Comment on Orbital Debris Research and Development Plan

December, 2021

Comment in response to Office of Science and Technology Policy (OSTP) 11/05/2021 Request for Comment (RFC) on Orbital Debris Research and Development Plan

Introduction

The National Space Society (NSS) urges the U.S. Government to continue to hold itself accountable for conducting responsible, safe, and sustainable space operations. Orbital debris jeopardizes the safety of spacecraft and crew, the functioning of critical communication and data systems, and the viability of economic activity in Earth's orbit. NSS strongly condemns the intentional destruction of space objects. This is especially relevant in light of Russia's recent anti-satellite (ASAT) test. ASAT testing by the U.S., China, India, and Russia, as well as the 2009 collision of Russia's Cosmos 2251 satellite with the U.S. Iridium 33 satellite, created significant spikes in the population of cataloged debris in low-Earth orbit (LEO). Now more than ever it is important for spacefaring entities to commit to orbital debris mitigation and remediation guidelines. NSS has published orbital debris risk management positions and research in three papers: *Space Debris Removal, Salvage, and Use: Maritime Lessons*; *Orbital Debris: Overcoming Challenges*, and *An SPD-3 and NAPA Informed Model for a Safe and Sustainable Space Economy: Six Recommendations*.

NSS hopes that through the R&D Plan the R&D Group will be able to close the critical gaps in the knowledge and capabilities needed to meet current and growing challenges of orbital debris risk management. NSS believes in a comprehensive approach for addressing orbital debris issues. Such an approach must effectively use Space Situational Awareness (SSA), norms of responsible behavior, mitigation, and remediation. For the rules of responsible space behavior, customary international law provides guidance. The UN General Assembly recently issued a report on "Reducing space threats through norms, rules and principles of responsible behaviours." The Secretary-General addressed the key threat posed by deliberate or negligent activity that could result in the generation of long-lasting debris. The Inter-Agency Space Debris Coordination Committee creates a normative basis for countries to refrain from the intentional destruction of space objects. The Committee's voluntary Space Debris Mitigation Guidelines include the fundamental principle of preventing explosive and collisional break-ups in low Earth orbit. It is important to note that international maritime law provides another source for policy on responsible behavior.

However, NSS recognizes the research and development (R&D) scope of the R&D Plan and this RFC. The NSS comment will thus focus on risk management efforts within SSA, mitigation, and remediation. This comment prioritizes three crucial R&D areas: SSA tracking and characterization of small debris, mitigation strategies for end-of-mission approaches, and remediation technologies for large objects. Studies conducted by multiple space agencies have found that orbital debris has already reached critical mass. The U.S. must recognize that collisional cascading is already occurring. Although humanity has many decades before it significantly blocks or prevents space activity, action must be taken now. In fact,

> Multiple studies by NASA and other space agencies have found that orbital debris has already reached critical mass, and collisional cascading will eventually happen even if no more objects are launched into orbit. According to NASA, by 2005 the amount and mass of debris in LEO had grown to the point that even if no additional objects were launched into orbit, collisions would continue to occur, compounding the instability of the debris environment and increasing operational risk to spacecraft by 2055 unless measures were taken to curb the growth of the debris population . . . . [E]ven if global spacefaring entities achieve a 90 percent compliance rate with post-mission disposal, it will not be sufficient to slow the growth of orbital debris without the active debris removal of at least five defunct spacecraft a year. — National Aeronautics and Space Administration, *NASA's Efforts to Mitigate the Risks Posed by Orbital Debris*, IG-21-011, 14-17 (January 21, 2021)

Finally, the NSS comment emphasizes the importance of cost-benefit assessments in both mitigation and remediation. Many efficiency principles inform the R&D plan. Short-term and long-term R&D initiatives will have different results. Commercial sector activities within orbital debris risk management significantly increase the potential impact of the R&D plan. R&D in LEO will have a greater impact than the same efforts in geostationary orbits (GEO), which are much less populated with objects. Further, consistent with NASA's position, mitigation will have a greater impact than remediation. With time and resource constraints, the U.S. Government should apply these principles to its R&D plan while expanding its data integration and agency coordination. NSS hopes this next year brings the world a step closer to a sustainable space environment. That stability will allow the U.S. to use the vast resources of space for the dramatic betterment of humanity.

