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Orbital Debris Research and Development Plan	)	86 FR 61335
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COMMENTS OF ASTROSCALE U.S. INC.

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I. Introduction

Astroscale U.S. ("Astroscale") is pleased to provide comments into the Office of Science and Technology Policy (OSTP)'s Request for Comment regarding its Orbital Debris Research and Development (R&D) Plan (hereafter "the Plan") to inform the Orbital Debris Research and Development Interagency Working Group's implementation of the Plan. We thank the Office for their leadership in supporting the U.S. space enterprise, and for continuing to spotlight the pressing issue of space safety and orbital debris.

Astroscale's mission is to secure long-term spaceflight safety and orbital sustainability for the benefit of future generations. Through the creation of new technologies, business cases for on-orbit services, and globally-minded policies and best practices, Astroscale is actively driving the ecosystem to support a new era of space environment management[1] and stewardship.

Over the past two decades, as the price of access to space has fallen, a host of new space operators and activities have proliferated in Earth orbit. With the growth of commercial capabilities, data transmitted from space has become deeply integrated into industry and infrastructure across a range of sectors, forming a backbone of the modern global economy. The COVID-19 pandemic and an increase in severe weather events due to climate change both further illustrate the vital role that space-based systems and data play in serving the public: advancing connectivity, improving weather prediction, and aiding natural disaster and emergency response efforts. But this boom in space systems has also intensified orbital congestion, increasing operational risk to active satellites, and adding to the population of orbital debris.

The Plan outlines R&D activities within three core elements to manage the risks posed by orbital debris: the limitation of debris generation by design, the tracking and characterization of the debris population, and the remediation or repurposing of orbital debris.[2] Each element is vital to comprehensively address the orbital debris problem; a focus on any one element alone will be insufficient to sustain the orbital environment for long-term use. This Comment will explore various aspects of each element that will accelerate short-term and long-term progress in combatting orbital debris, including any missing R&D areas. Overall, advancements across all three research areas will generate the methods, technologies, and practices necessary to sustain space systems without degrading the orbital environment.

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[1] Charity Weeden, *A Space Environment Management (SEM) Framework*, Astroscale U.S. (Dec. 14, 2021), https://astroscale-us.com/a-space-environment-management-sem-framework/.

[2] ORBITAL DEBRIS RES. & DEV. INTERAGENCY WORKING GRP., NAT'L SCI. & TECH. COUNCIL, NATIONAL ORBITAL DEBRIS RESEARCH AND DEVELOPMENT PLAN (Jan. 2021) [*hereinafter* National Debris Plan].

Also touched upon in this Comment, works supporting the Plan and proposed R&D should include policy development. Domestically, harmonizing orbital debris mitigation and remediation efforts across the interagency is in the best interest of the U.S. space industry. Clear organization will assist the numerous small and medium enterprises with limited resources in identifying and supporting various government efforts. Additionally, the United States can couple invigorated technological research with policy advancements, cementing U.S. global leadership in the development of robust standards, modernizing regulation, and an operational culture that values safe practices in space.

The United States has a strong history of supporting R&D and encouraging endeavors to categorize and combat orbital debris.[3] While this Comment will now turn to consideration of the Plan and the future, Astroscale continues to celebrate the past and current great accomplishments undertaken to enable a sustainable space future.

II. Expedited Progress in *Both* Mitigation and Remediation R&D Topical Areas Addresses Orbital Debris Challenges.

A balanced approach to R&D is needed to sufficiently address orbital debris challenges. Recognizing that tracking and characterization of orbital debris underpins all efforts in space sustainability and space environment management,[4] the three core elements of the Plan[5] can broadly be broken down into

[3] *See, e.g.,* Nicholas L. Johnson, *Activities on Space Debris in U.S.*, 3 PROC. EUR. CONF. SPACE DEBRIS 13 (Mar. 2001).

[4] Space Environment Management was first conceptualized by Tim Maclay and Darren McKnight, consisting of "mitigating the potential for new missions to create more debris (debris mitigation) and cleaning up pre-existing potential sources of debris (debris remediation). Astroscale has expanded upon this concept and supports it as a wholistic framework to promote even handed stewardship of the orbital debris environment. *See* T. Maclay & D. McKnight, *Space Environment Management: Framing the Objective and Setting Priorities for Controlling Orbital Debris Risk,* 70TH INT'L ASTRONAUTICAL CONGRESS No. IAC-19-A6.8.3 (2019), https://oneweb.net/assets/news/media/Space-Environment-Management-Framing-the-Objective-and-Setting-Priorities-for-Controlling-Orbital-Debris-Risk.pdf; *see also* Weeden, *supra* note 1.

[5] The "three essential elements" are the parent categories: (1) limit debris generation by design; (2) track and characterize debris; and (3) remediate or repurpose debris. National Debris Plan, *supra* note 2, at 3.

two *active* methods of addressing debris: mitigation (the 'prevention,' which reduces the generation of new debris)[6] and remediation (the 'cure,' which addresses existing debris currently on orbit).[7]

More than a decade of U.S. space policy supports the pursuit of mitigation *and* remediation efforts as dual pillars of the comprehensive orbital debris solution. The 2010 National Space Policy,[8] Space Policy Directive-3,[9] and 2020 National Space Policy[10] all recognize the need to support mitigation and remediation endeavors. Most recently, the United States Space Priorities Framework released by the Biden Administration reaffirmed this commitment in no uncertain terms, stating "…The United States will increase efforts to mitigate, track, and remediate space debris."[11]

In the field of mitigation, there is a positive and growing movement to proactively limit the creation of orbital debris. Mitigation successes to date include improvements in shielding, timely and robust compliance with post-mission disposal (including methods of "safeing" a spacecraft), national adoption and proliferation of the Orbital Debris Mitigation Standard Practices (ODMSP),[12] and international adoption and adherence to international standards.[13] However, simply preventing the generation of new debris will not be enough to solve the problem of orbital debris.[14]

Mitigation efforts must be paralleled by concurrent remediation efforts. "[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

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[6] *See* OFF. INSPECTOR GEN., NASA, REP. NO. IG-21-011, NASA'S EFFORTS TO MITIGATE THE RISK POSED BY ORBITAL DEBRIS 7 (Jan. 27, 2021) ("Mitigation measures can take the form of curtailing or preventing the creation of new debris; designing satellites to withstand impacts by small debris; and implementing operational procedures such as using different orbital regimes with less debris, adopting specific spacecraft altitudes, and operators maneuvering on-orbit assets to avoid collisions.") [*hereinafter* NASA OIG Report].

[7] [7] "Remediation refers to active removal of existing debris, including defunct spacecraft, before it explodes, collides, or fragments in orbit." *Id.* at 4.

[8] EXEC. OFFICE OF THE PRESIDENT, NATIONAL SPACE POLICY OF THE UNITED STATES OF AMERICA 7 (June 28, 2010).

[9] Space Policy Directive-3: National Space Traffic Management Policy, 83 Fed. Reg. 28969 at § 5(iii) (June 18, 2018).

[10] National Space Policy, 85 Fed. Reg. 81755, 81764 (Dec. 16, 2020).

[11] EXEC. OFFICE OF THE PRESIDENT, UNITED STATES SPACE PRIORITIES FRAMEWORK 7 (Dec. 2021).

