at the end of Phase II, and the Phase II integration path.
- Proof-of-concept simulation and/or bench top demonstration (TRL 3-4).

Phase II Deliverables:

- Midterm Technical Report.

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- Final Phase II Technical Report with specifications including: design, development approach, tests to verify the prototype, verification matrix of measurements with pass/fail ranges for each quantity verified, constraints on other systems, and operations guide. Opportunities and plans for potential commercialization should also be included.
 - Fully-functional engineering prototype of proposed product (TRL 5-6).

Navigation Topic O4

NASA seeks 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 (<https://www.spacecomm.nasa.gov/spacecomm/default.cfm> [21]). NASA's Space Communication and Navigation Office considers the three elements of PNT to represent distinct, constituent capabilities: - positioning, by which we mean accurate and precise determination of an asset's location and orientation referenced to a coordinate system - 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 - 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 technology in Metric Tracking of Launch Vehicles, Position, Navigation, and Timing (PNT) Sensors and Components, and Flight Dynamics Technologies and Software. These areas include tracking during launch and landing operations, and research and technology relevant to the planning and development of PNT support and services that NASA may undertake over the next several years. Some of the subtopics in this topic could result in products that may be included in future flight opportunities. Please see the Science MD Topic S4 for more details as to the requirements for small satellite flight opportunities, and the Facilitated Access to the Space Environment for Technology Development and Training (FAST) website at (http://ipp.nasa.gov/ii_fast.htm [22]).

Sub Topics:

04.01 Metric Tracking of Launch Vehicles

Lead Center: KSC

Participating Center(s): GSFC, MSFC

The goal of this subtopic is to have a highly reliable way of tracking vehicles from launch to orbit. Launch vehicles can exhibit high dynamics during flight and there can be external interference on the GPS frequency. Proposals can either address a single area as described below or a combination of multiple areas. The following technology areas are of interest:

Position, Attitude, and Inertial Metrics

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 high dynamic platforms. Factors to address include:

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- 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.
 - Robust tracking during separation.

Use of GPS and Ability to Mitigate Interference Signals

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 that degrade the GPS signals can be obtained by differencing the available carrier phase and pseudo range measurements and then removing these differences from the navigation solution.

Technologies are sought that combine spatial processing of signals from multiple antennas with temporal processing techniques to mitigate 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).

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.
- 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:

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- Working model of proposed product, along with full report of development and measurements, including populated verification matrix from phase II (TRL 5).
 - Final Phase II Technical Report.
 - Demonstration hardware/software/field test.
 - Opportunities and plans should also be identified and summarized for potential commercialization.

O4.02 PNT (Positioning, Navigation, and Timing) Sensors and Components

Lead Center: GSFC

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

This subtopic 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:
 - NASA Copyright, licensable technology.
 - (http://ipp.gsfc.nasa.gov/ft_tech_geons.shtml [23]).
 - AutoNav (NTR 43546 Deep Impact Autonomous Navigation (AutoNav) Flight Software 23-FEB-2006).
- Navigator:
 - US Patent 7,548,199.
 - <http://patft1.uspto.gov/netacgi/nph-Parser?patentnumber=7548199> [24].
 - http://techtransfer.gsfc.nasa.gov/ft_tech_gps_navigator.shtml [25].
- GIPSY:
 - <https://gipsy-oasis.jpl.nasa.gov/> [26].

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- Electra:
 - http://descanso.jpl.nasa.gov/Monograph/series9_chapter.cfm [27].

 - Blackjack:
 - <http://www.jpl.nasa.gov/releases/2000/blackjackgps.html> [28].

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. We seek to maximize the work listed above in the new work sought for this subtopic.

General Operational Needs, Requirements and Performance Metrics:

Onboard Near-Earth Navigation Systems

NASA seeks proposals that would develop a commercially viable transceiver with embedded orbit determination software to provide enhanced accuracy and integrity for autonomous onboard GPS- and TDRSS-based navigation and time-transfer in near-Earth space via augmentation messages broadcast by the proposed TDRSS Augmentation for Satellites Signal (TASS; <http://www.gdgps.net/system-desc/papers/Bar-Sever.pdf> [29]). Innovations that will increase the integration, reducing the size, weight, and power of such transceiver platforms, and improving their performance in high radiation environments, are sought. 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 AutoNav navigation software packages already support the capability to ingest many one way forward Doppler, optical sensor observation, and accelerometer data types. In addition, NASA is seeking innovative solutions in the area of planetary surface navigation.

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 Planetary Relay Satellites

NASA seeks planetary 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 bases on other planetary surfaces 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:

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- 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 Technologies and Software

Lead Center: GRC

Participating Center(s): ARC, 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:

- GPS-Enhanced Onboard Navigation Software: http://techtransfer.gsfc.nasa.gov/ft_tech_gps_navigator.shtm [25].
- General Mission Analysis Tool: <http://sourceforge.net/projects/gmat/> [30].
- GPS-Inferred Positioning System and Orbit Analysis Simulation Software: <http://gipsy.jpl.nasa.gov/orms/goa/> [31].
- Optimal Trajectories by Implicit Simulation: <http://otis.grc.nasa.gov/> [32].

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.

Antenna Technology Topic O1.01

NASA seeks advanced antenna systems and technologies to enable communications for future space operations, space science, Earth science and solar system exploration missions. These areas, in priority order, are:

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. Emerging novel technologies such as ferroelectrics, multiferroics and spintronics concepts leading to new antenna designs are desirable.

Smart, Reconfigurable Antennas

Smart antennas, reconfigurable in frequency, polarization and radiation pattern, are of interest for space and planetary exploration missions. In particular, antenna designs and proof-of-concepts leading to the reduction of the number of antennas needed to meet the communication requirements associated with rovers, pressurized surface vehicles, habitats, etc., are highly desired. In addition to the aforementioned reconfigurability requirements, specific antenna 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.

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 technology standardization across each NASA network (i.e., DSN, NEN, and SN), within the framework of the newly envisioned NASA integrated network architecture, at Ka-band frequencies and above, are highly desired.

Phased Array Antennas

High performance phased array antennas, i.e., with efficiencies at least 3X that of state-of-practice MMIC-based phased arrays, 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, extravehicular activities (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 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.

Large Aperture Deployable Antennas

Large aperture deployable antennas with surface root-mean-square (rms) quality better than $\lambda/40$ 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., $\rho/2$). These large Gossamer-like antennas are required to provide high-capacity communication links with low fabrication costs from deep space (Mars and beyond). Concepts addressing antenna adaptive beam correction with pointing control are also of interest.

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: 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 Deliverables: 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.