NSS Comment

1. **The extent to which progress in the R&D topical areas identified in the Orbital Debris R&D Plan will address the orbital debris challenges. What, if any, R&D areas are missing?**

Element 1 on mitigation should include three additional R&D areas. The first R&D area is the development and standardization of best practices for mission design. Currently, satellite owners lack common orbital debris-related standards to support a risk management framework for active-mission collision avoidance and decision-making. The second missing R&D area is the development of models for risk and cost-benefit analysis for mitigation. NASA does not currently track the costs associated with mitigating orbital debris risks, including shielding, tracking, and collision avoidance.[1] One factor in this analysis is how much the mitigation method will reduce the debris hazard to space operations. This includes the number and mass of debris that would be prevented and the threat this debris would pose to valuable orbital regions. Another factor is the difficulty and cost (taking into account the opportunity cost) of implementing the mitigation method. Consideration should be given to how on-going reduction in launch costs change the trade space for shielding as compared to other mitigation strategies. Additionally, research should consider "absorptive" shields that collect debris without creating a new generation of smaller debris. Such shields might also form a part of a remediation strategy for very small objects. A risk and cost-benefit analysis would help answer what mitigation methods to implement and when and where to implement them. Finally, the third R&D area that needs to be identified is the development of mitigation technologies that will extend the design life of spacecraft. For satellite operators specifically, on-orbit fueling and hardware replacement technology are examples for how to increase mission life and efficiency. This may help reduce the number of additional launches and end-of-mission activities.

2. **Among the topic areas listed in the R&D Plan, what are the highest priority R&D areas (up to five) for making progress in addressing the challenges posed by orbital debris to the space environment?**

<u>*Element 1.6*</u> *Incorporate end-of-mission approaches to minimize debris into spacecraft and mission design.*[2]

End-of-mission approaches are the most crucial component of mitigation in orbital debris risk management. Spacecraft design is important to minimizing the probability of accidental explosion in defunct batteries. Propellant burning or venting helps eliminate all onboard sources of stored energy.

But end of mission design is the only way to prevent spacecraft from being a source of future pollution, through collision, fragmentation, or decommission (into space junk). Spacecraft are properly retired when they are deorbited or maneuvered to disposal orbits.[3] The former involves shortening the orbital lifetime until a burnup during reentry into the

Earth's atmosphere. Deorbiting is especially important and effective in the congested LEO environment. It can require retrograde propulsion burns or assisted thrust. Mission design would also have to incorporate the perturbing forces from low perigee decay, atmospheric drag, and the Sun and Moon's gravity. The latter is viable mostly in GEO rather than LEO because collision velocities are lower and debris is spread over a wider volume of space. Objects in GEO undergo orbital decay that may take thousands of years and could result in movement outwards rather than inwards. The 1992 Ad Hoc Expert Group of the International Academy of Astronautics recommended disposal orbits at a minimum of 300 km above GEO.

Element 2.1 *Characterize the orbital debris and the space environment.*

Characterizing orbital debris and the space environment is the first step to effective and comprehensive orbital debris risk management. This characterization internalizes SSA and is necessary to defining the orbital debris pollution problem and the associated risk. SSA data supports space operations and satellite infrastructure. These services include overflight satellite warning, launch maneuvering, communications window planning, reentry mission designing, and collision avoidance in outer space. According to the NASA Orbital Debris Program Office (ODPO) there is a critical knowledge gap in SSA for debris 3-mm in size and smaller. This gap is most extensive in the 400 to 1,000 km range of LEO. Millimeter-sized debris has the highest penetration risk for most missions in LEO. They pose a mission-ending threat to spacecraft and damage solar panels and communication arrays. This type of debris is also too small to be detected so operators are unable to change course to avoid it. Indeed, most ground radar sensors, besides the Department of Defense's (DOD) Space Fence and Long Range Discrimination Radar (LRDR), cannot track such tiny debris. There are over 100 million pieces of millimeter-sized debris. Better SSA tracking would lead to fewer false alarms and improved satellite owner compliance with collision avoidance maneuvers. Greater sensor data for millimeter-sized debris is necessary for the complete characterization of the space environment and for effective SSA.