[12] Orbital Debris Mitigation Standard Practices (U.S. Gov., updated Nov. 2019), https://orbitaldebris.jsc.nasa.gov/library/usg_orbital_debris_mitigation_standard_practices_november_2019.pdf.

[13] Adopted international standards include the International Standard Organization (ISO)'s Standard 24113 and the Inter-Agency Debris Coordination Committee (IADC) Guidelines. *See* Int'l Org. Standardization, ISO 24113:2019, Space Systems – Space Debris Mitigation Requirements (July 2019); Inter-Agency Space Debris Coordination Comm., IADC-02-01, Space Debris Mitigation Guidelines (revision 2, Mar. 2020).

[14] *See, e.g.*, NASA OIG Report, *supra* note 6, at p. 14 (stating that multiple studies have concluded that preventing future debris is "not enough to stabilize the orbital environment.").

year, beginning in the year 2020."[15] If the United States wishes to demonstrate leadership in the stewardship of space, the breadth and depth of support to both mitigation and remediation must be equitable.

Unfortunately, U.S. efforts supporting the second pillar to address orbital debris challenges – remediation – have been historically hamstrung by a lack of centralized coordination, clear authorization, and requisite appropriations.[16] Despite the broad directive in the 2010 National Space Policy for both NASA and the Department of Defense to research remediation technologies and techniques, neither were explicitly tasked with developing a U.S. government active debris removal (ADR) mission.[17] Additionally, in 2014, NASA adopted a policy of not supporting ADR research beyond technical readiness level (TRL) 4.[18] In practice, this means that NASA will not support R&D for ADR beyond lab-based testing.[19] As the major Federal agency with a history of successfully supporting R&D and fostering commercial success,[20] NASA must be enabled to support robust contributions to ADR R&D.[21]

Balanced progress across mitigation and remediation R&D will spur the greatest advances in addressing orbital debris challenges. To date, efforts in mitigation have received the most support.[22] These breakthroughs in good stewardship should be celebrated, but not allowed to outshine the need for wholistic

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[15] *Id.* at 17.

[16] Brian C. Weeden, IAC-16.A6.8.3, *The Evolution of U.S. National Policy for Addressing the Threat of Space Debris*, 67TH INT'L ASTRONAUTICAL CONGRESS (Sept. 2016), https://swfound-staging.azurewebsites.net/media/205624/iac-16a683-weeden_evolution_us_space-debris_policy-paper.pdf.

[17] *See* Eileen K. Stansbery, *Debris Remediation*, NASA, https://orbitaldebris.jsc.nasa.gov/remediation/ (last visited Dec. 17, 2021).

[18] Debra Werner, *NASA's Interest in Removal of Orbital Debris Limited to Tech Demos*, SPACENEWS (June 22, 2015), https://spacenews.com/nasas-interest-in-removal-of-orbital-debris-limited-to-tech-demos/.

[19] *Id.*; *see* Irene Tzinis, *Technology Readiness Level*, NASA (Apr. 1, 2021), https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level.

[20] *See, e.g.*, Dan Lockney, *NASA Technology Transfer Program*, NASA, https://technology.nasa.gov/ (last visited Dec. 8, 2021) (website portal for NASA's Technology Transfer Program); Sarah Loff, *NASA Hails Success of Commercial Space Program*, NASA (Aug. 7, 2017), https://www.nasa.gov/content/nasa-hails-success-of-commercial-space-program (discussing success of the Commercial Orbital Transportation Services, a program between NASA and commercial partners to "achieve safe, reliable, and cost-effective commercial transportation not and from the space station and low-Earth orbit.").

[21] *See, e.g.,* NASA OIG Report, *supra* note 6, at p. 21 (discussing two early-stages studies for ADR that were "promising," but which NASA's Space Technology Mission Directorate decided not to fund for further development).

[22] For example, both NASA and DOD implement NASA-led debris mitigation guidelines – the ODMSP – through internal policies. Furthermore, mitigation requirements are passed on to commercial entities through licensing bodies in the FAA, FCC, and NOAA. *Id.* at p. 9.

progress across mitigation *and* remediation.[23] With the close of 2021, the world has already fallen behind the target number of defunct spacecraft to remove to protect the space environment.[24]

III. R&D of Remediation Technologies, Economic Modeling, End-of-Mission Approaches, and Data are the Highest Priority for Addressing Challenges Posed by Orbital Debris.

There is no silver bullet for eliminating the threat of orbital debris. Addressing this challenge – which has been decades in the making – will take collective action. This section presents five key topical areas for wholistic progress in addressing the challenges posed by orbital debris to the space environment.

Priority #1	Topical Area 3.1	*Develop remediation and repurposing technologies and techniques for large-debris objects*
Priority #2	Topical Area 3.3	*Develop models for risk and cost-benefit analysis*
Priority #3	Topical Area 1.6	*Incorporate end-of-mission approaches to minimize debris into spacecraft and mission design*
Priority #4	Topical Area 2.2	*Develop technologies to improve orbital debris tracking and characterization*
Priority #5	Topical Area 2.4	*Improve data processing, sharing, and filtering of debris catalogs*

A. The Federal Government Should Spearhead the Development and Demonstration of Remediating Large Debris Objects.

Large debris is a significant problem. The kinetic energy of a collision on-orbit is proportional to the mass of the colliding objects; with average derelicts[25] weighing several tons, a collision between two can have upwards of a *hundred-thousand times more energy* than collisions between smaller pieces of

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[23] "[A] study by the [Orbital Debris Program Office] showed that even if no future launches occurred, collisions between existing satellites would increase the 10-cm and larger debris population faster than atmospheric drag would remove objects. The "No New Launches" scenario highlights the eventual need for remediation of the existing debris population." Stansbery, *supra* note 17.

[24] Recalling the above study that five defunct spacecraft per year should be removed to slow the growth of debris, starting in 2020.

[25] Derelicts being expended upper-stages of rockets or defunct satellites.

debris. As the 2009 Iridium-Cosmos collision demonstrated, large debris can simultaneously create more debris *and* distribute it over a larger area.[26]

The remediation of large debris will have an immediate and measurable impact on the risk posed by orbital debris. Large bodies contribute greatly to the number and severity of collision warnings in valuable orbits.[27] For example, in an analysis of potential conjunctions, derelict rocket bodies make up eighteen percent of the top two hundred statistically riskiest objects.[28] Remediation of large objects is the best way to control growth of the *long-term* debris population growth; it negates the threat of fragmentation from old and decaying objects, and provides the greatest reduction in the probability of cascading collisions across orbits.[29]

The United States, through Congressional action and Executive Orders, has recognized for the past decade that remediation and mitigation are twin pillars of the orbital debris solution.[30] However, the U.S. has yet to demonstrate, or support the demonstration of, an on-orbit capability to remove large debris.[31] It is important that the U.S. Government invest in long-term space stewardship through prioritization of remediating large object debris.

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[26] Analysis indicates that more than half of the over 500 pieces of debris generated by Iridium 33 will stay in orbit for over 100 years. N. N. Smirnov et al., *Physical and Mathematical Models for Space Objects Breakup and Fragmentation in Hypervelocity Collisions*, 176 ACTA ASTRONAUTICA 598 (2020); Brian Weeden, *2009 Iridium-Cosmos Collision Fact Sheet*, SECURE WORLD FOUNDATION. (Nov. 10, 2010), https://swfound.org/media/6575/swf_iridium_cosmos_collision_fact_sheet_updated_2012.pdf.

