Z8.09  Small Spacecraft Transfer Stage Development

Scope Title:

Small Spacecraft Transfer Stage Development

Scope Description:

NASA and industry represent prospective customers for sending small-spacecraft payloads in the near term to the cislunar environment, with longer term potential for farther destinations such as near-Earth objects, Mars, or Venus. The lunar destinations in this case include the lunar surface, with specific interest in the South Pole, low lunar and frozen lunar orbits, and cislunar space, including Earth-Moon Lagrange points (e.g., E-M L3) and the lunar Near Rectilinear Halo Orbit (NRHO) intended for Gateway. In future missions, NASA may transport small spacecraft to Venus for scientific discovery, to Mars to serve as precursors and infrastructure for human (and scientific) exploration, and on small-spacecraft missions to near-Earth objects for science measurements needed to understand prospective threats to Earth, and perhaps even for resource extraction and return to Earth. The ultimate goal is to exploit the advantages of low-cost and rapidly produced CubeSats and small spacecraft, defined as total mass less than 180 kg fueled, by enabling them to reach these locations. Due to the current limits of SmallSat propulsion capabilities and the constraints of rideshare opportunities, NASA has an interest in the development of a low-cost transfer stage to guide and propel small spacecraft on trajectories to the vicinity of the Moon, then enable their insertion into the above-referenced orbits with the transfer stage or within sufficient proximity to achieve and maintain final orbit under their own power. These same capabilities and others will later need to be extended for small spacecraft to explore nearby planets.

Transfer stage architectures and designs shall be compatible with U.S. small launch vehicles that are currently flying or will be launching imminently. Proposals shall identify one or more relevant small launch vehicles, describe how their designs fit within the constraints of those vehicles, and define the transfer capability of the proposed system (i.e., from low Earth orbit (LEO), geosynchronous transfer orbit (GTO), etc., to low lunar orbit (LLO), NHRO, E-M L3, etc.). Transfer stage designs shall contain all requisite systems for navigation, propulsion, and communication in order to complete the mission. Any and all propulsion chemistries and methods may be considered, including electric propulsion, as long as the design closes within the reference mission constraints. Transfer stages shall also include method(s) to deploy one or more SmallSat payloads into the target trajectory or orbit. Innovations such as novel dual-mode systems that enable new science missions or offer improvements to the efficiency, accuracy, and safety of lunar missions are of interest. Concepts that can demonstrate improvements in cost and reliability and those that reduce requirements (thermal, power, etc.) on the payload are also highly desired.
This subtopic is targeting transfer stages for launch vehicles that have a capability range similar to that sought by the NASA Venture Class Launch Services. Rideshare applications that involve medium- or heavy-lift launch vehicles (e.g., Falcon 9, Atlas V) or deployment via the International Space Station (ISS) airlock are not part of this topic.

Lunar design reference mission:

- Launch on a small launch vehicle (ground or air launch).
- Payload (deployable spacecraft) mass: at least 25 kg.
- Provide sufficient delta V and guidance to enter into Trans Lunar Injection (TLI) orbit after separation from small launch vehicle. An example mission is the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE)/NRHO Pathfinder 12U (25 kg) CubeSat that requires a TLI orbit with a C3 of -0.6 km²/s².
- (Alternative) Provide sufficient delta V and guidance to place a 25- to 50-kg spacecraft directly into lunar NHRO or E-M L3 orbit.
- Deploy spacecraft from transfer stage.
- Safe and disposal of transfer stage.

A stretch goal is extensibility of the design for planetary design reference missions: Similar to the above, for Venus, Mars, or near-Earth object destinations.

Expected TRL or TRL Range at completion of the Project: 4 to 6
Primary Technology Taxonomy:
Level 1: TX 01 Propulsion Systems
Level 2: TX 01.1 Chemical Space Propulsion
Desired Deliverables of Phase I and Phase II:

- Prototype
- Hardware
- Software
- Analysis

Desired Deliverables Description:

A Phase I effort should provide evidence in the feasibility of key elements of cost, assembly, integration, and operations through fabrication or testing demonstrations. A prototype system should reach a "near CDR" level during Phase I with a mapping of key performance parameters (mass, power, cost, etc.) from the prototype to the flight design, along with potential opportunities for technology demonstration and commercialization.

It is highly desired that the Phase II deliverable include demonstration test of the prototype system along with detailed metrics (mass, power, cost, etc.) traceable to a flight design for the reference mission. Efforts leading to Phase II delivery of integrated prototype systems that could either be ground- or flight-tested as part of a post-Phase II effort are of particular interest.

State of the Art and Critical Gaps:

Many CubeSat/SmallSat propulsion units are designed for low delta-V maneuvers such as orbit maintenance, stationkeeping, or reaction control. Larger delta-V systems are employed for larger satellites and science/exploration missions, but are often costly and integrated as part of the satellite design. Systems typically range from cold-gas to bipropellant storables with electric systems also viable for very small systems. Rocket Lab has recently introduced an upgraded version of their monopropellant kick stage, which includes a bipropellant engine, advanced attitude control, and power subsystems. This system will be used for the first time for NASA's
CAPSTONE mission and is suggested to have capability for orbits beyond the lunar environment. At the component level, Aerojet Rocketdyne and Moog, Inc. are prominent suppliers of state-of-the-art (SOA) thrusters, including commonly used variants of the R-4D engine, while companies like Blue Canyon Technologies offer spacecraft bus solutions absent dedicated propulsion elements. Advanced manufacturing, electric pumps and actuators, nontoxic propellants, and electrospray thrusters all offer potential improvements in the flight capabilities of small propulsion systems. System concepts that enable improved spacecraft performance and control, such as dual-mode systems, provide potential advancements to the current SOA, especially those that enable new science missions and those that offer potential improvements to the efficiency, accuracy, and safety of future lunar manned missions. While many of these component technologies are reasonably mature, no integrated system capability has been developed and implemented specifically as a rapid, low-cost solution for translunar or cislunar mission designs.

Relevance / Science Traceability:

This subtopic extends the capabilities of the Flight Opportunities Program and Launch Services Program by seeding potential providers to establish lunar/cislunar transfer capabilities. The Small Spacecraft Technology Program (SSTP) also seeks demonstrations of technical developments and capabilities of small spacecraft to serve as precursor missions (such as landing site investigation or in situ resource utilization (ISRU) prospecting) for human exploration, and as communications and navigation infrastructure for follow-on cislunar missions. SSTP CAPSTONE is an example mission.

Many technologies appropriate for this topic area are also relevant to NASA’s lunar exploration goals. Small stages developed in this topic area would also be potential flight testbeds for cryogenic management systems, wireless avionics, or advance guidance systems and sensors. Sound rocket capabilities are being improved with options financed through this topic.

Small launch vehicles provide direct access for a small spacecraft to the destination or orbit of interest at a time of the small spacecraft mission’s choosing. In support of exploration, science, and technology demonstration missions, further expansion of these vehicle’s reach beyond LEO is needed. To expand the risk-tolerant small spacecraft approach to deep space missions, frequent and low-cost access to destinations of interest beyond Earth is required.

In the longer term, technical capabilities of small spacecraft at Venus, Mars, or NEO destinations will be demonstrated by SSTP, and ultimately new kinds of transfer vehicles derived from these capabilities may be needed to propel them there.

References:

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