NASA SBIR 2022 Phase I Solicitation

Z8.13 Space Debris Prevention for Small Spacecraft

Lead Center: MSFC

Participating Center(s): ARC

Scope Title
Onboard Devices for Deorbit and/or Disposal of Single Spacecraft

Scope Description
The rise in individual small spacecraft launches alongside increased deployment of small spacecraft swarms is greatly contributing to congestion in Low Earth Orbit (LEO). Between 2012 and 2019, the number of small spacecraft launches increased 5x to ~500 put into orbit in 2019. To date, this number continues to grow, with some companies planning/implementing swarms of several thousand, even tens of thousands, of small spacecraft. In recognition of the threat posed by space debris to Earth’s orbital environment and the greater space industry, orbital debris prevention has been incorporated in every U.S. National Space Policy since 1988, with the latest Space Policy (2020) providing the strongest language yet, outlining that “the United States shall … Limit the creation of new debris, consistent with mission requirements and cost effectiveness, during the procurement and operation of spacecraft, launch services, and conduct of tests and experiments in space” [Refs. 1, 2, 3]. Concern has grown as “the number of objects orbiting the Earth [has] grown substantially in recent years with well over 90% being dead objects (inoperative satellites, spent upper stages, and fragmentation debris)” [Ref. 4], and a number of studies from NASA and other national and international agencies and organizations have shown dire outcomes and possible “runaway debris situations” for “business-as-usual” scenarios in debris population growth predictions for the future [Ref. 5], as well as significant strain on the current space traffic management architectures to prevent such scenarios [Ref. 6]. Now there is significant concern that the situation will get worse with the ubiquitous emergence of small satellite (SmallSat) technologies and the planned deployment of swarms and constellations of thousands of satellites in LEO—many of which qualify as “SmallSats”—by multiple commercial companies, such as SpaceX, OneWeb, Theia, Boeing, Amazon Kuiper, Inmarsat, etc. Per Reference 4, “if all of these plans materialize, the population of operational satellites in LEO would jump by over a factor of ten—from ~1,000 today to over 16,000 within the next 10 to 20 years” and “has the potential to affect the space environment for generations and push any space traffic management system beyond its limits.” As a result, all spacecraft LEO operators could be faced with disruptive numbers of conjunction alerts and collisions between spacecraft and/or orbital debris, further exacerbating the situation.

While the challenges posed by space debris and the management of large constellations within that environment is a multidimensional problem with multifaceted solutions, this subtopic scope focuses on technical solutions for the deorbit and/or disposal aspects that relate to the safe end-of-life operations of SmallSat swarms and constellations. The lifetime requirement for any spacecraft in LEO is 25 years post-mission, or 30 years after launch if unable to be stored in a graveyard orbit [Ref. 7]. With increased use of higher orbital regimes by small spacecraft and regulatory attention on long-term debris concerns, it is critical that the small spacecraft community responsibly manage
deorbiting and disposal in a way that preserves both the orbital environment and efficiency of small missions. Development and demonstration of low size, weight, power, and cost (SWaP-C) deorbit capabilities that are compatible with common small spacecraft form factors is required to maintain the agility of Earth-orbiting small spacecraft missions while complying with regulatory activity. These low SWaP-C deorbit or disposal technologies are being solicited in this scope. In particular, deorbit/disposal technologies that enable higher orbits than currently possible are desired. Further, technologies that enable controlled deorbit/disposal are desired—that is, can actively be controlled throughout the disposal process to further protect against collisions and interferences with both active and inactive spacecraft and debris.

Clear key performance parameters should be given as a part of the offeror's solution. These performance parameters (e.g., SWaP-C) should be quantified, compared to state of the art (SOA), and put into context of a planned, proposed, or otherwise hypothetical mission to highlight the advantages of the offered technology over SOA and other proposed solutions.