[27] *See* Michael J. Nicolls & Darren McKnight, *Collision Risk Assessment for Derelict Objects in Low-Earth Orbit*, FIRST INT'L ORBITAL DEBRIS CONF. # 6096 (2019) (in an 8-month study, the authors found "28 events involving massive objects (>775 kg in size) with probability of collision greater than 10-4, which is the typical maneuver Pc for operational satellites…it is safe to say that the rocket bodies and defunct satellites involved in the majority of these conjunctions did not execute a collision avoidance maneuver.")

[28] Darren McKnight et al., *Updating the Massive Collision Monitoring Activity – Creating a LEO Collision risk Continuing*, 8TH EUROPEAN CONF. SPACE DEBRIS at 5-6 (2021).

[29] *See* ORBITAL DEBRIS: A TECHNICAL ASSESSMENT 162 (Nat'l Acad. Press, 1995) ("Limiting the number of potentially harmful objects in orbit can sharply reduce growth in the short-term debris hazard and can restrict growth in the long-term hazard to some regions, but will have little effect on slowing or preventing collisional cascading. Limiting the total mass and cross-sectional area…,on the other hand, can prevent or slow the onset and growth of collisional cascading and can also ameliorate the short-term collision hazard.").

[30] *See, e.g.*, EXEC. OFFICE OF THE PRESIDENT, *supra* note 8, at 7; *see also* National Aeronautics and Space Administration Transition Authorization, Pub. L. 115-10, 131 Stat. 18, 72 (2017).

[31] *See, e.g.*, Christopher R. May, *Triggers and Effects of an Active Debris Removal Market*, AEROSPACE 6 (Jan. 2021), https://aerospace.org/sites/default/files/2021-01/adr%20paper.pdf (listing U.S.G. as "primary leaders" on only 2 of 10 current on-orbit servicing missions). While NASA is working on robotic refueling technologies through the OSAM-1 mission, this mission will not address removal. NASA OIG Report, *supra* note 6, at p. 21.

Recommendation: Implementation of the Plan should prioritize R&D topical area 3.1 – *Develop remediation and repurposing technologies and techniques for large debris objects.* Specially, "Agencies should develop and conduct… full system prototype demonstration tests to prove both the performance capabilities and cost-efficacy of various approaches."[32]

By prioritizing investment in remediation of large object debris, the United States can make substantial process in long-term space stewardship.

i. Prioritizing R&D for a Large-Body Remediation and Repurposing Mission Will Spur Innovation in Missing R&D Areas.

A flagship large-body debris remediation mission will help advance R&D in several areas that are currently under-addressed.[33] Within topical area 3.1 – *Develop remediation and repurposing technologies and techniques for large debris objects*, both remediation and repurposing need subcategorical R&D to support a holistic mission.

Astroscale has identified the following areas that require additional R&D to support remediation and repurposing missions:

1. Develop capabilities for autonomous navigation, rendezvous, and proximity operations
2. Improve sensor capabilities for debris inspection
3. Advance fuel technologies to support repeat missions
4. Characterize object tumble rates and generate methods to de-tumble objects
5. Create guidelines to support risk-management during remediation missions
6. Incorporate assured spectrum accessibility for in-orbit servicing into national spectrum planning
7. Transition to multi-functional tools, with characterization of sensitivities
8. Demonstrate prototype technologies for in-space assembly, integration, and disassembly

The unique needs and benefits of each of these additional missing R&D categories are discussed below.

#1. Develop capabilities for autonomous navigation, rendezvous, and proximity operations. The Plan lacks subcategorical R&D in autonomous real-time navigation, rendezvous, and proximity operations needed to support remediation and repurposing.[34] Autonomous navigation capabilities will be critical for docking with prepared and unprepared objects. Additionally, creation of autonomous servicer vehicles is more economically feasible than servicers with real-time communications, which require complex ground

[32] National Debris Plan, *supra* note 2, at 12.

[33] This section responds to the second part of Question #1 - "What, if any, R&D areas are missing?".

[34] The Plan touches on "autonomous collision avoidance" in Topical Areas 1.3, 1.5, 2.2, and 2.4. National Debris Plan, *supra* note 2, at 6-7, 9-10. However, the Plan self-limits by only conceiving that R&D in autonomous navigation is applicable to *only* collision avoidance, when these mechanisms are applicable to a whole range of autonomous navigation – including rendezvous and proximity operations.

support. By removing ground relay, autonomous capabilities also enhance mission safety – these vehicles are equipped to abort autonomously, without waiting for ground input.

R&D should include development of algorithms to support vision processing, ranging, bearing, positioning, and docking mechanisms. Advancement in autonomous real-time navigation will support debris remediation and repurposing of all sizes: large-object detection is technically less challenging and will provide for refinement towards detection of small debris objects.

#2. Improve sensor capabilities for debris inspection. Remediation missions to remove large debris objects will rely on extensive sensor suites for on-orbit inspection and characterization of debris object 'health' conditions. The Plan fails to recognize the need for R&D in these sensor capabilities.[35] Sensors, such as visible-light cameras, infrared detectors, and LiDAR, all reduce risk during large-debris remediation by providing more detailed data on the state of a client debris object than is possible to obtain from ground-based observations.[36] Sensor data collected from orbit allows servicing spacecraft to assess and adjust operations upon arrival to account for client object health and integrity, which may have degraded in the on-orbit environment. Improving sensor capabilities will jointly contribute to future mitigation abilities: sensors can perform "forensics" for mishaps and anomalies, including diagnoses or validation of spacecraft issues and failures on-orbit.

#3. Advance fuel technologies to support repeat missions. Fine propulsion control is a driving requirement of debris remediation missions. When conducting rendezvous and proximity operations, servicing spacecraft need to make repeated minute adjustments to their position in relation to large debris objects. Additionally, spacecraft designed for multiple servicing missions require careful fuel expenditure calculus to support both long-duration missions and fuel-intensive delta-V changes. Upon docking, precision six-degree-of-freedom maneuverability is necessary to control the "joint stack" of spacecraft. The Plan too narrowly scopes the benefits of fuel advancements – mentioning only improved maneuverability as it relates to post-mission disposal – and would benefit from recognition of a broader R&D topical area for propulsion methods, including fine control capabilities necessary for remediation and disposal missions.[37]

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[35] The Plan mentions *in situ* sensor technologies for characterizing the debris environment, but fails to extrapolate improvements in *in situ* sensor technologies as applicable to debris-removal missions. National Debris Plan, *supra* note 2, at 9.

[36] *See, e.g.*, *Space Station Robotic Arm Receives New Grappling Hand in Challenging 7-Hour Spacewalk*, SPACEFLIGHT 101 (Jan. 23, 2018), https://spaceflight101.com/iss/us-eva-47-successfully-completed-outside-iss/ (noting that the Latching End Effectors of the robotic arms on the ISS "hold a multitude of components including cameras and a wealth of force and other sensors").

[37] National Debris Plan, *supra* note 2, at 6.

Another facet of fuel technologies R&D that should be supported is refueling interfaces. The ability to refuel spacecraft supports long-duration missions and is also a form of end-of-life mitigation. R&D, especially dedicated to standardized refueling interfaces, would promote rapid propagation of this promising component of fuel technologies.

