Z8.09  Small Spacecraft Transfer Stage Development

Lead Center: MSFC

Participating Center(s): AFRC, GRC, JSC

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-circular 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 and enable their insertion into the above-referenced orbits. In addition, NASA has interest in the transfer stage being able to provide support services to the spacecraft post-deployment, such as communications relay or positioning, navigation, and timing (PNT) services. Advancement and extension of these capabilities will be needed for future planetary exploration.

Transfer stage 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), NRHO, E-M L3, etc.). Establishment of a partnership or cooperative agreement with a launch vehicle provider is strongly encouraged. Transfer stage designs shall contain all requisite systems for navigation, propulsion, and communication to complete the mission. Novel 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 propulsion systems that enable new science missions or offer improvements to the efficiency, accuracy, and safety of lunar missions are of interest. Concepts that enable small cargo delivery and inspections to support on-orbit servicing, assembly, and manufacturing platforms are also desired. Additionally, technologies with dual-use potential (such as hypersonic or suborbital demonstrations) are applicable to this subtopic. The ability of the transfer stage to provide support services, such as Communications Relay or PNT, after spacecraft deployment...
is highly desirable.

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, which requires a TLI orbit with a $C_3$ (characteristic energy) of -0.6 km$^2$/s$^2$.
- (Alternative) Provide sufficient delta-v and guidance to place a 25- to 50-kg spacecraft directly into lunar NRHO or E-M L3 orbit.
- Deploy spacecraft from transfer stage.
- Perform transfer stage safing and disposal operations.

Stretch goals are:

1. Extensibility of the design for planetary design reference missions: Similar to the above, for Venus, Mars, or near-Earth object destinations.
2. Ability to provide postdeployment spacecraft support services such as Communications Relay and/or PNT. Proposer to outline the performance and duration these support services can achieve for applicable orbital environments.
3. Enable small-cargo delivery and inspections to support on-orbit servicing, assembly, and manufacturing platforms.

**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 of the feasibility of key elements of cost, assembly, integration, and
operations through fabrication and testing demonstrations. A flight concept should reach sufficient maturity to be able to clearly define mission environments and performance requirements. A prototype system design should reach sufficient maturity to define test objectives and map key performance parameters (mass, power, cost, etc.) from the prototype to the flight design. Hardware development during the Phase I effort should provide confidence in the design maturity and execution of the Phase II effort. Lastly, the Phase I effort should identify potential opportunities for mission infusion and initiate partnerships or cooperative agreements necessary for mission execution.

The Phase II deliverable should provide significant evidence of the progress toward mission infusion (PMI) as outlined in the 2020 NASA Small Spacecraft Technology: State of the Art report. Phase II objectives should meet the intent of the In-Development or Engineering-to-Flight classifications, including demonstrations in a relevant environment or execution of a qualification program. Efforts leading to Phase II delivery of an integrated system 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, station-keeping, 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 Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) mission and is suggested to have capability for orbits beyond the lunar environment. At the component level, suppliers of state-of-the-art (SOA) thrusters include Aerojet Rocketdyne, Moog Inc, and Bradford Space, among others, while companies like Blue Canyon Technologies offer spacecraft bus solutions absent dedicated propulsion elements. Advanced manufacturing, electric pumps, and actuators, nontoxic or nontraditional propellants, and electrospay 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, progress has been limited in the development and qualification of an integrated system as a rapid, low-cost solution for translunar or cislunar missions.

Deployment of small spacecraft beyond geosynchronous orbits typically exacerbates their limitations with respect to communications and navigation, by virtue of longer communication distances and limited ability to use Global Navigation Satellite System (GNSS) PNT services. This typically requires the spacecraft to throttle their communications and rely on more cumbersome ranging transponders with Earth for position knowledge, adversely affecting spacecraft designs and operations. Equipping transfer stages with such support services potentially allows for a less constraining environment for small spacecraft deployed in deep space. With respect to the current SOA, the Air Force Research Laboratory's EAGLE mission (Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) Augmented Geostationary Laboratory Experiment), launched into a near geosynchronous orbit, is an example of a host vehicle able to deploy smaller spacecraft as well as providing support services to hosted payload only.

Relevance / Science Traceability:

This subtopic extends the capabilities of the Flight Opportunities program and the Launch Services Program by seeding potential providers to establish lunar/cislunar transfer capabilities. The Small Spacecraft Technology (SST) program 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. SST 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 vehicles’ 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. Provision of support services by the transfer stage to the spacecraft post-deployment could enable more ambitious small-spacecraft missions.

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

References:

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3. What is Lunar Flashlight? | NASA
4. What is CAPSTONE? | NASA
5. Satellite Solutions | Rocket Lab (rocketlabusa.com)
7. Green Propulsion | Aerojet Rocketdyne
10. Building an Economical and Sustainable Lunar Infrastructure to Enable Lunar Science and Space Commerce: [https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170012214.pdf](https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170012214.pdf)