**Expected TRL or TRL Range at completion of the Project**

2 to 5

**Primary Technology Taxonomy**

**Level 1**

TX 09 Entry, Descent, and Landing

**Level 2**

TX 09.X Other Entry, Descent, and Landing

**Desired Deliverables of Phase I and Phase II**

- Research
- Analysis
- Prototype
- Hardware
- Software

**Desired Deliverables Description**

In Phase I, a contextual study to further understand the feasibility of the proposed solution is desired. Ideally, Phase I would conclude with a basic proof-of-concept prototype (hardware or software as appropriate). Critical requirements and interfaces should be defined alongside refinements of the proposed key performance parameters in Phase I. The Phase I effort should provide evidence of the feasibility of key elements such as cost, assembly, integration, and operations. The concept should reach sufficient maturity to show strong feasibility for the defined mission environments and performance requirements. The 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.

In Phase II, further development and technology maturation is desired. Ideally, Phase II would culminate with Technology Readiness Level (TRL) 5+ demonstration of the proposed solution. Both Phase I and Phase II should be approached with focus on infusion, ensuring solutions are being developed with the proper requirements, interfaces, performance parameters, partnerships, etc., such that they, through a Phase III award or otherwise, could be directly applied to real spacecraft and real missions.

**State of the Art and Critical Gaps**
The 2020 NASA State of the Art of Small Spacecraft Technology report [8], Section 14.0, Deorbit Systems, gives a comprehensive overview of the SOA for both passive and active deorbit systems. The report details drag systems, including tethers, the Exo-Brake, and others. Drag sails have been the primary deorbit technology to date. They have been developed, demonstrated, and even commercialized/sold for mission use. However, capability needs to continue to grow, especially for higher orbital application as well as for more controlled deorbit and disposal.

Relevance / Science Traceability

With increased use of higher orbital regimes by small spacecraft and regulatory attention on long-term debris concerns, it is critical that the small-spacecraft community responsibly manage deorbiting and disposal in a way that preserves both the orbital environment and the efficiency of small missions. Solutions are relevant to commercial space, national defense, and Earth science missions.

References


Scope Title

Autonomous Space Traffic Management Technologies for Small Spacecraft Swarms and Constellations

Scope Description

In recognition of the threat posed by space debris to Earth’s orbital environment and the greater space industry, orbital debris prevention has been incorporated in every U.S. National Space Policy since 1988, with the latest Space Policy (2020) providing the strongest language yet, outlining that “the United States shall … Limit the creation of new debris, consistent with mission requirements and cost effectiveness, during the procurement and operation of spacecraft, launch services, and conduct of tests and experiments in space” [Refs. 1, 2, 3]. Concern has grown as “the number of objects orbiting the Earth [has] grown substantially in recent years with well over 90% being dead objects (inoperative satellites, spent upper stages, and fragmentation debris)” [Ref. 4], and a number of studies from NASA and other national and international agencies and organizations have shown dire outcomes and possible “runaway debris situations” for “business-as-usual” scenarios in debris population growth predictions for the future [Ref. 5], as well as significant strain on the current Space Traffic Management architectures to prevent such scenarios [Ref. 6]. Now there is significant concern that the situation will get worse with the ubiquitous emergence of small satellite (SmallSat) technologies and the planned deployment of swarms and constellations of thousands of satellites in Low Earth Orbit (LEO)—many of which qualify as “SmallSats”—by multiple commercial companies, such as SpaceX, OneWeb, Theia, Boeing, Amazon Kuiper, Inmarsat, etc. Per Ref. 4, “if all of these plans materialize, the population of operational satellites in LEO would jump by over a factor of ten—from ~1,000 today to over 16,000 within the next 10 to 20 years” and “has the potential to affect the space environment for generations and push any space traffic management system beyond its limits.” As a result, all spacecraft LEO operators could be faced with disruptive numbers of conjunction alerts and collisions between spacecraft and/or orbital debris, further exacerbating the situation.
While the challenges posed by space debris and the management of large constellations within that environment is a multidimensional problem with multifaceted solutions, this subtopic scope focuses on technical solutions for autonomous space traffic management aspects that relate to the safe operations of SmallSat swarms and constellations, with the aim of reducing the strain on current space traffic management architectures, particularly by removing the “human-in-the-loop” and replacing it with faster decision-making autonomous systems; improving the accuracy of conjunction alerts, particularly reducing the number of "false alarms"; and ultimately reducing the risk of collision and generation of orbital debris by the collision of spacecraft with other spacecraft or debris.