#4. Characterize object tumble rates and generate methods to de-tumble objects. Large object debris remediation will require docking with unprepared and derelict objects. The tumble rate of an object and requirements to safely detumble it, in preparation for docking or servicing, will vary from mission to mission. The Plan misses this critical area of R&D.[38] To manage the risk of docking, further R&D to characterize high-rate tumbling of objects, as well as methods to safely detumble an object with a high tumble rate, is necessary.

#5. Create guidelines to support risk-management during remediation missions. Remediating large debris objects requires extensive R&D into risk assessment and management. Many large debris objects were not designed with reentry in mind. Derelict objects, especially those that are several decades old, often incorporate an uncertain number of components or materials that could survive atmospheric reentry, and therefore should be disposed utilizing a controlled re-entry over non-populated areas whenever possible.[39] Further R&D into mission design and risk mitigation during reentry is needed to inform remediation operations.

#6. Incorporate assured spectrum accessibility for in-orbit servicing into national spectrum planning. During remediation and repurposing missions, there are critical phases of commanding and telemetry that support close approach and equivalent stages of a servicing missions.[40] The National Table of Allocations does not currently allocate spectrum for remediation missions.[41] Further development is needed to ensure spectrum access during such critical phases, including possible allocations and licensing pathways.

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[38] Tumbling rates are only mentioned in relation to capabilities that can be derived from improved orbital debris and tracking characterization. National Debris Plan, *supra* note 2, at 9.

[39] *See*, *e.g.*, Henrik Simon & Stijn Lemmens, *A First Design for Demise Analysis for Launch Vehicles*, ESA, https://indico.esa.int/event/181/contributions/1464/attachments/1327/1552/2017_CSID_LemmensSimons_FirstDesign4DemiseAnalysis4LaunchVehicles.pdf (last visited Dec. 10, 2021) (presenting example modeling for reentry and demise of launch vehicles, including the lack of information on upper stages).

[40] *See*, *e.g.*, *CONFERS On-Orbit Servicing (OOS) Mission Phases*, CONSORTIUM EXECUTION COMMERCIAL RENDEZVOUS & SERVICING OPERATIONS 4-5 (Oct. 1, 2019), https://www.satelliteconfers.org/wpcontent/uploads/2019/10/OOS_Mission_Phases.pdf (discussing "way points" in RPO mission design).

[41] *See* Comments Astroscale U.S. Inc., Axiom Space Inx., Atomos Space, Sierra Space Corp., and SCOUT Inc., IB Docket 13-115, at 5 (Aug. 11, 2021).

#7. Transition to multi-functional tools, with characterization of sensitivities. The tools for remediation and repurposing will likely be multi-functional in design,[42] or a servicer spacecraft's mass would quickly reach unpractical ranges. For multifunctional tools, R&D of sensitivity values will be required, as well as methods to reconfigure a tool between uses. It is anticipated that for more complex future applications of on-orbit robotic servicing missions, such as repair, manufacturing, and reconfiguration, tools will need to be capable of grasping, manipulating, and closely inspecting components and subcomponents.[43]

#8. Demonstrate prototype technologies for in-space assembly, integration, and disassembly. Repurposing large debris objects will mandate R&D into how in-space assembly and integration can be undertaken, with a specific view of replacing system components or upgrading potential payloads. Depending on whether an object is simply being fitted to a new and unintended purposes, or modified for a new use, some aspects of *disassembly* in space will also need to be studied.

Overall, the top priority to address orbital debris is R&D area is 3.1 – *Develop remediation and repurposing technologies and techniques for large debris objects.* As shown, large debris objects present a critical threat to the debris environment, in terms of mass, cross-sectional area, and ability to create and scatter more debris. While prevention is a laudable goal for missions currently being built, the world is already behind in number of debris removal missions needed per year to stabilize the orbital debris environment.[44] This is the time, and opportunity, for the United States to be a leader in space safety and sustainability while concurrently supporting extensive R&D across remediation and repurposing of large debris objects.

B. Leading R&D in Economic Modeling Will Globally Convey the Value of a Secure Orbital Environment and Motivate International Cooperation in Debris Remediation.

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[42] *See, e.g.*, *Space Station Robotic Arm Receives New Grappling Hand in Challenging 7-Hour Spacewalk*, *supra* note 36 (discussing that the Canada arm on the ISS has a Latching End Effector "that can serve as the base point of the arm or as the free-flying end to manipulate items").

[43] *See*, Benjamin B. Reed, *The Restore-L Servicing Mission*, NASA slide 15 (Mar. 29, 2016), https://www.nasa.gov/sites/default/files/atoms/files/reed_restorel_tagged.pdf.

[44] *See* NASA OIG Report, *supra* note 6, at p. 17.

The second priority area that the Implementation Plan should support is topical area 3.3 – *Develop models for risk and cost benefit analysis.* Economic research will support potential legislative and regulatory actions while continuing a proud tradition of U.S. leadership in environmental stewardship.

Understanding and performing an accurate comparative cost-benefit analysis (CBA) and valuation exercises is key to enabling both users and regulators alike to make decisions about good space stewardship. CBA exercises, widely used in environmental policy, enable stakeholders to quantify the economic costs and benefits of a given attribute. For instance, the operational risk generated by space debris is a cost incurred by operators and passed to down-stream industries that rely on satellites. Cost-benefit analyses have already had success in incentivizing commercial operators to incorporate debris mitigation into system designs above and beyond minimum requirements: for example, NGSO satellite internet operator OneWeb performed their own analysis of the environmental cost of deploying a large constellation.[45] As a result of the study, OneWeb adopted increased mitigation measures for their fleet, such as increasing separation between orbital panes and targeting higher post-mission disposal reliability rates.[46]

Beyond cost incentives, economic R&D can assist lawmakers in selecting effective stewardship tools. For example, a recent survey of commercial satellite operators found a preference for financial incentives for post-mission disposal over punitive measures, such as fees, for polluting practices.[47] The Orbital Debris Working Group's implementation of the Plan should consider commissioning additional research into economic incentive models for orbital debris mitigation, such as orbital use-fees, pre-payment plans, performance bonds, cap-and-trade, or enhanced competitiveness for sustainable operators vying for government contracts.

U.S.-led economic research studies into orbital debris mitigation and remediation incentives can additionally inform and align regulations around the world. Some countries already employ or have begun experimenting with economic tools, such as third-party liability and mandatory debris plan disclosures.[48] If the United States can demonstrate leadership and accuracy in risk and cost benefit analysis for orbital debris,

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[45] *See* H.G. Lewis et al., IAC-19-A6.2.4, *Long-Term Environmental Effects of Deploying the OneWeb Constellation*, 70TH INT'L ASTRONAUTICAL CONGRESS (2019).

[46] *Id.*

[47] Marit Undseth, Claire Jolly & Mattia Olivari, *Space Sustainability: The Economics of Space Debris in Perspective*, 87 OECD 1, 37 (Apr. 2020).

[48] *Id.* at 30-1.

it is rational to expect continued and increasing international participation in environmental stewardship as well.[49]

i. Missed Challenges to Economic R&D: Quantifying Cost and Capturing an Emerging Market.

While the Plan categorizes developing risk and cost-benefit analyses as a part of remediating and repurposing debris, all three essential elements are missing a vital area of economic R&D: cost. Further quantitative R&D is needed to both create a realistic cost model for orbital debris, as well as to account solutions offered by the development of new technologies.

