NASA SBIR 2016 Phase I Solicitation

H2 Space Transportation

Achieving space flight remains a challenging enterprise. It is an undertaking of great complexity, requiring numerous technological advances conducted by a wide range of engineering disciplines with a high level of organizational skill. Human Exploration requires advances in space transportation systems, operations, and testing, for transport to the earth orbit, the moon, Mars, and beyond. NASA is interested in making space transportation systems more capable and less expensive. NASA is interested in technologies for advanced in-space propulsion systems to support exploration that reduce travel time, reduce acquisition costs, and reduce operational costs. The goal is a breakthrough in cost and reliability for a wide range of payload sizes and types supporting future orbital and exploration flight vehicles. 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, 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 in–space propulsion technologies that dramatically alter acquisition, reusability, reliability, and operability of space transportation systems.

Subtopics

H2.01 LOX/Methane In-Space Propulsion

Lead Center: GRC

Participating Center(s): JSC, MSFC

NASA is developing high thrust in-space chemical propulsion capabilities to enable human and robotic missions into the proving ground (Mars and beyond). Successful proposals are sought for focused investments on key technologies and design concepts that may transform the path for future exploration of Mars, while providing component and system-level cost and mass savings. In-space propulsion is defined as the development and demonstration of technologies for ascent, orbit transfer, pulsing attitude/reaction control (RCS), and descent engines.

The goal of this subtopic is to examine novel technology options that include the use of additive manufacturing or other low cost processes which save mass and/or cost compared to current state-of-the-art (SOA) technologies and fabrication methods. Technologies of interest for operation with liquid oxygen and methane specifically are sought.

Proposers shall show how their technology works and provide the following:

- Assessment of SOA with the key performance parameters (KPP) of their choosing (such as performance,

mass, response time, etc.), including specifics which may be referenced in backup material - provide SOA for each major technology element in the proposal.
- Address the outstanding technology performance being promised and the degree to which the concept is new, different, and important. Particularly how the technology and/or fabrication technique proposed saves cost and/or mass is desired.
- Provide quantitative assertions (e.g., x% improvement of y, z kg of mass savings, xx% in cost savings, etc.) to the advancement over the SOA.

Phase I Deliverables - Research to identify and evaluate candidate technology applications to demonstrate the technical feasibility and show a path towards a demonstration. Bench or lab-level demonstrations are desirable. The technology concept at the end of Phase I should be at a TRL of 4 to 5.

Phase II Deliverables - Emphasis should be placed on developing and demonstrating the technology under simulated mission conditions. The proposal shall outline a path showing how the technology could be developed into mission-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a TRL of 5 to 6.

For reference, current anticipated performance goals for liquid oxygen/liquid methane systems are:

- Reaction control thruster development in the 100-800 lbf thrust class. The reaction control engines would operate cryogenic liquid-liquid for applications requiring integration with main engine propellants; or would operate gas-gas or gas-liquid for small total impulse type applications. RCEs operating on liquid cryogenic propellant(s) should be able to tolerate operation for limited duty cycles with gaseous or saturated propellants of varying quality. Integrated RCS (IRCS) capability desired (common propellant tanks for RCS and main engines).
- Descent pump-fed engine development with 50,000 lbf thrust and a minimum vacuum specific impulse of 360-sec. The propulsion system should be capable of stable throttling to 5:1 (20% power). Space survival time of greater than 3 years.
- Ascent pump-fed engine development with 25,000 lbf thrust and a minimum vacuum specific impulse of 360-sec. The propulsion system should be capable of stable throttling to 5:1 (20% power). Space survival time of greater than 4 years.
- Integrated Propulsion and Feed System technologies, such as for integrated reaction control systems (RCS). This would include thermal conditioning features, self-pressurization/re-pressurization control, and system isolation control.

For reference, some specific propulsion technologies of interest are included below. In all cases – interest in using additive manufacturing or novel fabrication methods to save cost and mass are desired to achieve the specific component objectives identified below:

- Injector concepts with throttle range greater than 4:1 while maintaining stable combustion over the range of operation and inlet conditions and meeting performance goals at full throttle condition.
- Regenerative cooled combustion chamber technologies which offer improved performance, especially at sub-critical or trans-critical conditions, and provide adequate chamber life. This includes methods for addressing differential boiling within regenerative channels and/or start up transients (gas/gas, to two-phase, to high-quality liquid/liquid) for both fuel and oxidizer circuits.
- Turbopump technologies specific to liquid methane that are lightweight with a long shelf life that can meet deep-throttle requirements, including small durable high speed turbines, high speed lightweight electric direct current (DC) motor driven pumps, high fatigue life impellers, zero net positive suction head (NPSH) inducers, low leakage seals, and long life in-situ propellant fed bearings.
- Engine valves with a focus on light-weight (at the system level, considering supporting pneumatics, batteries, etc.), fast-acting, low-leakage throttle valves, which meet the following performance considerations: Maintain consistent mixture ratio (MR) over the throttle range, 50% (minimum) force margin, cold and warm operations, easily chilled in, with leakage in the 10^{-4} to 10^{-6} standard cubic centimeters per second (SCCS) range (gaseous phase oxygen and methane).