Sub Topics:

Reconfigurable/Reprogrammable Communication Systems Topic O1.02

NASA seeks novel approaches in reconfigurable, reprogrammable communication systems to enable the vision of space, exploration, science, and aeronautical flight systems. Advancements are required in communication systems to manage the demands of the harsh space environment on space electronics, maintain flexibility and adaptability to changing needs and requirements, and provide flexibility and survivability due to increased mission durations. NASA missions can have vastly different transceiver requirements ranging from 1's to 10's Mbps at UHF & S frequency bands while X & Ka frequency bands require 10's to 1000's of Mbps. Available mission resources also vary greatly depending on the science objective, operating environment, and spacecraft resources. For example, deep space missions are often power constrained; operating over large distances, and subsequently have lower data transmission rates when compared to near-Earth or near planetary satellites. These requirements and resource limitations are known prior to launch, which can be used to maximize transceiver efficiency while minimizing resources consumed. Larger platforms such as vehicles or relay spacecraft may provide more resources but may also be expected to perform more complex functions or support multiple and simultaneous communication links to a diverse set of assets.

This solicitation seeks advancements in reconfigurable transceiver and associated component technology with a goal of providing flexible, reconfigurable communications capability while minimizing on-board resources and cost. Technological domains of interest include the development of software defined radios or radio subsystems which demonstrate reconfigurability, flexibility, reduced power consumption of digital signal processing systems, increased performance and bandwidth, reduced software qualification cost, and error detection and mitigation technologies. Complex reconfigurable systems will provide multiple channel and multiple and simultaneous waveforms. Within these domains of interest, desired proposal focus areas to develop and/or demonstrate technologies are as follows:

- Software/firmware for the management of waveform and/or functional reconfiguration during simultaneous radio operation while adhering to the Space Telecommunications Radio System (STRS) is desired.
- Methods and tools for the development of software/firmware components that are portable across multiple platforms. Standards-based approaches are preferred.
- Dynamic/distributed on-board processing architectures that are scalable and designed to operate in space environments.
- Component technology advancements in bandwidth capacity and reduced resource consumption.
- Analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities.
- Novel techniques or processes to increase memory densities.
- Novel approaches to mitigate device susceptibility to radiation effects.

STRS Architecture documentation is available at the following link:

(<http://spaceflight systems.grc.nasa.gov/SpaceOps/CoNNeCT/> [10]).

The above URL also provides an overview of the Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT) flight program. The reconfigurable radios developed for this system represent the state-of-the-art in technology for space flight communication systems and may be used as a reference for the focus areas above. See also subtopic O1.06 - CoNNeCT Experiments for additional information.

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 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: 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 Deliverables: 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.

Sub Topics:

Game Changing Technologies Topic O1.03

NASA seeks revolutionary, highly innovative, game changing communications technologies that have the potential to enable order of magnitude performance improvements for space operations, exploration systems, and/or science mission applications. Research is geared towards far-term research focused in (but not limited to) the following areas:

- Develop novel techniques for size, weight, and power (SWAP) of communications systems by addressing digital processing and logic implementation tradeoffs, dynamic power management, hardware and software partitioning. Address high-speed, high resolution, low power consumption, and radiation tolerance (e.g., SiGe) to support near Earth and deep space mission environments. Investigate and demonstrate novel technologies to alleviate the demanding requirements (3- to- 5X improvement in sampling rate/resolution over state-of-the-art) on analog to digital converters (ADCs) and digital signal processors (DSPs).
- Develop technologies to evolve NASA communication networking and radio capabilities to autonomously sense and adapt to their environment, detect and repair problems and learn as they operate. Nodes will be dynamically aware of state and configuration of other nodes and adapt accordingly. Communications and navigation subsystems on future missions will interpret their situation on their own, understand their options, and select the best means to communicate or navigate.

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- High-performance, multifunctional, nano-structured materials are of interest for applications in human spaceflight and exploration. These materials (notably single wall carbon nanotubes) exhibit extraordinary mechanical, electrical, and thermal properties at the nanoscale and possess exceptionally high surface area. The development of nano-scale communication devices and systems including nano-antennas, nano-transceivers, etc. are of interest for nano-spacecraft applications.
 - Quantum entanglement, quantum key distribution or innovative breakthroughs in quantum information physics. Address proposed 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. Significant development is needed in high flux single photon sources and entangled pair sources for highly efficient, free space communications.
 - Small spacecraft, due to their limited surface area, are typically power constrained, limiting small spacecraft communications systems to low-bandwidth architectures. Technologies and architectures, which can exploit commercial or other terrestrial communication infrastructures to enable novel smallsat missions to enable a wider variety of space missions are desired. Address how existing communications architectures can be adapted and utilized to provide routine, low cost, high bandwidth communications capabilities for spacecraft to ground, and spacecraft to spacecraft applications.
 - Ultra wide-band (UWB) technology is sought to support robotic localization of surface assets. Whether two-way ranging (time -of-flight) or time-difference of arrival, the ability to synchronize the receivers determine the localization accuracy. Efficient Media Access Control (MAC) and networking protocols are paramount to ensure power efficiency and scalability. Integrating communications and positioning in an ad hoc network can indeed enable situational awareness, keeping track of location and relative position to other astronauts, robots, and vehicles at any time through visual and/or audio cues. Because initial synchronization or signal acquisition for Impulse Radio Ultra-Wide Band (IR-UWB) using equivalent-time sampling takes a long time especially for low pulse repetition rate systems, precise timing and coherent reception demand more power consumption and complexity than non-coherent IR-UWB. To maintain clock stability, most IR-UWB systems do not power down the receivers during operation. Narrower pulse width spreads the RF energy over a wider bandwidth but generation of precise low jitter (
 - Develop methods for use of neutrinos for communications, timing, and ranging. Neutrinos are small, near light speed particles with no electric charge. Since neutrinos travel through most matter, they could be used for extreme long-distance signaling. Detection of neutrinos currently require massive underground liquid detectors. Highly innovative concepts, methods, techniques to enable neutrino based communication, ranging, timing, are sought.

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. Within these domains of interest, desired proposal focus areas to develop and/or demonstrate technologies are as follows:

Isolation Platforms

Compact, lightweight, space qualifiable vibration isolation platforms for payloads massing between 3 and 50 kg that require less than 15 W of power and mass less than 3 kg that will attenuate an integrated angular disturbance of 150 micro-radians from 0.01 Hz to 500 Hz to less than 0.5 micro-radians 1-sigma.