Astroscale has identified the following areas that require additional R&D to inform the creation of risk and cost-benefit analyses:

1. Characterize the cost of operating among orbital debris across orbits
2. Incorporate novel mitigation and remediation technologies into cost-benefit analyses

#1. Characterize the cost of operating among orbital debris across orbits. At the most fundamental level, research is still struggling to understand the *cost* of operating among an increasingly congested orbital environment.[50] "The current economic impact of space debris is largely unknown because: (i) damage due to untracked debris is unreported, (ii) satellite operators are not transparent regarding the costs of protecting against debris they face, and (iii) investments in space debris monitoring and tracking not only benefit space debris mitigation but also have defense purposes."[51] Even NASA cannot account for its costs mitigating orbital debris risk.[52] Implementation of the Plan should not only evaluate the costs and benefits of potential approaches to remediation and repurposing,[53] but the costs associated with operating among orbital debris across orbits as it exists today.[54]

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[49] The U.S. is already seen as a leading expert on matters of orbital debris. For instance, the Inter-Agency Space Debris Coordination Committee has adopted guidelines that are consistent with NASA's Orbital Debris Mitigation Standard Practices. NASA OIG Report, *supra* note 6, at p. 11.

[50] Davide Vittori et al., IAC-21-E2.1.4, *No More Space in Space? Quantification of the Space-Enabled Economic Value at Risk and Assessment of the ADR Business Case*, 72ND INT'L ASTRONAUTICAL CONGRESS at 2-3 (2021).

[51] ROMAIN BUCHS ET AL., INT'L RISK GOVERNANCE CTR., ECOLE POLYTECHNIQUE FEDERALE DU LAUSANNE, COLLISION RISK FROM SPACE DEBRIS : CURRENT STATUS, CHALLENGES AND RESPONSE STRATEGIES 13 (2021).

[52] *See* NASA OIG Report, *supra* note 6, at p. 19.

[53] National Debris Plan, *supra* note 2, at 12.

[54] Costs associated with the impact of debris on the International Space Station (ISS) should be publicly well-documented and could be used as a guide to study costs on other operations in orbit caused by orbital debris. Astroscale suggests that NASA's Orbital Debris Program Office (ODPO) include a section in the Orbital Debris Quarterly

#2. Incorporate novel mitigation and remediation technologies into cost-benefit analyses. The risk and cost-benefit analyses R&D called for in the Plan must be informed by updated audits of what technology is commercially and civilly available. The last in-depth study within NASA's Science and Technology Mission Directorate to evaluate the technical viability of concepts for ADR was conducted in 2014.[55] In the years since, the market for ADR has advanced rapidly, with some market forecasts estimating the market for in-orbit servicing could grow to $3 billion by 2027.[56] Implementation of the Plan should include a state-of-the-field audit of emerging technologies across mitigation and remediation to inform accurate risk and cost-benefit modeling.[57]

Further works to support the Plan should make a clear call for cost-accounting of debris and ensure available new technologies are properly reviewed to inform risk and economic models.[58] Only with a whole-of-the-field scope for solutions can the United States hope to take on a whole-of-orbit stewardship role in coordination with allies and partners.

C. The United States Should Continue Supporting R&D for Implementing End-of-Mission Approaches.

Federal attention must first and foremost be given to a flagship remediation mission and removing current large debris. The second priority – developing economic models for risk and cost-benefit analysis – encourages global uptake of viable fiscal measures for good stewardship. Beside remediation and incentivization, prevention is a key piece of combating orbital debris.

Newsletter (ODQN) to be dedicated to statistics regarding high risk ISS conjunctions with debris/passively deorbiting objects and any other relevant information such as required maneuvering or impact to schedule.

[55] See NASA OIG Report, *supra* note 6, at p. 32.

[56] *See In-Orbit Servicing Market Set for Lift-off Given Operator Dynamics and Development of Key Offerings*, NORTHERN SKY RES. (Jan. 30, 2018), https://www.globenewswire.com/news-release/2018/01/30/1314007/0/en/In-Orbit-Servicing-Market-Opportunity-Exceeds-3-Billion.html.

[57] Undseth, Jolly & Olivari, *supra* note 47, at 47; *see* Chrystyna Harpluk, *Agenda for the OECD Space Forum Workshop on the Value and Sustainability of Space Infrastructure*, OECD (Oct. 27, 2021) (listing further questions in the economics of space debris, including "the role of public actors in supporting new markets for debris remediation," in a panel for discussion) (on file with author).

[58] Congress clearly supports the need to understand different possibilities in remediation and repurposing as well. H. R. Rep. No. 115-1102, at 39 (2018) ("This section consists of reaffirmations and a sense of Congress on the risks and need to understand options to address and remove orbital debris.")

The third highest priority area recommended in making progress in addressing the challenges posed by orbital debris is topical area 1.6 – *Incorporate end-of-mission approaches to minimize debris into spacecraft and mission design*. As identified in the Plan, this topical area addresses orbital debris by preventing the creation of further debris. The United States has already been active in addressing orbital debris through supporting end-of-mission approaches. For instance, the FCC currently requires space station applicants to demonstrate how energy sources will be removed or depleted at the end-of-life.[59]

One area of end-of-mission R&D, briefly identified in the Plan, holds particular promise: post-attachment. Currently being demonstrated by the ELSA-d mission, post-attachment is a newly-viable and commercially-led way to prevent the creation of orbital debris by removing LEO spacecraft with a servicer. Removal is ideally conducted before a client becomes disabled, in a controlled end-of-life disposal, but removal can also occur if and when a client becomes damaged, derelict, or otherwise nonresponsive.[60] The interfaces to enable post-attachment are minimally intrusive for operators: Astroscale's standardized interface is lightweight and attaches to a spacecraft with three external screws,[61] and other drag-enhancing devices hold promise.[62] Not only is post-attachment technologically possible, but there are indicators that it is an economically-viable solution for debris prevention.[63]

D. Plan Implementation Should Additionally Prioritize Improved Tracking and Characterization of Debris, as Well as Processing, Sharing, and Filtering of Debris Catalogues, as Data Priorities.

The two final recommended priority R&D areas for making progress in addressing the challenges of orbital debris are included to deliver knowledge of the ecosystem. The penultimate priority R&D topical area is 2.2 – *Develop technologies to improve orbital debris tracking and characterization*. The key to this

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[59] 47 C.F.R. § 25.114(14)(ii) (2021).

[60] *See Astroscale's ELSA-d Successfully Demonstrates Repeated Magnetic Capture*, ASTROSCALE (Aug. 25, 2021), https://astroscale.com/astroscales-elsa-d-successfully-demonstrates-repeated-magnetic-capture/.

[61] *Like a Tow-hook for Satellites: Astroscale Launches Docking Plate to Capture Defunct Satellites*, ASTROSCALE (Nov. 16, 2021), https://astroscale.com/like-a-tow-hook-for-satellites-astroscale-launches-docking-plate-to-capture-defunct-satellites/.

[62] *See* Jennifer L. Rhatigan & Wenschel Lan, *Drag-Enhancing Deorbit Devices for Spacecraft Self-Disposal: A Review of Progress and Opportunities*, 7 J. SPACE SAFETY ENG'G 340 (Sept. 2020).