H2.02 Nuclear Thermal Propulsion (NTP)

Lead Center: MSFC

Participating Center(s): GRC, SSC

Solid core NTP has been identified as an advanced propulsion concept which could provide the fastest trip times with fewer SLS launches than other propulsion concepts for human missions to Mars over a variety of mission years. The current NASA Strategic Space Technology Investment Plan states NTP is a high priority technology needed for future human exploration of Mars. NTP had major technical work done between 1955-1973 as part of the Rover and Nuclear Engine for Rocket Vehicle Application (NERVA) programs. A few other NTP programs followed including the Space Nuclear Thermal Propulsion (SNTP) program in the early 1990's. The NTP concept is similar to a liquid chemical propulsion system, except instead of combustion in the thrust chamber, a monopropellant is heated with a fission reactor (heat exchanger) in the thrust chamber. In addition, the engine components and surrounding structures are exposed to a radiation environment formed by the reactor during operation.

This solicitation will examine a range of modern technologies associated with NTP using solid core nuclear fission reactors and technologies needed to ground test the engine system and components. The engines are pump fed ~15,000-35,000 lbf with a specific impulse goal of 900 seconds (using hydrogen), and are used individually or in clusters for the spacecraft's primary propulsion system. The NTP can have multiple start-ups (>4) with cumulative run time >100 minutes in a single mission, which can last a few years. The Rover/NERVA program ground tested a variety of engine sizes, for a variety of burn durations and start-ups with the engine exhaust released to the open air. Current regulations require exhaust filtering of any radioactive noble gases and particulates. The NTP primary test requirements can have multiple start-ups (>8) with the longest single burn time ~50 minutes.

Specific technologies of interest to meet the proposed requirements include:

- Reactor fuel element designs with high temperature (> 2600K), high power density (>5 MW/L) to maximize hydrogen propellant heating. New additive manufacturing processes to quickly manufacture the fuel with uniform channel coatings and/or claddings to reduce fission product gas release and particulates into the engine's exhaust stream.
    - Composite or carbide designs with low burn-up coating technology.
    - Ceramic-metallic (cermet) based nuclear fuels need improved methods to apply W coatings on small UO_2 spheres and the best way to bond $W\text{-}UO_2$ wafers with integral claddings.
- Concepts to cool down the reactor decay heat after shutdown to minimize the amount of open cycle propellant used in each engine shutdown. Depending on the engine run time for a single burn, cool down time can take many hours.

- Low risk reactor design features which allow more flexible criticality control during burns beyond the reactor circumferential rotating control drums, and/or provide nuclear safety for ground processing, launch, and possible launch aborts.
    - Control of criticality with water submersion and compaction accidents.
    - Concept for quick restart of reactor (2-6 hours) after 30-40 minute burns and accounting for Xe135 buildup.
- Ground test engine effluent processing technologies for efficient containment and/or filtering of radioactive particles and noble gases, and management of high temperature, high flow hydrogen exhausts (16-39 lbs/sec). In particular, to produce large quantities of hot hydrogen, and develop robust materials, advanced instruments and monitoring systems capable of operating in extreme temperature and radiation environments.
    - Advanced materials to resist high-temperature (<4400° F), hydrogen embrittlement and radiation environment.
    - Efficient non-nuclear generation of high temperature (<5000° F), high flow rate hydrogen (<39 lb/sec).
    - Effluent processing technologies for efficient filtering and management of high temperature, high flow hydrogen exhausts. Specific interests include:
        - Filtering of radioactive particles and debris from exhaust stream having an efficiency rating greater than 99.9%.

        - Removal of radioactive halogens, noble gases and vapor phase contaminants from a high flow exhaust stream with an efficiency rating greater than 99.5%
    - Applicable Integrated System Health Monitoring and autonomous test operations control systems that provide diagnostic capability to detect reactor fuel degradation in the engine exhaust.
    - Technologies providing an affordable low power (<20 MW) nuclear furnace to ground test a variety of fuel elements at conditions replicating a full scale NTP engine.

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 (TRL 2-3). 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 component and/or breadboard validation measurements, including populated verification matrix from Phase I (TRL 4-5). Opportunities and plans should also be identified and summarized for potential commercialization.

H2.03 High Power Electric Propulsion

Lead Center: GRC

Participating Center(s): JPL, MSFC

The goal of this subtopic is to develop innovative, high-power (>100-kW) electric propulsion systems. High-power solar or nuclear electric propulsion may enable dramatic mass and cost savings for lunar and Mars cargo missions, including Earth escape and near-Earth space maneuvers, at power levels that enable a wide range of exploration missions. Innovations and advancements leading to improvements in the end-to-end performance of high power electric propulsion systems are of interest. Methods are sought to increase overall system efficiency; improve system and/or component life or durability; reduce system and/or component mass, complexity, and development issues; or provide other definable benefits. In general, thruster systems providing total impulse values greater than 10^7 N-sec are desired. Specific impulse values of interest range from a minimum of 1500-sec for Earth-orbit transfers to over 6000-sec for planetary missions.