Laser Transmitters

Space-qualifiable, greater than 20% DC to optical efficiency, 0.2 to 16 nanosecond pulse-width 1550-nm laser transmitter for pulse-position modulated data with from 16 to 320 slots per symbol, less than 35 picosecond pulse rise and fall times, near transform limited spectral width, single polarization output with at least 20 dB polarization extinction ratio, amplitude extinction ratio greater than 38 dB, average power of 5 to 20 Watt, massing less than 500 grams per Watt. 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.

Photon Counting Near-Infrared Detectors Arrays for Ground Receivers

Hexagonal close packed kilo-pixel arrays sensitive to 1000 to 1650 nm wavelength range with single photon detection efficiencies greater than 60% and single photon detection jitters less than 40 picoseconds 1-sigma, active diameter greater than 15 microns/pixel, and 1 dB saturation rates of at least 10 mega-photons (detected) per pixel and dark count rates of less than 1 MHz/square-mm.

Photon Counting Near-Infrared Detectors Arrays for Flight Receivers

For the 1000 to 1600 nm wavelength range with single photon detection efficiencies greater than 40% and 1dB saturation rates of at least 1 mega-photons/pixel and operational temperatures above 220K and dark count rates of

Ground-Based Telescope Assembly

Telescope/photon-buckets with primary mirror diameter ~2.5-m, f-number of ~1.1 and Cassegrain focus to be used as optical communication receiver/transmitter optics at 1000-1600nm. Maximum image spot size of ~20 micro-radian, and field-of-view of a~50 micro-radian. Telescope shall be positioned with a two-axis gimbal capable of 0.25 milli-radian pointing. Desired manufacturing cost for combined telescope, gimbal and dome in quantity (tens) of approximately \$2 M each.

Research should be conducted to convincingly prove technical feasibility during Phase I, ideally through hardware

development, with clear pathways to demonstrating and delivering functional hardware, meeting all objectives, 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 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 subtopic seeks to develop innovative long-range RF telecommunications technologies supporting the needs of space missions.

Purpose (based on NASA needs) and current state-of-the-art

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

Technologies of interest

This subtopic seeks innovative technologies in the following areas:

-
- Ultra-small, light-weight, low-cost, low-power, modular deep-space transceivers, transponders and components, incorporating MMICs, MEMs 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 DC-to-RF-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 mass and cost of reliable vacuum electronics amplifier components (e.g., TWTAs and Klystrons).
 - Ultra low-noise amplifiers (MMICs or hybrid, uncooled) for RF front-ends (
 - 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.

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 I (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.

Sub Topics:

CoNNeCT Experiments Topic O1.06

NASA has developed an on-orbit, reprogrammable, software defined radio-based (SDR) testbed facility aboard the International Space Station (ISS), to conduct a suite of experiments to advance technologies, reduce risk, and enable future mission capabilities. The Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT) provides SBIR recipients and through other mechanisms NASA, large business, other Government agencies, and academic partners the opportunity to develop and field communications, navigation, and networking technologies in the laboratory and space environment based on reconfigurable, software defined radio platforms. Each SDR is compliant with the Space Telecommunications Radio System (STRS) Architecture, NASA's common architecture for SDRs. The Testbed is installed on the truss of ISS and communicates with both NASA's Space Network via Tracking Data Relay Satellite System (TDRSS) at S-band and Ka-band and direct to/from ground systems at S-band. One SDR is capable of receiving L-band at the GPS frequencies of L1, L2, and L5.

NASA seeks innovative software experiments to run aboard CoNNeCT to demonstrate and enable future mission capability using the reconfigurable features of the software defined radios. Experiment software/firmware can run in the flight SDRs, the flight avionics computer, and on a corresponding ground SDR at the Space Network, White Sands Complex. Unique experimenter ground hardware equipment may also be used.

Experimenters will be provided with appropriate documentation (e.g., flight SDR, avionics, ground SDR) to aid their experiment application development, and may be provided access to the ground-based and flight SDRs to prepare and conduct their experiment. Access to the ground and flight system will be provided on a best effort basis and will be based on their relative priority with other approved experiments. Please note that selection for award does not guarantee flight opportunities on the ISS.

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

- Demonstration of mission applicability of SDR.
- Aspects of reconfiguration.
 - Unique/efficient use of processor, FPGA, DSP resources.
 - Inter-process communications.
- Spectrum efficient technologies.
- Space internetworking.
 - Disruption Tolerant Networking.
- Position, navigation and timing (PNT) technology.
- Technologies/waveforms for formation flying.
- High data rate communications.
- Uplink antenna arraying technologies.
- Multi-access communication.
- RF sensing applications (science emulation).
- Cognitive applications.

Experimenters using ground or flight systems will be required to meet certain pre-conditions for flight including:

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- Provide software/firmware deliverables suitable for flight (i.e., NASA Class C flight software).
 - Document development and build environment and tools for waveform/applications.
 - Provide appropriate documentation (e.g., experimenter requirements, waveform/software user's guide, ICD's) throughout the development and code deliverable process.
 - Software/firmware deliverables compliant to the Space Telecommunications Radio System (STRS) Architecture, Release 1.02.1.
 - Verification of performance on ground based system prior to operation on the flight system.

Methods and tools for the development of software/firmware components that is portable across multiple platforms and standards-based approaches are preferred.

Documentation for both the CoNNeCT system and STRS Architecture may be found at the following link:

(<http://spaceflightsystems.grc.nasa.gov/SpaceOps/CoNNeCT/> [10]).

These documents will provide an overview of the CoNNeCT flight and ground systems, ground development and test facilities, and experiment flow. Documentation providing additional detail on the flight SDRs, hardware suite, development tools, and interfaces will be made available to successful SBIR award recipients. Note that certain documentation available to SBIR award recipients is restricted by export controls and available to U.S. citizens only.

For all above technologies, Phase I will provide experimenters time to develop and advance waveform/application architectures and designs along with detailed experiment plans. The subtopic will seek to leverage more mature waveform developments to reduce development risk in subsequent phases. The experiment plan will show a path toward Phase II software/firmware completion, ground verification process, and delivering a software/firmware and documentation package for NASA space demonstration aboard the flight SDR. Phase II will allow experimenters to complete the waveform development and demonstrate technical feasibility and basic operation of key algorithms on CoNNeCT ground-based SDR platforms and conduct their flight system experiment. Opportunities and plans should also be identified and summarized for potential commercialization.

Phase I Deliverables:

- Experiment Reference Design Mission Document.
- Waveform/application architecture and detailed design document, including plan/approach for STRS compliance.

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- Experiment Plan.
 - Demonstrate simulation or model of key waveform/application functions.
 - Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 3-4).