[63] *See, e.g.*, *Astroscale UK Signs £ 2.5 Million Agreement to Develop Space Debris Removal Technology Innovations with OneWeb*, ASTROSCALE (May 24, 2021), https://astroscale.com/astroscale-uk-signs-2-5-million-agreement-to-develop-space-debris-removal-technology-innovations-with-oneweb/ (Astroscale's…ELSA-m, will develop the technology to remove multiple retired satellites in a single mission. "This multi-client strategy will drive down service costs and incentivize large satellite constellation partners to accelerate the speed at which they remove space junk.").

topical area is the recognition that R&D is needed for both ground-based and *in-situ* tracking and characterization.

Beginning on the ground, there is a stark inability to measure and characterize debris for valuable orbits. There are only three highly-sensitive (i.e., capable of reliably tracking objects < 10 centimeters in diameter) ground-based radars used for civil orbital measurements, and they are variably unavailable.[64] Happily, commercial companies are also making great advancements in space situational awareness (SSA) capabilities; LeoLabs' Global Phased Array Radar Network can track debris as small as 2 centimeters.[65]

Even though the United States has the highest-resolution space-object-imaging radar in the world, there still exists a data gap for debris smaller than 3 millimeters[66] in the most congested region of LEO from ground-based instruments.[67] R&D to increase radar sensitivity and support broader deployment would have the effect of greater characterization and greater safety across orbital operations. Beyond collection, many improvements can be made in sharing and downstream data analytics for SSA. Work to deliver actionable products and services, with heightened precision tracking and clarified uncertainties, will improve avoidance of damaging collisions. The Department of Commerce's Open Architecture Data Repository (OADR) could be the proving ground for a variety of data analytics regarding SSA, sharing mechanisms, and derived analytics.[68]

R&D for improved *in-situ* tracking and characterization is jointly necessary. Compared to their terrestrial counterparts, space-based sensors for tracking and characterization provide a "last mile" form of data. In-situ sensor technologies inform, cross-check, and validate ground-based detections, including those for autonomous collision avoidance, as well as rendezvous, docking, and other in-space operations. In-situ sensing can offer greater resolution than ground-based sensing given the proximity to sensed objects, including the ability to achieve similar orbits.

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[64] NASA OIG Report, *supra* note 6, at 22-3.

[65] *See Global Phased Array Radar Network*, LEOLABS (2020), https://www.leolabs.space/radars/.

[66] Debris larger than 1 millimeter presents the risk of "significant impact or loss of mission due to penetration of fuel tank and other critical infrastructure; erosion of surfaces; potential to crack windows and in the case of human spaceflight, penetrate spacesuits." There are over 100 million estimated pieces of debris 1 millimeter and large in low Earth orbit. NASA OIG Report, *supra* note 6, at p. 3.

[67] NASA OIG Report, *supra* note 6, at p. 22-4.

[68] *See* Dr. Diane Howard, U.S. Dep't Comm., presentation to the U.N. Comm't on the Peaceful Uses of Outer Space Sci. & Technical Subcomm 58th Session, *Open Architecture Data Repository* (Apr. 28, 2021), https://www.unoosa.org/documents/pdf/copuos/stsc/2021/tech-55E.pdf.

Overall, R&D prioritization of tracking and characterization technologies will provide a wholistic orbital environment picture; it will enable operators to characterize their surroundings and choose proper mitigation or remediation strategies as needed.

Expanding on the importance of a holistic environment picture, the final topical area of priority is 2.5 – *Improve data processing, sharing, and filtering of debris catalogs.* Data on orbital debris is ineffective if it is not processed and shared in an operable format. For instance, the catalogue which informs the Debris Assessment Software (DAS) does not yet incorporate tracked 3 to 10 centimeter debris objects, even though the data is available.[69] This leaves operators with an incomplete risk profile of mission-ending debris when conducting debris assessment and planning for missions.[70] The implementation of the Plan must include R&D to standardize, process, manage, and distribute a higher fidelity of information on orbital debris across operators.

Altogether, the five R&D priorities identified herein will have the biggest impact on the orbital debris environment. Above all, a flagship ADR mission to begin the removal of large debris must be prioritized: it can remove a statistically most concerning large object and springboard the subcritical R&D necessary across many mission designs. Second, economic modeling of risk, cost, and benefit will inform U.S. civil and commercial operators of the menu of technologies to address orbital debris, and just as critically, quantify the costs to the entire on-orbit environment if nothing is done. Ongoing activities to support end-of-mission design will slow the creation of further orbital debris. Finally, improving data collection and distribution will create an operable ecosystem of data for utilization in mitigation and remediation activities. Through demonstration, valuation, and preparation, the United States can begin to preserve the space environment that will serve generations to come.

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[69] DAS is informed by NASA's Orbital Debris Engineering Model (ORDEM). J.-C. Liou et al., *Debris Assessment Software User's Guide Version 3.0*, NASA at 2 (2019), https://orbitaldebris.jsc.nasa.gov/library/das3_0/das3.0_usersguide.pdf. ORDEM is based on the U.S. Space Surveillance Network catalogue, "which provides coverage down to approximately 10 cm in LEO and 1 m in GEO. Observational datasets from radar, in situ, and optical sources provide a foundation from which the model populations are statistically extrapolated to smaller sizes and orbit regions that are not well-covered by the SSN catalog, yet may pose the greatest threat to operational spacecraft." M. Matney et al., *The NASA Orbital Debris Engineering Model 3.1: Development, Verification, and Validation*, FIRST INT'L ORBITAL DEBRIS CONF. (2019), https://www.hou.usra.edu/meetings/orbitaldebris2019/orbital2019paper/pdf/6134.pdf.

[70] *See* NASA OIG Report, *supra* not 6, at p. 3 (noting debris 1 centimeter and larger create mission-ending potential risk).

IV. Near-Term Actions by the Federal Government to Direct NASA Technical Development, Adopt Industry Standard Interfaces, and Ensure Adequate Resourcing and Authorization for Industry in R&D Efforts Will Quickly Ameliorate the Orbital Debris Threat.

Humanity has been leaving objects in orbit since Sputnik 1 launched in 1957. Many of these objects have lingered in orbit for decades: Vanguard 1, first launched in March of 1958, holds the unfortunate title of oldest piece of debris in orbit today. The problem of orbital debris is not a small undertaking and has been exacerbated by recent growth in object population as access to space has diversified. Nevertheless, as the United States takes up the mantle of good stewardship and prioritizes demonstration, valuation, and preparation, much-needed progress will follow.

Astroscale submits the following near-term Federal government actions to advance progress in high-priority R&D areas:

1. Work with Congress to authorize and appropriate adequate funding for NASA to develop debris remediation and repurposing missions through TRL 9.
2. Require adoption of industry-developed standardized on-orbit servicing interfaces for U.S. government space systems in LEO.
3. Ensure adequate authorization and monetization for industry involvement in R&D efforts across each of the three core element areas defined in the Plan.

Each of these are discussed separately below.

A. Broadening NASA Remediation and Repurposing Mission TRL Development to TRL 5-9 and Requiring an ADR Mission Adheres to National Space Policy.

As discussed previously, NASA has self-limited its ability to conduct important works in supporting a possible remediation or repurposing mission. Recall in 2014, NASA adopted a policy to not support ADR research beyond technical readiness level ("TRL") 4,[71] forestalling the possibility of investment in R&D for ADR beyond lab-based testing.[72] The first near-term action the Federal government can take to support prioritizing a flagship remediation mission is to require NASA to develop ADR R&D at TRL 5 – 9.