As part of this scope, the following technologies are being solicited:

- **Low size, weight, power, and cost (SWaP-C) small spacecraft systems for cooperative identification and tracking:** Development and demonstration of low SWaP-C and low-complexity identification and tracking aids for small spacecraft that can be scaled, produced, and readily standardized under the paradigm of small spacecraft ecosystems. With increased demands on existing space situational awareness capabilities, and with regulatory attention on the threat of spacecraft that are unidentified, misidentified, or too small to track, the small spacecraft community needs such technologies to allow the community to operate with lower risk to all spacecraft in orbit—without negatively impacting the efficiency of small missions—and to minimize the risk of space debris generation.

- **Low SWaP-C spacecraft systems for autonomous reactive operations of small spacecraft swarms and constellations:** Development and demonstration of low SWaP-C small spacecraft technologies, such as sensors and coupled maneuvering systems, that enable small spacecraft swarms and constellations to operate in formation, in close proximity to other objects (cooperative or uncooperative), or beyond where the capacity of human-in-the-loop control will be required to process input onboard and execute correct responses autonomously, ensuring the safety of both spacecraft and object.

- **Supporting software modules that enable the above:** Development and demonstration of software to be hosted aboard single spacecraft, across the spacecraft swarm/constellation, or on the ground, that enable the cooperative identification and tracking and/or autonomous reactive operations, and whose primary functions can be developed and demonstrated within the budget of standard NASA Phase I and II SBIR awards. This includes artificial intelligence/machine learning (AI/ML) techniques and applications that can enable autonomous orbit adjustment and other actions to mitigate the potential for in-orbit collisions. Also included are software applications and/or network applications that enable:
  1. Efficient information exchange between individual spacecraft.
  2. Minimal reliance on ground commanding.
  3. Efficient use of space-qualified computing architectures.
  4. High-precision swarm navigation and control.

- **Supporting ground systems that enable the above:** Development and demonstration of Ground Systems that enable the cooperative identification and tracking and/or autonomous reactive operations, and whose primary functions can be developed and demonstrated within the budget of standard NASA Phase I and II SBIR awards.

In the above descriptions, the terms “SmallSat” and “small spacecraft” are to be interpreted as interchangeable and apply to Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) class spacecraft and below, including CubeSats, with masses of 180 kg and less. Where applicable, technologies that apply to CubeSats are highly desirable, as that would favor greater adoption of the technology.

In all of the above, clear key performance parameters should be given as a part of the offeror’s solution. These performance parameters (e.g., SWaP-C) should be quantified, compared to state of the art, and put into context of a planned, proposed, or otherwise hypothetical mission. Technologies that, in addition to performing the requirements outlined above, can also be ported from LEO to deep space environments—enabling new science and exploration SmallSat swarms/constellation-based missions—are highly desirable.

**Expected TRL or TRL Range at completion of the Project**
2 to 5

Primary Technology Taxonomy

Level 1

TX 17 Guidance, Navigation, and Control (GN&C)

Level 2

TX 17.2 Navigation Technologies

Desired Deliverables of Phase I and Phase II

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description

In Phase I, a contextual study to further understand the feasibility of the proposed solution is desired. Ideally, Phase I would conclude with a basic proof-of-concept prototype (hardware or software as appropriate). Critical requirements and interfaces should be defined alongside refinements of the proposed key performance parameters in Phase I. The Phase I effort should provide evidence of the feasibility of key elements such as cost, assembly, integration, and operations. The concept should reach sufficient maturity to show strong feasibility for the defined mission environments and performance requirements. The 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.

In Phase II, further development and technology maturation is desired. Ideally, Phase II would culminate with Technology Readiness Level (TRL) 5+ demonstration of the proposed solution. Both Phase I and Phase II should be approached with focus on infusion, ensuring solutions are being developed with the proper requirements, interfaces, performance parameters, partnerships, etc., such that they, through a Phase III award or otherwise, could be directly applied to real spacecraft and real missions.