Phase II Deliverables:

- Experiment Requirements Document.
- Simulation or model of waveform application.
- Demonstration of waveform/application in the laboratory on CoNNeCT breadboards or engineering models.
- Software/firmware application source and binary code and documentation. Source/binary code will be run on engineering models and/or demonstrated on-orbit in flight system (at TRL-5-7) SDRs.

Sub Topics:

Nano/Small Sat Launch Vehicle Technology Topic O2.01

The space transportation industry is in need of low-cost, reliable, on-demand, routine space access. Both government and private entities are pursuing various small launch systems and architectures aimed at addressing this market need. Significant technical risk and cost exists in new system development and operations - reducing incentive for private capital investment in this still-nascent industry. Public and private sector goals are aligned in reducing these risks and enabling the development of small launch systems capable of reliably delivering payloads to low Earth orbit. The Nano/Micro Launch Vehicle (NMLV) will provide the nation with a new, small payload access to space capability. The primary objective is to develop a capability to place nano and micro satellites weighing up to approximately 20 kilograms into a reference orbit defined as circular, 450 kilometer altitude, from various inclinations ranging from 0 to 98 degrees.

This SBIR subtopic seeks commercial solution in the areas of nano and micro spacecraft launch vehicle technologies.

This subtopic will particularly focus on higher risk entrepreneurial projects for dedicated nano and micro spacecraft launch vehicles. This subtopic seeks proposals including, but not limited to, the following areas:

- Sub-orbital booster conceptual designs of system/architectures capable of reducing the mission costs associated with the launching of small payloads to LEO.

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- Sub-orbital booster technologies traceable to an orbital capable Nano/Micro Launch Vehicle (NMLV)*, whereby specific technologies are identified for Phase II development and test.

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: Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product.

Also required are for all technologies are performance predictions, cost objectives, and development and demonstration plans for the Nano/Micro Launch Vehicle (NMLV). Formulate and deliver a verification matrix of measurements to be performed in Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

The report shall also provide options for commercialization opportunities after Phase II.

Phase II Deliverables: Working engineering model of proposed Phase I components or technologies, along with full report on development and measurements, including populated verification matrix from Phase I. The prototype hardware shall emphasize launch cost reduction technologies, and possess sufficient design information to fabricate, integrate, and operate the selected high-risk component(s) for demonstration. Refinement of the sub-orbital booster design is required as knowledge is gained through the critical component development process. Exit TRL 5-6 is expected at the end of Phase II

*The NMLV would be a smaller vehicle than the Pegasus launch vehicle which is considered a Small Launch Vehicle (SLV).

Sub Topics:

Propulsion Technologies Topic O2.02

Current launch to orbit vehicles, both expendable and reusable, require months of preparation for flight. Although there are available (in-production) practical propulsion options for such a vehicle, the costs for outfitting the booster stage are in the hundreds of millions of dollars. If reusable, additional months are required to verify all components and systems before re-flight. These costs severely limit what missions NASA can perform. The propulsion systems are a major focus during this time, yet aircraft engines are checked and certified for re-flight in less than an hour. While rocket engines actually have many similarities to aircraft engines, there are several factors that drive the complexity and therefore the cost of rocket engines. These include toxic propellants that require special protections for personnel and the environment, cryogenic propellants that require complex tank fill operations and costly specialized ground support equipment, high combustion chamber temperatures for increased performance and thrust, and high combustion chamber pressures for increased performance and reduced engine size and weight.

To move more toward low cost access to space, the above barriers to low-cost propulsion systems must be addressed and overcome. Of primary focus are non-toxic propellant combinations that provide adequate performance without requiring excessive specialized handling equipment and procedures, and engines that provide reliable and adequate performance without needing to push the far limits of temperature and pressure

environments. Component technologies that move toward these top-level goals that are of interest include:

- Ablative materials and manufacturing techniques that increase capability while reducing production time and cost.
- Innovative chamber cooling concepts that reduce manufacturing complexity, reduce pressure drop, and minimize performance losses caused by cooling.
- Development of non-toxic propellants and technologies that enable their use such as catalysts, compatible materials, feed/storage systems, etc.
- Low-cost nozzle materials, manufacturing techniques, and coatings to reduce the amount of active cooling required.
- Ignition concepts that require low part count and/or low energy to be used as either primary or redundant ignition sources.
- Manufacturing techniques that lower the cost of manufacturing complex components such as injectors and coolant channels. Examples include, but are not limited to, development and demonstration of rapid prototype techniques for metallic parts, power metallurgy techniques for the manufacture of geometrically complex parts, and application of nanotechnology for near net shape manufacturing.
- Sensors, instruments, and algorithms to diagnose the health of the engine valves, injector, igniter, chamber, coolant channels, etc. without requiring hours of manual inspections.

Specified target metrics include:

- A cost target of
- Reduced ground support equipment.
- Increased performance margin (e.g., operating temperature % of material limit, operating stress % of component limit, etc.).

These are critical technology improvements that are required in the next 3 - 8 years. Projects are required to demonstrate the component or technology to a TRL level of 5 - 6 in order to allow for infusion into low-cost earth-to-orbit propulsion systems. The NASA Office of Chief Technologist has developed Technology Roadmaps that identify technology gaps and needs to enable certain future missions. This subtopic calls for technologies that are discussed in more detail in the Technology Area 1 (Launch Propulsion Systems) and Technology Area 13 (Ground & Launch Systems Processing) roadmaps. These are available for viewing at <http://www.nasa.gov/offices/oct/home/roadmaps/index.html> [13]). Proposals should reference specific elements from these and other relevant roadmaps and explain how the proposed technology will address identified technology gaps and needs.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase II 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: Lab-scale component or technology demonstrations and reports of target metric performance.

Phase II Deliverables: Subscale component or technology demonstrations and reports of target metric performance. Opportunities and plans should also be identified and summarized for potential commercialization.

Sub Topics:

21st Century Spaceport Ground Systems Technologies Topic O2.03

This subtopic seeks innovative solutions that will allow spaceport launch service providers to operate in an efficient, low cost manner and increases capabilities associated with integration, checkout, and preparations required to configure and ready space systems for launch. The goal is a set of technologies, processes, and strategic concepts that can be collectively used to facilitate launch vehicle processing by reducing complexity, turn-around times, and mission risk while implementing novel concepts for the processing of launch vehicles.

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. Additional key operating characteristics for a spaceport focus are interoperability, ease of use, flexibility, safety/environmental protection, support multiple concurrent operations, and the de-coupling of pre-launch processing from other users on the range.