Requiring all-TRL technical development for remediation and repurposing missions at NASA will have near-term effects in addressing orbital debris. The Federal Government should direct NASA to conduct R&D for ADR missions at TRL 5 – 9 over the next three years. Project growth from TRL 5 to 9

[71] Werner, *supra* note 18.

[72] *Id*.; *see* Tzinis, *supra* note 19.

indicates prioritization of effort and investment, commensurate with the significance of the orbital debris problem.

B. Near-term Adoption of Industry Standard Interfaces for U.S. Government Missions Will Promote Expansion of Mitigation Capabilities in LEO.

A second near-term action the federal Government can take, to support mitigation of debris, is simple: lead by example. The Government should adopt standard servicing interfaces to support mitigation efforts.

Directly, including servicing interfaces aligns with R&D priority area 1.6 – incorporating end of mission approaches to minimize debris into spacecraft design. Incorporation of interfaces on government satellites will prepare them for less cost-intensive and more routine services during their service lifetimes. These include life extension, transfer, end-of-life disposal, or repurposing for other mission objectives. The United States should adopt industry-standard servicing interfaces for government LEO satellites and incorporate appropriate on-orbit servicing capabilities when designing government space architectures, operations, and life cycle planning. Through uptake of standard industry servicing interfaces for U.S. Government missions, the government will enhance its own end-of-life capabilities and promote interface suppliers and servicers.

Beyond Federal uptake of standardized interfaces, the Government should also support mitigation (priority area 1.6) through preferential contracting. For example, pricing preferences can be given to operators able to procure, or already incorporating, standard spacecraft interfaces for post-attachment or other servicing. This government action has the additional affect rewarding American businesses for their own mitigation R&D endeavors so far. Contracting price preferences can be enacted as a near-term action that will support debris mitigation.

C. The U.S. Government Must Ensure Adequate Authorization and Develop Partnerships for Industry Involvement in R&D Efforts.

The final near-term action the Federal Government can make to support progress in high priority R&D areas is adequate authorization and appropriation.

Authorization. As demonstrated by the Plan, there are several different agency missions that have overlapping alignment on R&D topical areas.[73] To support near-term actions, there must be a clear demarcation of authority and tasks between agencies.[74] Clear demarcation in authorizations should be supported by a coordinating body which oversees complementary missions and avoid duplicative efforts. Clarity from mission authorization is vital not only for agencies, but also for industry to know where information and innovations are coming from. A "storefront" for information flow will help rapid information exchange as technology continues to develop.

Models for Government/Industry Partnerships. The Federal government has a long history of resource provision to kickstart critical industries, and the challenge of orbital debris mitigation and remediation is no different. The Federal government should support a program for orbital debris removal modeled after NASA's Commercial Orbital Transportation Services (COTS) commercialization initiative.

The goal of the COTS program was to reduce U.S. dependence on Shuttle, Soyuz, and Progress for human-rated transport to the ISS and foster competition for launch service providers in United States.[75] Contracts with COTS companies were openly competed, fixed-price and milestone-driven, meaning that companies themselves also invested and schedule or cost overruns were not the responsibility of the U.S. taxpayer. By opening bids on the contracts to U.S. private industry and engaging in limited investments in the highest-scoring proposals, the U.S. government financed the advancement the U.S. domestic space launch sector. COTS-initiated investments in the U.S. launch market resulted in a more robust U.S. commercial launch industry, lower costs per kilogram to orbit, and new customer bases.

The maturity of commercial on-orbit services makes the orbital debris problem ripe for the application of a COTS-like program for public-private partnership. Applying this model to foster a commercial marketplace of on-orbit services aligns with other U.S. policy goals, including:

- Ensuring robust options for resiliency of U.S. government space architectures;
- Demonstrating U.S. leadership in responsible norms of behavior in space;
- Assure a sustainable U.S. space presence and access to space; and,

[73] National Debris Plan, *supra* note 2, at 13.

[74] For example, NASA did not concur with a finding that they should explore commercial alternatives to Space Fence, stating that: "The recommendation to explore commercial alternatives to obtaining information on debris smaller than 10 cm until Space Fence becomes fully operational would add unreasonable cost-burden to OSMA for a task that the Administration has Assigned to DoD." NASA OIG Report, *supra* note 6, at p. 40.

[75] REBECCA HACKLER & REBECCA WRIGHT, NASA/SP-2014-617, COMMERCIAL ORBITAL TRANSPORTATION SERVICES: A NEW ERA IN SPACEFLIGHT (2014), https://www.nasa.gov/sites/default/files/files/SP-2014-617.pdf.

- Securing the long-term growth and diversification of economic activities for U.S. space companies.

Near-term action to appropriate funds in support of such public-private partnerships can repeat the success of NASA's COTS program for technologies solving the orbital debris problems today.

V. In the Long-Term, the Federal Government Must Support Space Environment Management by Creating a Civil Space Traffic Management Capability.

The creation of domestic space traffic coordination and management (STCM) infrastructure will have a resounding impact on orbital debris. STCM infrastructure is composed of the R&D primarily listed in topical area 2.5 – *Transition research on debris tracking and characterization into operational capabilities*. STCM includes operational elements, such as more transparent and widely standardized practices for how operators should respond to conjunction assessments, and alerts and determine 'right of way' thresholds for executing collision avoidance maneuvers. A centralized civil space traffic coordination and management authority would bolster the ability to solicit stakeholder input into any directives for 'rules of the road' in space, after which the United States would then be prepared to coordinate multilaterally to codify them among international allies.

VI. The Federal Government Can Find Partners Across Industry, Academia, and Internationally, Willing to Partner Through Traditional and Non-traditional Exchanges.

The risks to the space domain operations posed by orbital debris do not discriminate between operators of defense, civil, commercial, academic, or amateur space systems. All functional assets in space are impacted by degradation of the stability, predictability, security, and safety of operations within the space environment.

Recommendation: The Office and the Interagency Working Group, or any other agency that champions debris mitigation and remediation efforts, should coordinate U.S. R&D efforts with international allies and partners to foster norms of responsible behavior in space beyond U.S. borders, to enable a prosperous space economy for the benefit of future generations.

Sustained situational understanding of actors and innovative activities in the modern space economy is essential given the rapid expansion in the number and types of space operators, and the types of missions conducted in space since the turn of the century.[76]

Government. The United States has a long history of engagement in multilateral and bilateral cooperation on space activities. Partnerships in space activities are lasting avenues to strengthen strategic stability, build transparency and trust in international norms, and jointly deliver wide-ranging quality-of-life benefits to the global public. The challenges of orbital debris present an opportunity to continue to build on these successes. International coordination efforts on mitigation standards are already underway in various organizations, such as the Inter-Agency Debris Coordination Committee (IADC) and the U.N.'s working group for the Long-Term Sustainability Guidelines[77].

The Office and the Interagency Working Group should continue its support of those efforts, while also initiating bilateral and multilateral R&D investments for SSA, STCM, and orbital debris mitigation and remediation technologies with international allies and partners. Partnership would hasten the standardization of common data formats, practices, 'rules of the road,' and other operational principles for space safety and information-sharing.