Large debris can be detected, tracked, and catalogued, while smaller debris might not. Yet, even the smaller debris that can be detected cannot be tracked. Millimeter-sized debris is thus inputted into models of the orbital debris environment using statistical estimates. These models include data on the amount, location, and type of debris.[4] Additional algorithms and experimental and sensor data are also included to allow these models to provide an assessment of the risk of collision. Hypervelocity impact tests are critical to orbital debris characterization. These tests connect debris environment models to the risk of debris collision by simulating orbital collision, damage, and fragmentation. Hypervelocity test data is often not formally shared. Debris impact data may be inaccessible between facilities, government agencies, and commercial entities. Many of the engineering models for orbital debris environments and risk analysis are not standardized. A lack of data accessibility, sharing, integration, and standardization is likely to have limited the accuracy of existing models on the orbital debris environment.

<u>Element 2.4</u> Improve data processing, sharing, and filtering of debris catalog.

The accurate and extensive tracking, characterizing, and cataloguing of SSA data is necessary for mitigation and remediation efforts to be successful. Prohibitive difficulties currently exist in the integration of heterogenous data in real time.[5] Public and private space operators use different systems for object tracking. They also have different uncertainty level tolerances, data formats, and proprietary restrictions. There are different architectures for data storage, data correlation systems, data algorithms, data models, and data fusion approaches. There is a need for R&D into techniques for how to maintain data integrity as the SSA input increases from new sensors and commercial entities. This area includes R&D in data quality, data mining, and cross-tagging errors across databases. Data mining specifically would involve artificial intelligence and machine learning.

SSA is largely a predictive analytics activity requiring raw sensory data to be converted into actionable information. Element 2.1 on SSA demands a level of accuracy achievable only through broad interoperability and standardization. The scope of SSA data processing, sharing, integrating, and filtering must be international, as well as public and private.

<u>Element 3.1</u> Develop remediation technologies and techniques for large debris objects.

International space agencies and the scientific community already agree that mitigation alone will not be sufficient to create a sustainable and stable space environment. And space activity is increasing rapidly. Effective orbital debris risk management requires mitigation combined with strategic remediation efforts. NASA estimates that active debris removal needs to include at least five defunct spacecraft from orbit every year. But the U.S. Government has yet to assign, fund, or actively undertake orbital debris remediation efforts. Remediation technologies and missions are in very early stages of development.

There are over 26,000 large debris objects. All of them would have a catastrophic impact upon collision. The collision or fragmentation of these objects would create massive spikes in the population of orbital debris. Each of these objects also represents a significant portion of total debris mass. They are, however, easy to detect and accurately track. The active removal of a few large debris objects will have a greater impact in the long-term than similar efforts for removing many small debris objects. Within remediation methods, R&D into technologies and techniques for removing large debris objects must therefore be a priority.

<u>Element 3.3</u> Develop models for risk and cost-benefit analyses.

The current cost-benefit analysis for remediation is disproportionate for individual space entities and thus disincentivizes most commercial space operators. In this tragedy of the commons the individual costs of conducting remediation activities are high, but the individual benefits are low and do not capture the high positive social externalities. Government intervention, investment, or R&D is important in these market scenarios. It should be noted that the great majority of large derelict objects in space were launched by governments, creating an ethical obligation for them to remediate.

The consolidation of information regarding the risks, costs, and benefits of remediation technology may prove to be the most important tool for guiding this industry through its infancy while promoting innovation. It certainly will help show which technologies and techniques are feasible. It will also support the private sector stakeholders who control many of the resources critical to this endeavor. The costs associated with failing to remove defunct spacecraft will ultimately outweigh the costs of conducting active debris removal.

3. What near-term actions can be taken by the Federal government to make progress towards high priority R&D areas? How would these specific actions address the orbital debris challenges in the near term?