State of the Art and Critical Gaps

Current space traffic management architectures typically have a significant involvement of “humans-in-the-loop” for the identification of conjunction threats, for making the decision on if and how to respond, and for implementation of the response. Currently the U.S. Air Force 18th Space Control Squadron provides conjunction advisories to virtually all space operators worldwide following measurements taken with its assets. The operators then assess and weigh the risks to their assets and the resources to be expended to mitigate those risks. This is a time-consuming process, typically on timescales that do not allow for rapid reaction to a rapidly evolving threat. It is further aggravated by the large uncertainties associated with the conjunctions, which can lead to many false alarms, resulting in an inability for operators to respond to all alerts, as it would consume too many resources, as well as “complacency that naturally occurs when the mission analysts are inundated with large numbers of alerts that turn out to be false alarms” [Ref. 4]. For instance, “under current tracking accuracies, the actual collision between Iridium-33 and Cosmos 2251 did not stand out from other conjunctions that week as being noticeably dangerous” and therefore was not acted upon, with the impact only identified after its occurrence.

To help address such situations, various stakeholders have been implementing solutions of their own, but these solutions are likely to run into limitations, particularly as more spacecraft are deployed and systems need to be
For example, to help protect its nonhuman spaceflight assets, NASA established its Conjunction Assessment and Risk Analysis (CARA) program, with operational interfaces with the 18th Space Control Squadron to receive close-approach information in support of NASA mission teams. As a whole, however, the system still features humans in the loop, and if further investments are not made, it may run into combined scalability and time-responsiveness issues as more commercial and/or noncooperative foreign assets deploy and/or pass through the operational orbits of NASA spacecraft. While regulatory solutions are part of the mix to help resolve the issues encountered, such as the Space Act Agreement between NASA and SpaceX to identify how each party will respond [Ref. 7], those solutions are slow to implement and have legislative limitations. Technical solutions will inevitably be necessary to address gaps posed by regulatory means.

Deployers of SmallSat swarms and constellations are increasingly implementing software solutions for spacecraft to autonomously decide and implement collision-avoiding maneuvers. However, given the large capital and labor-intensive investment required to implement them, such systems may not be within the reach of all spacecraft operators, especially startup or single-spacecraft mission operators. Furthermore, with such technologies in their infancy, and with commercial operators racing to deploy and scale their spacecraft constellations to achieve market dominance, there is a very real risk that such systems may struggle to interface adequately with other autonomous and nonautonomous constellations, as was experienced by OneWeb and SpaceX [Ref. 8]. There may even be a risk of enhanced collision risk as each autonomous system independently takes evasive action that, unbeknownst to the other, increases the risk of collision, much like two persons unsuccessfully trying to avoid each other in a corridor.

Relevance / Science Traceability

- Low SWaP-C small spacecraft systems for cooperative identification and tracking: With increased demands on existing space situational awareness capabilities, and with regulatory attention on the threat of spacecraft that are unidentified, misidentified, or too small to track, the small spacecraft community needs low SWaP-C identification and tracking aids. Employing such methods would allow the community to operate with lower risk to all spacecraft in orbit without negatively impacting the efficiency of small missions. There is a clear need to develop and demonstrate low-cost and low-complexity identification and tracking aids that can be scaled, produced, and readily standardized under the paradigm of small spacecraft ecosystems.
  - Technologies used for identification and tracking aids in LEO may also have extensibility to the growing number of cislunar missions.
- Low SWaP-C spacecraft systems for autonomous reactive operations of small spacecraft swarms and constellations: Small spacecraft operating in formation, in close proximity to other objects, or beyond the capacity of human-in-the-loop control will be required to process input onboard and execute correct responses autonomously.
  - These sensor-driven operations will be enabling for safe proximity operations with spacecraft or small bodies as well as the detection and reaction to transient events for observation, such as would be required for sampling a plume from Enceladus. Furthermore, enabling multiple small spacecraft operating in coordinated orbital geometries or performing relative station-keeping can further expand human knowledge deeper into the universe by performing coordinated occultation, acting as virtual telescopes, and forming distributed apertures that would be prohibitively complex and expensive to launch into space as monolithic structures. Small spacecraft formation flight can also enable swarm gravimetry, synchronized observation of transient phenomena, and proximity operations for inspection of other assets.

References