Further, multilateral cooperation would facilitate cost- and burden-sharing for technically and financially resource-intensive topical areas within each of the three core research elements in the Plan. Jointly conducted efforts for R&D in debris remediation technologies and missions can serve as a forcing function to resolve legal and regulatory hurdles encumbering early-stage commercial service offerings in on-orbit services, which in turn would decrease the regulatory burden on other emerging commercial space activities in Earth orbit and cislunar space.

The United States should also look to incorporate lessons from other science and technology industries and models that have proved successful for other governance issues when engaging multilaterally

[76] *U.S. Government Support of the Entrepreneurial Space Age*, SPACE CAP. (2019), https://spacecapital.docsend.com/view/zgbff2a.

[77] Developing partnerships for the purposes of long-term space sustainability shows commitment to the UN COPUOS Long-term Sustainability (LTS) Guidelines, particularly guidelines C1 (Promote and facilitate international cooperation in support of the long-term sustainability of outer space activities), C3 (Promote and support capacity-building), D1 (Promote and support research into and the development of ways to support sustainable exploration and use of outer space), and D2 (Investigate and consider new measures to manage the space debris population in the long term). *See* Comm. on the Peaceful Uses of Outer Space, Conf. Room Paper by the Chair of the Working Group on the Long-Term Sustainability of Outer Space Activities, A/AC.105/2018/CRP.20 (June 27, 2018).

with other nations. For example, it should seek to establish a regular cadence of international diplomatic sessions to conduct capacity-building activities (such as joint R&D projects) for debris remediation. These sessions would advance formal international commitments and contributions to joint debris remediation efforts, capitalizing on the strengths of each national participant (akin to a Paris Climate Agreement model).[78]

Industry. The United States should bolster engagement with industry on guidelines and best practices for safe space operations. Private space operators already play a significant role in formation of precedent for responsible space actions. Industry-led coalitions, consortia, and other groups exchange technical and operational expertise within global multilateral fora to validate and collaborate on space sustainability initiatives, such as the Paris Peace Forum's Net Zero Space[79] initiative. Inputs from industry should continue to be encouraged for future UN COPUOS Long-term Sustainability (LTS) efforts.

Examples of industry-led groups relevant to orbital debris mitigation and remediation include:

- **CONFERS:** Established in 2017 with initial seed funding from the Defense Advanced Research Projects Agency (DARPA), the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) is an industry-led organization. CONFERS uses best practices from government and industry to inform research, development, and publication of non-binding, consensus-derived technical and operations standards for on-orbit servicing and RPO. Its Recommended Design and Operational Practices,[80] which were revised in October 2021, provide "…technical and safety standards for responsible performance of on-orbit activities involving commercial satellites, including rendezvous and proximity operations (RPO) that don't involve physical contact with satellites and robotic servicing operations that would."[81] The Practices provide "…a clear technical basis for definitions and expectations of responsible behavior in outer space".

[78] For more on the application of models such as the Paris Agreement to international cooperation on space debris, *see* Gershon Hasin, *Confronting Space Debris Through the Regime Evolution Approach*, 97 INT'L L. STUD. 1073, 1137 (2019).

[79] Net Zero Space, PARIS PEACE F., https://parispeaceforum.org/en/initiatives/net-zero-space/ (last visited Dec. 27, 2021).

[80] C*ONFERS Recommended Design and Operational Practices*, CONSORTIUM EXECUTION COMMERCIAL RENDEZVOUS & SERVICING OPERATIONS (Oct. 2021), https://www.satelliteconfers.org/wp-content/uploads/2021/11/CONFERS_Operating_Practices_Revised-Oct-21.pdf.

[81] Ana Saplan, *Consortium for Execution of Rendezvous and Proximity Operations (CONFERS)*, DARPA, https://www.darpa.mil/program/consortium-for-execution-of-rendezvous-and-servicing-operations (last visited Dec. 27, 2021).

- **Space Safety Coalition:** Formed in 2019, the Space Safety Coalition (SSC) is ad hoc coalition of operators which also developed a set of Best Practices for the Sustainability of Space Operations,[82] encompassing physical and communications safety in spaceflight operations. Through endorsing these Practices, several industry stakeholders have committed to implement measures that, upon their release in 2019, already surpassed the efficacy of those that have been reached within multilateral, consensus-based government debris mitigation forums, such as the Inter-Agency Debris Coordination Committee (IADC) Guidelines. Examples of such measures within the SSC's Best Practices include consideration of the sustainability of each launch provider's practices, and that operators of satellites utilizing chemical or electric propulsion to deorbit should complete the deorbit phase within a 5-year timeline following end-of-mission, not 25 years. These practices recently surpassed 50 endorsees and will be revisited for further iteration in 2022.

In short, some segments of industry not only recognize the value of collaboration with governmental and regulatory bodies to enhance space environment management practices, but in fact often solicit it directly, even when such efforts result in more robust requirements for their own missions and for government programs they seek to bid on.

Academia and Other Non-governmental Organizations. Academic institutions are optimally positioned to serve as hubs for collaboration between government agencies, academic researchers, non-governmental organizations, and industry. There are already a range of programs at U.S. universities for R&D within several topical areas identified in the Plan, particularly with regards to the tracking and characterization of debris. For example, U.S. academic institutions such as the University of Texas at Austin, Embry Riddle Aeronautical University, and Massachusetts Institute of Technology (MIT)'s Lincoln Laboratory are leading the way in R&D of both ground system and spacecraft design considerations to enhance trackability and object characterization. In addition, space situational awareness tools such as architectures for data curation, processing, fusion, formatting, and information-sharing are underway. Representatives of these institutions actively advocate for the adoption of their R&D efforts, by: regularly testifying before Congressional hearings on space sustainability; responding to Requests for Information and public comment proceedings by government stakeholders, and; collaborating across organizations to develop

[82] *Best Practices for the Sustainability of Space Operations*, SPACE SAFETY COALITION (Sept. 16, 2019), https://spacesafety.org/wp-content/uploads/2021/11/Endorsement-of-Best-Practices-for-Sustainability_v42.pdf.

multilateral space safety governance and incentives tools, such as the Space Sustainability Rating,[83] among others.

In addition to academic institutions, NGOs are optimal forces to bring diverse actors together in one forum to exchange viewpoints. Both NGOs and academia are fitting venues for emerging partnerships, as they already well-versed in multilateral collaboration, and have long been proactive players in the development and deployment of space sustainability technologies.

VII. Conclusion

The challenges that face us today and into the future due to congestion and orbital debris are not unsolvable. At a minimum, the first step the U.S. Government can take is to prioritize R&D in remediation demonstration, economic valuation, end-of-mission preparation, and data optimization to preserve the space environment that will serve generations to come. In the near term, the federal Government can support prioritized R&D with expanded NASA capabilities, modeling adoption of standardized removal interfaces, and above all – clear mission authorization and appropriation. The Government should also work towards a function STCM capability as a key part of space environment management. And while the United States should show leadership, it does not have to do it alone because opportunities to partner internationally, institutionally, and academically will all support collective action to combat our collective challenge of orbital debris.

Astroscale thanks the Science and Technology Policy Office for creating this Request for Comment and working to advance space stewardship.

Respectfully submitted,

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[83] *The Space Sustainability Rating*, MIT MEDIA LAB, https://www.media.mit.edu/projects/ssr-space-sustainability-rating/overview/ (last visited Dec. 27, 2021).