Advanced high-power concepts that provide quantifiable benefits over state-of-the-art electric propulsion systems are to be developed. Key figures of merit include: thrust density (to decrease thruster footprint), thruster efficiency (>60%), lifetime (>10’s khrs), reliability, and scalability. A practical and affordable method of performing relevant ground testing should be discussed, taking into account the pumping capabilities of state-of-the-art vacuum facilities. The proposed propulsion system should be mindful of the development of an efficient, low specific mass power processing unit, with an emphasis on reducing complexity and cost. Specific technologies of interest include but are not limited to:

- Nesting/clustering moderately powered thrusters to reach a desired total throughput: This component development can include: an assessment of system performance and plasma plume interactions, a thermal characterization of the system, and an assessment of the system lifetime during multi-thruster operation. The impact of multi-thruster operation on the power processing unit and feed system performance should also be addressed.
- High-current electromagnetic accelerators that directly addresses thruster efficiency and lifetime. This component development can include an investigation of electrode geometries, thermal management designs, and material selection to mitigate electrode erosion, the major lifetime limiter. Innovative, high efficiency power processor architectures/convertors for high-amperage thrusters that can be evolved into space flight hardware and survive thermal and radiation environments are desired.
- Scalable, high-perveance gridded ion engines with thrust densities that significantly exceed the current state-of-the-art (~3 N/m^2 for the NEXT ion engine). This component development can include the development of novel designs of the discharge chamber and ion optics for maximizing anode current and beam extraction capability, respectively.

- Long-life hollow cathode technologies for use with high-power electrostatic engines. The cathodes should be tested in a relevant environment (e.g., comparable magnetic field environment) and provide sufficient current densities for high-power thruster operation.
- Components for inductively pulsed plasma thrusters, in particular highly accurate flow controllers and fast acting valves; and solid state switches capable of high current (MA), high repetition rate (up to 1-kHz), long life (? 109 pulses) operation. High-voltage converters for pulsed power applications with a high-efficiency, low-complexity architecture that can be evolved into space flight hardware and survive thermal and radiation environments are desired.
- Advanced manufacturing methods for the fabrication of high power thruster components and associated systems; of particular interest is additive manufacturing for complex geometries, which may include: ceramic insulators, ion optics, and magnetic poles. Figures of merit include lower cost, rapid turnaround, and material and structural integrity comparable to or better than components or systems produced using current fabrication methods.

Proposals addressing advanced technology concepts should include a realistic and well-defined roadmap defining critical technology development milestones leading to an eventual flight system. Sub-scale, proof-of-concept experiments are highly desired for the Phase I effort. In addressing technology requirements, proposers should identify candidate thruster systems and potential mission applications that would benefit from the proposed technology.

H2.04 Cryogenic Fluid Management for In-Space Transportation

Lead Center: GRC

Participating Center(s): JSC, MSFC

This subtopic solicits technologies related to cryogenic propellant (such as hydrogen, oxygen, and methane) storage, and transfer to support NASA's exploration goals. This includes a wide range of applications, scales, and environments consistent with future NASA missions. Such missions include but are not limited to the Exploration Upper Stage (EUS), In-situ Resource Utilization in cooperation with Mars Landers, and the evolvable Mars Campaign.

Specifically, listed in order of importance:

- High Power/High Efficiency cryocoolers and cryocooler components (specifically compressors, turbines/expanders, or recuperative heat exchangers) for systems designed to reject >150 W at 90 K with a specific power of less than 15 W (input power)/W (heat rejection) and specific mass of less than 12 kg/W (of heat rejection) at the design point. The cryocooler components should be suitable for space flight.
- Novel structural solutions that can be partially disconnected post launch which the upper stage has successfully reached orbit. Full scale structural solutions (5 – 10 m diameter tanks) should be able to support > 20 mT at up to 5 g’s sustained compressive loads and have no structural modes below 50 Hz. Post disconnection, the supports should still be able to support 20 mT, but at 0.2 g’s sustained compressive loads. Solutions (which do not have to be full scale at this point) should also attempt to minimize the residual heat load to the propellant tank after disconnection.
- Liquid acquisition devices (or propellant management devices) capable of preventing gas ingestion into engine feedlines in low gravity. The liquid acquisition devices should maintain bubble-free flows of 37 liters per minute while having an expulsion efficiency of 97%.
- Lightweight fluid coupling for low (< 50 psi, Cv > 5) pressure cryogenic liquids with low internal (~ 1 sccm) and external (~ 3 sccm) leakage on both halves. Coupling should be designed either for ease of use by Astronauts (i.e., bulky gloves and minimal force) or easy automation.