Specific areas of interest:

- End-to-End Command and Control Services.
- Technologies and Capabilities that enable flexible and adaptable control by integrating enterprise capabilities with remote and distributed control functions while simultaneously maintaining security and safety for critical operation.
- Communications Services and RF/Optical Services to enable virtual distributed teams for control, engineering, safety analysis and support.
- Technologies and Capabilities that enable multi-government teams to operate existing or new assets in the most cost efficient manner. In, addition technologies or capabilities that would move existing government provided capabilities and provide a path to commercialization in the future.
- Preventative and condition based maintenance along with self-healing capabilities for ground systems.
- Technologies and Capabilities that reduce required work content, through an automated understanding of when and if maintenance work needed to be performed, in addition, capabilities that reduce cost or provide additional mission assurance capabilities at comparable or reduced cost.
- De-coupled pre-launch processing where the strategy for de-coupling involves the spaceport's capacity,

configurability and Space-Based capabilities.

- Technologies and Capabilities that reduce the amount of ground operations that must be coordinated with other Range users, which would enable every user on the Range to believe they are the only user of the range throughout the ground flow.
- Spaceport and Range technologies and capabilities that increase launch attempts per day and/or consecutive days across the entire Florida Launch and Range Complex.
- Technologies and Capabilities that provide, localized, accurate forecasting of weather in support of Ground Operations.
- Improve security and control of range hazard areas.
- Technologies and Capabilities that improve the security of the range while reducing the cost to perform and monitor the Range volume.
- Innovative systems for payload recovery techniques with advancements in the areas of Mid-Air Retrieval (MAR) systems and guided payload recovery systems (such as a guided parafoil system).
- Technologies and Capabilities that allow in-flight recovery of small vehicles and payloads. In addition, Technologies and Capabilities that significantly reduce the cost of recovery operations.

Priority will be given to innovative solutions that:

- Enable low-cost concepts that reduce operations and life cycle costs.
- Demonstrate a transition path into spaceport operations.
- Can achieve high-fidelity ground-based demonstrations within the next 4 years; longer-term development proposals will be accepted, but will be considered at a lower priority for funding.

Research should be conducted to convincingly prove technical feasibility during Phase I, with clear pathways to demonstrating and delivering functional prototypes, meeting all objectives, 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 model of proposed product, along with full report of development and measurements, shall emphasize cost reduction and efficiency technologies, and include a populated verification matrix from Phase II (TRL 5). Opportunities and plans should also be identified and summarized for potential commercialization.

Sub Topics:

Advanced Tank Technology Development Topic O2.04

The objective of this subtopic is to dramatically reduce the cost of achieving low Earth orbit by advancing the technology required for spaceflight propellant tank development. The ability for launch vehicles to combine the significant weight savings of composite tanks and composite overwrap pressure vessels (COPVs) with airline like operations could be possible if these tanks are reusable, reliable, and need little to no maintenance between flights.

Composite and composite overwrap tanks offer significant weight savings, however, 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 designs. This subtopic seeks to mature such emerging technologies pertaining to high performance, light-weight tanks and pressure vessels suitable for cryogenic and non-cryogenic temperatures at high pressures; seeks to develop technologies that extend life and/or decrease cost while being mindful of permeability, damage tolerance, safe-life and checkout issues; and seek out seal and joint development, increasing tank robustness and life while not increasing weight or cost; all against the current state-of-the-art capabilities and technologies.

Areas of interest to develop and/or demonstrate are as follows:

- **Material Development:** New composite material development specifically for cryogenic use demonstrating cycling, reparability, and knowledge of permeability and damage tolerance. Data should clearly show materials and processes used in producing a vessel that performs well under long-term use in a cryogenic condition. Vessel performance and cycling should be analyzed at and during operational conditions (i.e., cryogenic conditions) to verify material integrity. The vessel would minimize micro cracking, should be damage tolerant and repairable, and have mounting capabilities. Permeability of the material should be addressed and evaluated against current material usage and limitations.
- **Reusability and Reliability:** Reusable, reliable, and low cost tanks that need little to no maintenance between flights and minimal check-out are required for economic and operational sustainability. These innovative propellant tank (either cryogenic or non-cryogenic) 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 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 during cycling and on material integrity. 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.

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

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

Sub Topics:

Advanced Propulsion Testing Technologies Topic O2.05

The aim of this subtopic is to develop new technologies to reduce cost and schedule, improve reliability and quality, and increase safety of Rocket Propulsion Testing. To this end, proposals for technology development will be accepted for any of the following four subject areas:

- Critical Vacuum Sensing.
- Helium Recovery.
- Robust Components.
- Advanced Propulsion Test Data Management.

Critical Vacuum Sensing Technology

Develop new innovative methods for remotely and automatically locating and quantifying vacuum leaks in large vacuum chambers subject to harsh environmental conditions. A new test stand, A3, is being built at SSC to test rocket engines at altitude conditions. Information on A3 Test Stand can be found at the following URLs:

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- <http://sscfreedom.ssc.nasa.gov/etd/ETDTestFacilitiesA3.asp> [14].
 - http://www.tulane.edu/~sse/FORUM_2010/pdfs/e1.pdf [15].
 - http://www.nasa.gov/centers/stennis/pdf/436170main_A-3%20Test%20Stand%20FS-2010-03-00093.pdf [16].

To simulate altitude during rocket engine testing, A3 test stand produces a vacuum of 0.15psia inside a large, 40 ft diameter, rocket engine test chamber using 27 chemical steam generators and a 2-stage diffuser/ejector system. If vacuum leaks occur, the desired simulated altitude may not be achievable thus any leaks must be located and repaired. However, personnel access to the vacuum test chamber during operation is restricted due to the hazardous nature of its operation. This makes locating vacuum leaks difficult, if not impossible. Therefore, automated remote detection and location of areas of air in-leakage is required. Due to the unique nature of this test facility, innovation in these technologies is necessary. Performance metrics include accuracy and sensitivity in detecting leaks in the harsh operational environment with high levels of noise and vibration while not producing false leak indications, as well as robust design for the harsh environment.

Helium Recovery Technology

Helium is a rare and nonrenewable resource with many properties critical to the commercial, military, and fundamental scientific research sectors. NASA consumes approximately 1 million pounds of helium each year, primarily for purging of cryogenic propellant systems in which the helium is discharged to atmosphere and lost. The goal of this subtopic thrust area is to develop innovative helium recovery technologies that economically dissociate helium from large volumes of mixtures of helium, air, and hydrogen purge discharge, and pressurize the reclaimed helium for storage and reuse. The total cost of recovering and reusing helium, from both capital and energy expenditure, should be less than procuring the same amount of helium from traditional sources. Also, particular emphasis is placed on portability (i.e., not a fixed installation) and speed of separation (near-real-time) that accommodates a single system servicing numerous distinct sources of helium, air, and hydrogen mixtures developed over the range of rocket propulsion testing and ground and flight operations and the temporal transient nature of production of these mixtures.