Short-term priorities for R&D should concentrate on SSA data characterization, processing, sharing, integrating, and filtering. NSS concludes that *element 2* R&D areas are critical to filling the knowledge gaps in the orbital space environment. This is a necessary first step to comprehensive orbital debris risk management. As a second priority, R&D efforts should increase the capabilities of end-of-mission design so that mitigation can be more readily used.

The Department of Commerce (DOC) Office of Space Commerce (OSC) should expand the Open Architecture Data Repository and allow commercial entities to add to it.[6] The Repository should also integrate the Federal Aviation Administration's (FAA) Office of Commercial Space Transportation's (AST) launch window software and systems. These specific near-term actions will promote SSA data sharing and processing efforts. Another action would be to create an Actuarial Index that catalogs the risk, in both probability and severity of collision, of every trackable piece of orbital debris.[7] These statistical calculations would mirror NASA's impact risk models for asteroids. This rank-ordered index of the collision risk of debris would support data filtering and risk analyses efforts. The U.S. Government should also expedite the updates of the NASA ODPO's engineering models. The new models incorporate the element of debris shape and thus more accurately reflect the current debris environment. They also continue to add data on intentional and accidental space object explosions and on the material types and densities of individual debris. These models improve collision avoidance systems and risk analyses assessments. The U.S. Government should encourage satellite owners and operators to share fragmentation and anomaly data to further strengthen these models.

At a macro-level the orbital debris community should exercise more peer review to maximize the accuracy of its statistical algorithms and models. This near-term action requires that debris characterization and impact data, from sources such as hypervelocity impact tests, becomes more accessible. Further integration and standardization of SSA models and engineering software would be beneficial. The U.S. Government can increase SSA data sharing between its agencies, commercial satellite operators, and SSA service providers. These R&D actions make unclassified SSA data more accurate and extensive.

This can promote the growth of unified debris cataloging databases, such as the DOD's Space-Track.Org.

4. **What R&D activities would be most valuable in the long-term or would be the most transformative to addressing orbital debris challenges?**

Long-term R&D activities should focus on remediation since active debris removal technologies are in their early stages of development. The U.S. Government should promote innovation by procuring commercially provided remediation services rather than developing systems in-house. It could also provide additional funding through contract procurement competitions or business accelerators. The U.S. Government needs to set a long-term vision that emphasizes the remediation of large orbital debris objects. It should also begin supporting initiatives or working groups that model the risks and cost-benefit analysis for different removal technologies and techniques.

Developing remediation methods like capture and repurpose will also create a new relationship between commercial space operators and orbital debris—as a resource rather than a hazard. One focus of remediation R&D should be on repurposing and recycling technologies. The largest pieces of debris, like inactive satellites and rocket bodies, could be upgraded or salvaged in-orbit. Technologies, like Nanoracks' Mission Extension Kit (MEK), could augment defunct spacecraft by lending them power, communications, and navigation capabilities. It is important to develop several kinds of technologies in tandem. Some of these technologies or techniques should involve deorbiting large space objects, especially if they will burn up in Earth's atmosphere. The International Space Station (ISS), and eventually commercial space stations, can be used to test and deploy remediation technologies to prove that they work in expected operating conditions. As part of cost-benefit analyses the U.S. Government should also create a list of the largest and highest risk items of large space debris in orbit. For example, the decommissioned, NASA-launched Quick Scatterometer Earth satellite weighs 2,000 pounds, has batteries that cannot be disconnected, and is in a highly populated LEO orbit. It clearly would be near the top of the list, warranting priority in its removal.

A secondary element in this long-term R&D should be improvements in SSA capabilities. These efforts would include the development of new ground radar sensor technology. It would also involve the construction of new ground radars, both government and commercial, to support DOD's Space Fence. SSA sensor technology must also have space-based tools in its arsenal. NASA's ODPO has concluded that direct measurement data is needed for the safe operation of future missions. The U.S. Naval Research Laboratory Optical Orbital Debris Spotter (OODS) is an example of a space-based SSA technology. It is a compact, low cost, and low power sensor that can be attached to satellites or flown independently. The OODS would use a laser light to detect a field of debris, even 0.1 millimeter-sized pieces, in real-time. RemoveDEBRIS has tested similar technology on its spacecraft, using a flash LiDAR and color camera as a vision-based navigation sensor. Finally, R&D is needed for how to create an effective international system for collecting, storing, and distributing data on orbital debris. This would hopefully include a unified database accurately cataloging all space debris based on SSA data from most global sensors.