Robust Component Technologies

Rocket propulsion test hardware as well as ground and flight launch operations hardware regularly experience large and rapid changes in pressures, temperatures, vibration, and fluid flow rates while demanding high precision control and reliability. Typical ranges in these parameters are pressures from vacuum all the way up to 10,000 psi, working fluids at ambient temperature all the way down to -420F, vibration environments in the 100's of G RMS acceleration. These parameters can span their entire range in milliseconds. State of the art propulsion system testing hardware has evolved over time as better materials and experience in hardware interactions with these environments have progressed. Innovation in component performance diagnostics technology is required to continue the current progression in hardware operational reliability, cost, and weight optimization. Accordingly, the goal of this subtopic thrust area is to develop innovative in situ hardware performance measurement and diagnostics technology along with the accompanying data acquisition and management systems required for utilization the new technologies.

Advanced Propulsion Test Data Management Capability

Substantial advances in data capture and storage technologies have exponentially increased real and near-real time data availability in rocket propulsion testing. Effective utilization of this increase in data availability requires

evolution of data management technologies, methods, and concepts that will enable greater and more effective real-time access, manipulation, and application in the control and quality of propulsion systems testing. Recent initiatives in development of hardware-in-the-loop technologies, merging measured and simulation data in real time feedback with propulsion test hardware have demonstrated the feasibility and utility of this technology. The goal of this subtopic thrust area is to develop innovative ways to take advantage of increased propulsion test data availability utilizing high performance hardware such as GPU based computer systems along with innovation in algorithms and software to implement new data management technologies, methods, and concepts.

In these subject areas, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward hardware and/or software development as appropriate, which occurs during Phase II and culminates in a proof-of-concept system.

Phase I Deliverables: A final report describing optimal design for the technology concept including feasibility, trade studies, detailed results of Phase I analysis, modeling, prototyping, and testing as applicable. The report should also contain a detailed path towards Phase II hardware and/or software proof-of-concept system. The technology concept at the end of Phase I should be at a TRL of 3-4.

Phase II Deliverables: A working proof-of-concept system successfully demonstrated in a relevant environment and delivered to NASA for testing and verification. The technology at the end of Phase II should be at a TRL of 6-7.

Sub Topics:

Remotely Operated Mobile Sensing Technologies for inside ISS Topic O3.01

This subtopic seeks proposals to develop technologies that advance capabilities for space telepresence and mission operations situation awareness, fault diagnosis, isolation, and recovery onboard the ISS using an onboard free-flyer as a mobile sensor platform. In order to increase productivity and reduce risks on long-missions on spacecraft, such as the ISS, leading toward human exploration, commercialization, and colonization of space, ground personnel have a need to remotely command a wide-variety of sensors on mobile platforms to collect data from a variety of positions within spacecraft. The sensors include, but are not limited to, those capable of performing imaging, identifying inventory, and measuring electromagnetic radiation, temperature, acoustics, atmospheric properties, and chemical concentrations. To increase crew productivity, it is highly desirable that the mobile platform be capable of being deployed by ground command, move to the commanded location, collect data, and then return to its storage dock where it is recharged all without requiring crew assistance.

This subtopic solicitation calls for developing a variety of software and hardware technologies that would enable a free-flyer to operate in multiple modules inside ISS including but not limited to:

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- Free-flyer localization capability without engineering environment.
 - Collision avoidance capability.
 - Adjustable autonomous control software that supports safe operation with low-bandwidth, intermittent command communication loop with varying latencies > 10 sec.
 - EXPRESS rack-based auto-docking, recharging, refueling, deployment mechanism with matching free-flyer mechanism.
 - Quiet propulsion capability meeting ISS noise limit requirements (
 - Vision-based object identification capability.
 - RFID-based inventory identification capability.

Proposals may address any one or a combination of the above or related subjects.

Three SPHERES satellites have operated inside ISS since 2006. In addition to performing dozens of experiments, these satellites demonstrate that mobile platforms in the form of free-flyers can be operated on ISS. However, these satellites have not been operated by ground personnel and their current design is inadequate to meet the needs described above for several reasons, e.g., the satellites require crew assistance to operate, require that batteries and CO₂ cartridges (propellant) be replaced by crew between test sessions, and are confined to a work area bounded by external beacons used by the satellites to localize themselves within their workspace, approximately 2x2x2 meters. However, the SPHERES satellites may be useful in demonstrating technologies called for by this subtopic. Proposals are encouraged that leverage the SPHERES satellites operating onboard ISS and SPHERES engineering units at the NASA Ames Research Center. More information on SPHERES is at:

- http://www.nasa.gov/mission_pages/station/research/experiments/SPHERES.html [17].
- <http://ssl.mit.edu/spheres> [18].

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:

- Midterm Technical Report.
- Final Phase I Technical Report with a feasibility study including: simulations and measurements demonstrating the approach used to develop and test the prototype, constraints on other systems, concept

of operations, verification matrix of measurements with pass/fail ranges for each quantity to be verified at the end of Phase II, and the Phase II integration path.

- Proof-of-concept simulation and/or bench top demonstration (TRL 3-4).

Phase II Deliverables:

- Midterm Technical Report.
- Final Phase II Technical Report with specifications including: design, development approach, tests to verify the prototype, verification matrix of measurements with pass/fail ranges for each quantity verified, constraints on other systems, and operations guide. Opportunities and plans for potential commercialization should also be included.
- Fully-functional engineering prototype of proposed product (TRL 5-6).

Sub Topics:

ISS Utilization Topic O3.02

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 now make it possible to measure the diffusion coefficient of experimental systems using the Light Microscopy Module (LMM) on the International Space Station (ISS). The light scattering instrument (laser, detector, optics) to be mounted on a Leica DM/RXA microscope camera port should be about the size of a 40mm diameter tube around 60mm long) with associated support electronics (including the correlator) being able to fit into a volume of about 30mm x 100mm x 100mm, or less. The intensity dynamic range should be able to cover between 10^{-10} to 10^{-7} Watts. The relaxation time range should be capable to spanning 200nsec to 50sec. This peer-reviewed science was considered a decade ago but not developed due to

technology limitations. It is now possible to meet the required performance criteria (with the above size and power requirements) to measure diffusion coefficients. From the measured diffusion coefficient, particle size can be extracted, or the temperature determined for the location being viewed (e.g., in a capillary cell with a temperature gradient along it) can be deduced (for known particles and solvents) using the Stokes-Einstein equation.