5. **What are the opportunities to partner with entities outside the Federal government, nationally and internationally? What are the viable and potentially innovative mechanisms to partner most effectively?**

At the international front numerous organizations are involved in orbital debris risk management, whether directly or tangentially. The U.S. Government already works with the Inter-Agency Space Debris Coordination Committee (IADC), other space agencies and countries, and the UN Office of Outer Space Affairs (UNOOSA) Committee on the Peaceful Uses of Outer Space (COPOUS) and COPOUS' Scientific and Technical Subcommittee.[8] The U.S. Government would benefit from more active and long-term engagement with many of the other space-related international entities. These include: the International Academy of Astronautics, the International Organization for Standardization (standards for space systems), the Space Safety Coalition (space operation best practices), the World Economic Forum's Space Sustainability Rating Design Team, the Satellite Industry Association (principles of space safety), and the Space Law Committee of the International Law Association.[9] At the domestic level, organizations such as NSS and the American Institute of Aeronautics and Astronautics continue to provide support on orbital debris risk management research. Many of these organizations may have time and resources to provide to the R&D Group. Outsourcing research assignments, policy development efforts, and idea generation would help the R&D Group excel.

Additionally, NSS believes the R&D Plan provides viable opportunities for the U.S. Government to partner with other entities on SSA projects. Working groups, open-access databases, and SSA Sharing Agreements all provide innovative mechanisms for effective cooperation. Agency contract procurement for SSA services will also be more cost effective in the long-run. Analytical Graphics, Inc. provides SSA services through its Commercial Space Operations Center (ComSpOC). ExoAnalytic Solutions provide SSA services through its SpaceFront web-application and its ExoAnalytic Space Operations Center (ESpOC). Kayhan Space provides a collision avoidance system called Pathfinder. The Space Data Association and the Consultative Committee for Space Data Systems may provide additional help in facilitating the exchange of highly technical data. The International Scientific Optical Network (ISON), the Actionable Refinement of Ephemeris (STARE) Project, the Space Surveillance and Tracking Consortium, and the Canadian Near Earth Object Surveillance Satellite (NEOSSat) may provide supplemental SSA tracking and characterization for orbital debris.

Most importantly, U.S. Strategic Command should increase its SSA Sharing Agreements with commercial, government, and intergovernmental operators. For example, U.S.-Russia bilateral orbital debris agreements would end up covering over 75% of the mass in LEO. Where unclassified data falls short, national security partnerships are augmented with classified agreements to enhance military missions and provide specialized data. DOC's OSC could increase SSA data sharing by expanding the Open Architecture Data Repository and allowing commercial entities to add to it.

**Note on U.S. Government Agency Coordination*

The U.S. Government should increase R&D coordination and integration between all its space offices. This would include: DOD, the Joint Space Operations Center's (JSpOC) 18th and 20th Space Control Squadrons, U.S. Strategic Command, NASA's ODPO, the National Oceanic and Atmospheric Administration, the Federal Communications Commission, DOC's OSC, FAA's AST, and the Space Force. Such an effort should include standardizing all SSA and Space Traffic Management interfaces.[10] The DOD should concentrate on military relevant SSA and offload unclassified SSA data to DOC's OSC. This was recommended by both the 2020 Space Traffic Management Report by the National Academy of Public Administration and by Space Policy Directive-3.

Conclusion

The U.S. Government orbital debris risk management should involve a comprehensive approach that combines mitigation and remediation. R&D efforts should emphasize improving SSA for millimeter-sized debris in LEO, perfecting mitigation strategies for end-of-mission approaches, and developing remediation technologies for large debris. While current collisional cascading is problematic, the U.S. has an immense range of public, private, and international resources at its disposal. NSS looks forward to the increased safety and stability of Earth's orbital regime.

Thank you to the R&D Group for its contribution to the National Orbital Debris Implementation Plan.

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