- Providing compact laser tweezers and supporting software. Development of a compact robust Holographic Laser Tweezers (LT) instrument and associated control scripts for use with a microscope on the International Space Station (ISS) based on the recent developments of holographic techniques. This could expand the types of experiments conducted on orbit. The laser tweezers that would mount on a Leica DM/RXA microscope should be less than ~100mm on a side and the associated control electronics should be less than ~150mm on a side. This technology should now be robust since it is solid-state and no longer requires gimbaled mirrors. 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 to better than one micron 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. Because of its use on space station, the instrument should be self-calibrating. 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 and material science 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; an atomic force microscope (for biological and material science samples), 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/research/experiments_category.html [9].

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 Demonstration & Development of Improved Exploration Technologies Topic O3.03

The focus of this subtopic is on technologies and techniques that may advance the state of the art of spacecraft systems by utilizing the International Space Station as a technology test bed.

Successful proposals will address using the long duration, microgravity and extreme vacuum environment available on the ISS to demonstrate component or system characteristics that extend beyond the current state of the art by:

- Increasing capability/operating time including overall operational availability.
- Reducing logistics and maintenance efforts.
- Reducing operational efforts, minimizing crew interaction with both systems and the ground.
- Reducing known spacecraft/spaceflight technical risks and needs.
- Providing information on the long-term space environment needed in the development of future spacecraft technologies through model development, simulations or ground testing verified by on orbit operational data.

While selection for award does not guarantee flight opportunities, the proposed demonstrations should focus on increasing the TRL in the following technology areas of interest:

- Propulsion (in-space and novel, electromagnetic and/or very high specific impulse systems).
- Power and energy storage.
- Robotics tele-robotics and autonomous (RTA) Systems.
- Human health, life support and habitation systems.
- Science instruments, observatories and sensor systems.
- Nanotechnology.
- Materials, structures, mechanical systems and manufacturing.
- Thermal management systems including novel heat radiation techniques.
- Spacecraft (including ISS) plasma and contamination in-situ diagnostics.

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- Environmental control systems, including improved carbon dioxide removal.

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: 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 Deliverables: 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.

Sub Topics:

Vehicle Integration and Ground Processing Topic O3.04

This subtopic seeks to create new and innovative technology solutions to 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. The following areas are of particular interest:

Control of Material Degradation

Technologies are needed to reduce costs due to material degradation of materials in spaceport and propulsion test facility infrastructure and ground support equipment, Material solutions must meet current and emerging environmental restrictions and endure today's corrosive and highly acidic launch environments. These needs include:

- New environmentally friendly technologies for paint removal and surface preparation that can be applied to large structures. New technologies must achieve better performance than conventional abrasive blasting techniques by reducing the cost of collecting and/or processing waste while keeping blasting rates the same or better than conventional technologies. These technologies must work for inorganic zinc coating.
- New environmentally friendly technologies for prevention/reduction of microbial corrosion in steel piping systems utilizing brackish or untreated water.
- Sub-scale or laboratory tests that can be used to evaluate the suitability of refractory concrete for use in launch pad and rocket test facilities flame deflectors. Proposed tests must show that they are relevant to full scale blast effects.
- Innovative refractory material application methods to ensure field applications have the same properties (strength, density, performance, etc...) as small scale test coupons.

Spaceport Processing Evaluation/Inspection Tools

Innovative solutions are desired that reduce inspection times, provide higher confidence in system reliability, increase safety and lower life cycle costs. Technologies must support identifying composite material defects, evaluating material integrity, damage inspection and/or acceptance testing of composite systems. These include:

- Technologies in support of defect detection in composite materials.
- Methods for determining structural integrity of composite materials and bonded assemblies.
- Non-intrusive inspection of Composite Overwrapped Pressure Vessels (COPV), Orion heat shield and other composite systems.
- In-situ evaluation of refractory concrete as installed in the flame trenches associated with propulsion test and launch pad infrastructure.

Hypergolic Propellant Sensing Technologies

Technologies for leak detection and leak visualization for hypergolic propellants, such as:

- Novel, cost effective technology solutions to provide leak detection of hypergolic propellants at concentrations of 10ppb with minimal environmental sensitivity (i.e., humidity). Sensors and leak detection systems should provide quantitative data with minimum interferences, drift, and exposure and recovery time.
- Novel, cost effective technology solutions to provide leak detection of hypergolic propellants at concentrations of 1ppm with minimal environmental sensitivity (i.e., humidity). Sensors and leak detection systems should provide quantitative data with minimum interferences, drift, and exposure and recovery time.
- Technology to provide leak visualization of hypergolic propellants to support operations (propellant loading, pressurization, leak check).

Cold Gas Storage and Servicing of Launch Vehicle Systems

Storing high-pressure pneumatic gases in a chilled state increases the on board density of gasses used for pressurization during flight. Traditional solutions embed these 3000 - 6000 psig metallic tanks into the flight vehicles' main cryogenic propellant tanks. To achieve the lightest weight tanks, final pressurization takes place after the tanks are immersed to maximize strength gained by the lower temperatures. Under these conditions, it takes several hours to achieve thermal equilibrium with the host tank and maximize mass density of the compressed gas. Solutions are sought to reduce this time to less than 60 minutes to achieve thermal equilibrium of the compressed gas with the host liquid cryogen tank and maximize pneumatic gas mass on board the flight vehicle.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware or software demonstration and delivering a demonstration unit or 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)

Sub Topics:

Advanced Motion Imaging Topic O3.05

Digital motion imaging technologies provide great improvements over analog systems, but also present significant challenges. Digital High Definition Television (HDTV) cameras flown on the Shuttle and International Space Station have shown higher susceptibility to ionizing radiation damage, manifested by visible "dead" pixels in the image. In order to practically deploy HDTV cameras, sensors and processors 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 without performance degradation from ionizing radiation that would require frequent upmass to orbit to replace components or systems.

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.

Domains of Interest

Domains of interest in the near term address needs for space environment, radiation tolerant, HDTV and digital cinema cameras and down-stream video processors. Mid and Long term goals include radiation tolerant, reprogrammable, highly bandwidth efficient encoders and improved distribution systems for video data signals. Current HDTV transmissions from the ISS require approximately 25 Mbps. Bitrates with equal or better video quality are desired at half that bit rate. These systems are highly desired by the human spaceflight programs.

Technologies of Interest

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 designs and development plans with plausible data and rationale that demonstrates why the designs and plans should mitigate radiation effects on the sensors, and a detailed path towards Phase II hardware demonstration. The report shall also provide options for commercialization opportunities after Phase II.

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 defined expected lifespan of the sensors.

Sub Topics:

Environmental Control Systems & Technologies for NR & Cubesats Topic O3.06

A significant challenge faced by free-flying spacecraft and shared by ISS-bound experiment packages is the requirement for a controlled (or at least known) environment while the payload is awaiting launch on the launch vehicle or is in transit to the ISS. Due to the retirement of the Space Shuttle, NASA has a need for flight qualified, environmentally conditioned transportation systems compatible with new space launch systems capable of sustaining and extending the life of perishable materials and specimens until experiment packages can be installed and properly interfaced on-board ISS. This solicitation seeks to develop innovative environmental control technologies for the ground and space transportation of nanorack cubes and cubesats.

Cubesat integration timelines frequently call for passively mating to the launch vehicle or deployer system many weeks in advance of launch. The environment that the payload experiences plays a major role on the shelf life of certain materials and specimens within the spacecraft. Technologies capable of monitoring and extending the shelf life of perishable payloads are of interest to NASA as the environment in and around the launch vehicle is not always controlled in a manner favorable to a payload. Technologies can be either integrated directly into the Cubesat or external to the Cubesat.

Two applications for these technologies are sought:

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- ISS Nanorack Transportation System.
 - This system will have the ability to maintain temperatures within relevant ranges for biological and/or perishable Nanorack payloads from time of experiment preparation at the payload processing facility until installation into the host facility on ISS. This also includes ground transportation phases of the mission.
 - The Transportation System will also provide a time history of relevant parameters ie temperature, relative humidity, vibration, etc, during the transportation periods up to payload installation on ISS.

 - Cubesat applications.
 - Cubesat applications involve technologies that may be incorporated into the Cubesat spacecraft itself, or systems that can be used as adjuncts to monitor and control the environment in and around the Cubesat payload/spacecraft. These technologies can be passive and/or active in nature.
 - Cubesat applications will also provide a time history of relevant parameters ie temperature, relative humidity, etc during the dwell time on the pad while awaiting launch.

Innovative approaches to this problem will significantly increase the utility of Nanoracks modules and/or Cubesat spacecraft in that this technology will enable an expanded set of experiment types and mission scenarios. Such a capability may also be extended in support of ground control experiments where on-orbit environments must be duplicated in the lab.

Nanorack information can be found here: <http://nanoracks.com> [19].

Cubesat information can be found here: <http://cubesat.org/> [20].

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:

- Midterm Technical Report.
- Final Phase I Technical Report with a feasibility study including: simulations and measurements demonstrating the approach used to develop and test the prototype, constraints on other systems, concept of operations, verification matrix of measurements with pass/fail ranges for each quantity to be verified at the end of Phase II, and the Phase II integration path.
- Proof-of-concept simulation and/or bench top demonstration (TRL 3-4).

Phase II Deliverables:

- Midterm Technical Report.
- Final Phase II Technical Report with specifications including: design, development approach, tests to verify the prototype, verification matrix of measurements with pass/fail ranges for each quantity verified, constraints on other systems, and operations guide. Opportunities and plans for potential commercialization should also be included.
- Fully-functional engineering prototype of proposed product (TRL 5-6).

Sub Topics:

Metric Tracking of Launch Vehicles Topic O4.01

The goal of this subtopic is to have a highly reliable way of tracking vehicles from launch to orbit. Launch vehicles can exhibit high dynamics during flight and there can be external interference on the GPS frequency. Proposals can either address a single area as described below or a combination of multiple areas. The following technology areas are of interest:

Position, Attitude, and Inertial Metrics

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 high 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.
- Robust tracking during separation.

Use of GPS and Ability to Mitigate Interference Signals

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 that degrade the GPS signals can be obtained by differencing the available carrier phase and pseudo range measurements and then removing these differences from the navigation solution.

Technologies are sought that combine spatial processing of signals from multiple antennas with temporal processing techniques to mitigate 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).

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.
- 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 model of proposed product, along with full report of development and measurements, including populated verification matrix from phase II (TRL 5).
- Final Phase II Technical Report.
- Demonstration hardware/software/field test.
- Opportunities and plans should also be identified and summarized for potential commercialization.

Sub Topics:

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

This subtopic 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:
 - NASA Copyright, licensable technology.
 - (http://ipp.gsfc.nasa.gov/ft_tech_geons.shtm [23]).
 - AutoNav (NTR 43546 Deep Impact Autonomous Navigation (AutoNav) Flight Software 23-FEB-2006).

- Navigator:
 - US Patent 7,548,199.
 - <http://patft1.uspto.gov/netacgi/nph-Parser?patentnumber=7548199> [24].
 - http://techtransfer.gsfc.nasa.gov/ft_tech_gps_navigator.shtm [25].

- GIPSY:
 - <https://gipsy-oasis.jpl.nasa.gov/> [26].

- Electra:
 - http://descanso.jpl.nasa.gov/Monograph/series9_chapter.cfm [27].

- Blackjack:
 - <http://www.jpl.nasa.gov/releases/2000/blackjackgps.html> [28].

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. We seek to maximize the work listed above in the new work sought for this subtopic.

General Operational Needs, Requirements and Performance Metrics:

Onboard Near-Earth Navigation Systems

NASA seeks proposals that would develop a commercially viable transceiver with embedded orbit determination software to provide enhanced accuracy and integrity for autonomous onboard GPS- and TDRSS-based navigation and time-transfer in near-Earth space via augmentation messages broadcast by the proposed TDRSS Augmentation for Satellites Signal (TASS; <http://www.gdgps.net/system-desc/papers/Bar-Sever.pdf> [29]). Innovations that will increase the integration, reducing the size, weight, and power of such transceiver platforms, and improving their performance in high radiation environments, are sought. 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 AutoNav navigation software packages already support the capability to ingest many one way forward Doppler, optical sensor observation, and accelerometer data types. In addition, NASA is seeking innovative solutions in the area of planetary surface navigation.

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 Planetary Relay Satellites

NASA seeks planetary 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 bases on other planetary surfaces 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 Technologies and Software 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:

- GPS-Enhanced Onboard Navigation Software: http://techtransfer.gsfc.nasa.gov/ft_tech_gps_navigator.shtm [25].
- General Mission Analysis Tool: <http://sourceforge.net/projects/gmat/> [30].
- GPS-Inferred Positioning System and Orbit Analysis Simulation Software: <http://gipsy.jpl.nasa.gov/orms/goa/> [31].
- Optimal Trajectories by Implicit Simulation: <http://otis.grc.nasa.gov/> [32].

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 re-duce 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 (be-yond 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 ac-curacy.
- 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:
