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Bridging National and International Efforts on Space Debris Remediation

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Abstract

After more than a decade of discussion, several countries are making plans for space debris remediation demonstration missions. The European Union, Japan, United Kingdom, and United States have announced plans, proposals, or contracts for national efforts to remove individual pieces of their own debris from orbit. While a positive step forward, these efforts by themselves are unlikely to resolve the long-standing policy, economic, and legal obstacles to creating widespread international efforts to clean up existing space debris.

This paper discusses two proposals - one national and one international - that combined together can help move towards more widespread remediation efforts. First, it outlines a more robust national space debris remediation program for the United States that is modeled on NASA's very successful programs to develop Commercial Cargo and Crew capabilities, which could also be implemented in other countries. Second, it discusses how a trusted non-governmental broker can establish international agreements and contracts that in turn help foster international space debris remediation efforts. Combined, these two proposals provide a roadmap for both national governments and the international community as a whole to put in place a robust space debris remediation effort.

Keywords: space debris, active debris removal

Acronyms/Abbreviations

Active Debris Removal (ADR)
Advance Market Commitment (AMC)
Critical Path Institute (C-Path)
Department of Defense (DoD)
European Space Agency (ESA)
Federally Funded Research and Development Center (FFRDC)
High Mass Debris in High-LEO (HMDHLEO)
Inter-Agency Space Debris Coordination Committee (IADC)
Intergovernmental Organization (IGO)
International Civil Aviation Organization (ICAO)
International Debris Removal Satellite Organization (INREMSAT)
International Institute of Space Law (IISL)
International Non-governmental Organization (INGO)
Just-in time (JIT)
Low Earth Orbit (LEO)
National Aeronautics and Space Administration (NASA)
Non-governmental Organization (NGO)
Private Financing Initiative (PFI)
United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS)
United Nations Economic and Social Council (ECOSOC)

1. Introduction

There has been a significant amount of scholarship over the last decade plus discussing the need for orbital debris remediation, often referred to as active debris removal (ADR). Much of this work stems from the landmark paper by Liou, Johnson, and Hill, which showed that it is necessary to remove at least five large debris objects per year to stabilize the existing orbital debris population and prevent an acceleration in long-term growth of that population due to debris-on-debris collisions [1]. Since then, numerous other international studies have confirmed the need for ADR to help address the threat posed by orbital debris, but also that ADR should be considered alongside other capabilities such as enhanced orbital debris mitigation and just-in-time (JIT) collision avoidance [2].

However, the scientific rationale for orbital debris remediation has not translated to widespread action by spacefaring nations. Japan [3], the United Kingdom [4], the United States [5], and the European Union [6] have announced programs in the last few years to either develop remediation technologies or conduct early stage on-orbit demonstrations, but so far no country has announced a robust program for developing, let alone employing, remediation capabilities. At the same time, the technology to do remediation has been maturing across the world [7]. A significant factor in the lack of progress to date is the debate over the economics of debris remediation [8]. While scholars have recognized the prospect of an "economic Kessler syndrome" [9], there are a wide range of burdens, benefits, actors and alternative solutions to consider in the global commons of space. In addition, there remain several significant legal and policy challenges that need to be addressed, in addition to the technological development, for remediation to be realized [10].

This paper discusses two proposals – one national and one international – that combined together can help move towards more widespread remediation efforts. In section 2, it uses the National Aeronautics and Space Administration's (NASA) very successful programs to develop Commercial Cargo and Crew capabilities as models for a national program to develop orbital debris remediation capabilities, which could be implemented in the United States or any other country with the required political will. Section 3 discusses the concept of a nongovernmental broker that can help establish international agreements and contracts between countries to manage some of the legal, policy, and economic challenges. Section 4 concludes with how these two programs can work together to move towards a more robust international approach, including priorities for next steps.

2. A Robust National Remediation Program

While there has been a significant amount of literature discussing the various remediation capabilities and their underlying technologies that could or should be developed, far less attention has been paid to *how*, in a bureaucratic sense, to create a program to develop them. This section explores this issue, focusing on three areas.

The first area is the need to identify an organization within a government that is willing and able to take on the remediation mission. The second is to determine what success in a remediation program looks like and how it should be measured. The third aspect is what model should be adopted to ensure that the desired outcomes are reached.

2.1 Finding a Champion

One of main challenges in building a national remediation program is to identify which organization or agency within the governmental system is appropriate to lead the program. While the specific answer likely differs between countries, given differences in how they are organized, the rationale for identifying a leader largely remains the same.

Previous work has discussed the public policy and public administration fundamentals of why bureaucracy matters in this context [11]. In short, a government is a collection of bureaucracies that are each a rational, goal-seeking group of individuals motivated by self-interests, which can be created when a government decides there is a need to perform a new function. These become the agencies, departments, etc. that make up a government. One of the key notions is that these bureaucracies within a government create autonomy by identifying their role and purpose as unique and separate from other bureaucracies, and to obtain the resources to sustain its functions.

Thus, in most governments the functions of what different agencies and departments do, and their available resources, is based on their role and purpose. In some cases, these characteristics are defined by a higher executive or legislative authority, but in other cases the role and purpose of an organization can emerge or evolve over time from its activities.

To see how this impacts creation of a remediation program, we can look at the example of the United States. While U.S. national space policy has directed the development of remediation capabilities for more than a decade, this policy goal has not been met in large part because no organization has come to embrace remediation as part of its mission [11]. None of the existing agencies that might take up this mission, such as NASA or the Department of Defense (DoD) have done so, in large part because they do not see orbital debris remediation as part of their core mission area and are loathe to take on an unfunded program. At the same time, there is no political will to create an entirely new agency to take the orbital debris remediation mission. As a result, there is no bureaucratic "champion" that is pushing implementation of this issue, nor putting in budget requests to fund it, despite the top-down policy direction.

Determining which organization within a government is the lead for orbital debris remediation will help resolve these issues and create the opportunity for progress to happen. Top-down policy direction is not enough, as that is usually a fleeting source of continued pressure as other policy priorities emerge. There needs to be an organization within the larger federal bureaucracy that can "catch" that direction and turn it into action.

2.2 Setting Goals and Defining Success

Defining "success" for a public policy program is a complicated endeavor. There are many different types of success, which are a function of the overall political and policy objectives of the program. In some cases, the goal is to develop a new capability or technology, while in others the goal is to influence how other countries behave or act, and in still yet other cases the goal is to create some sort of change in the private sector. All of these options depend on the objectives for which the program was created.

Setting clear policy objectives at the very beginning is critical to a successful national remediation program. Ideally, these objectives should be developed as the result of an interagency or whole-of-government process that pulls in viewpoints from the civil, national security, and commercial sectors. Doing that will help shore up political support for the remediation program and help ensure it delivers a broader range of benefits.

While there will be differences in these objectives between countries, there are some core objectives that are likely to be common between them. The first is that a national remediation program should create more economic opportunities and jobs. Many countries see this as a central rationale for a national space program in the first place. In many industrialized countries such as the United States, Europe, and Japan, this is likely to take the form of stimulating private sector growth, although it may include public sector growth as well. Either way, remediation should be seen as part of satellite servicing, which represents a set of capabilities that could enable and enhance many other parts of the space industry and more sustainable, efficient, and sophisticated space capabilities that, in turn, create widespread economic development and opportunities, not to mention benefitting national security.

Second, a national remediation program must address the regulatory and legal issues, not just the engineering challenges accompanying remediation. In most complex problems, science and engineering often turn out to be the easy part, while the cultural norms, regulatory framework, and public policy implications necessary for acceptance and implementation prove to be much more difficult. When you add in the international nature of space, these "non-technical" aspects are on the critical path for success and must be an inherent part of the program, not an afterthought.

Finally, a successful national remediation program must create a sustained market beyond just government spending. This is likely the most difficult element to achieve and the most important. One-off government contracts and prize competitions are unlikely to meet this goal by themselves, particularly when faced with a large technological leap, non-technical regulatory obstacles, and lack of a well-established market for customers. The recent history of space prizes such as the Ansari X-Prize [12] and the Google Lunar X-Prize [13] demonstrate this. While useful for generating public interest and advancing technologies, they do not have a good track record for yielding a sustainable, long-lasting commercial industry [14].

2.3 Choosing a Role Model

The final major consideration in designing a national remediation program is how to design the program itself to meet the overall goals. Here, there are an overwhelming set of choices to draw from that can be categorized by their degree of public sector and private sector involvement. On one end of the spectrum is an entirely government-funded and run effort that creates a capability operated by a government agency. On the other end of the spectrum is an entirely private sector program, such as the aforementioned prize initiatives. Both approaches have their advantages and disadvantages. Blended public-private models occur across the world and serve a variety of purposes [15].

In the case of a national orbital debris remediation program, it is likely that a program somewhere in the middle will be the most successful at meeting all the goals. This is because there is unlikely to be enough economic incentive to develop and sustain remediation capabilities absent government funding, but there is also unlikely to be the political will to sustain the capability solely from public funding. Governments also need to play a role in resolving the legal and policy challenges, but the private sector is likely to be the best source of innovative ideas that will drive down costs.

Thankfully, there are plenty of examples of such a middle-of-the-road program design, and many of them stem from a concept known as Advance Market Commitment (AMC). Under the AMC model, the government, donors, or other entities promise to buy or subsidize a certain number of products at a price premium that gives a market incentive for companies to develop those products. The products can then be purchased by other government or private sector actors at market price. AMC has been successfully applied to vaccine development with extremely promising results [16], including most recently with COVID-19.

An example of AMC applied in the space world is NASA's effort to develop commercial cargo and crew transportation capabilities for low Earth orbit. This was done through a set of programs developed and run by NASA over the last two decades that included public-private sharing of the R&D costs, competitions to select multiple winners that met government capability thresholds while also being commercially viable, and the promise of government service contracts at the end [17]. As a result, the United States now has a commercial capability to deliver cargo and crew to low Earth orbit for far less than it would have cost to develop a traditional government capability [18]. Moreover, other governmental and private sector actors are now leveraging those same commercial capabilities, which could create a robust market that leads to further innovation and reduced costs [19].

This same approach should be adapted to develop a diverse set of commercial capabilities for orbital debris remediation. Ideally, the program would lead to the development of a robust set of commercial remediation capabilities from multiple companies that all governments can then leverage to reduce the near and long-term threat posed by orbital debris. Towards this end, the program should include remediation demonstrations involving both different countries and objects to help clarify several legal and policy grey areas currently acting as obstacles to a robust orbital debris remediation market.

3. A Trusted Broker for Orbital Debris Remediation

The considerations for designing a national debris remediation program discussed in Section 2 are important, but national programs by themselves will not be enough to meaningfully reduce overall risk in space from debris. To understand why international cooperation across political fault lines is necessary, one must look more closely at the most dangerous debris in space.

3.1 "High Mass Debris in High-LEO"

"High Mass Debris in High-LEO" (HMDHLEO) consists of more than two thousand mostly intact derelict rocket bodies and spacecraft left in space by just seven governments: Russia, the United States, China, France, the European Space Agency (ESA), Japan and India, before the commercial space era began. These government-owned objects, each weighing between one and ten tons, share characteristics which make them amenable to consideration for remediation purposes as a single class or "market". In fact, many emerging remediation technologies across the world are designed around those similarities.

Clusters of these objects litter a few specific orbital shells between 750-1500 km in altitude [20]. They will stay in orbit for hundreds or thousands of years, slowly drifting (at very high speeds) through heavily populated lower orbits before re-entering Earth's atmosphere. Each time one of these high mass objects collides with another derelict or with a functioning satellite, thousands of lethal fragments will be spawned, further endangering active satellites and increasing the cost of operating in space for everyone, for any purpose. These objects (or their conjunctions with other objects) [21] have been specifically identified and are even roughly ranked in terms of the threat they present [22]. Although the majority of these objects are Russian, just seven governments share responsibility for these most dangerous objects.

3.2 Why National Programs are Not Enough

The unique characteristics and constituency of HMDHLEO make purely national solutions unlikely or unable to provide meaningful risk reduction, for a number of reasons.

First, physical similarities of these objects (e. g., size, shape, materials, tumbling characteristics) and their clustering in or above highly desirable orbits cry out for multi-object missions unconstrained by legal ownership or other domestic considerations, for cost savings and other efficiencies. Making remediation affordable is crucial - "to each, your own" will not get the job done.

Second, purely from a statistical perspective, to effectively reduce overall risk from HMDHLEO through unilateral national programs, all seven stake-holder governments must act independently, but one government acting alone does not guarantee another will act. If the United States, for example, were to remove its own objects, Russian objects would still dominate risk probability scenarios. A corollary statistic is also worth noting - the risk these objects pose has recently increased significantly simply because of the growing population of commercial space objects in nearby neighborhoods.

Third, approaching remediation from a purely national posture is based on a flawed "fault-based" premise. All seven governments responsible for HMDHLEO left spent rocket bodies and dead satellites in space as a customary practice during the last third of the twentieth century.* But for the recent commercial race to space, these objects might have been left to decay naturally over hundreds of years without posing significant risk, so it would be historically revisionist to hold any government responsible today for past acceptable (and thus arguably non-negligent) conduct. More pointedly, Russia's forced remediation today of a disproportionately larger number of objects at their own expense would disproportionately reduce future risk to other governments at no cost to them! Remediation can't be motivated by threats of litigation, particularly those influenced by self-interest.

Fourth, the "global commons" nature of space means every individual action impacts everyone else while diluting personal accountability. This has inhibited remediation of cross-border environmental pollution on Earth and would apply equally to remediation of debris in space. Like the Prisoners' Dilemma, cooperation is necessary for an optimum solution, but is unlikely.

Finally, national remediation programs carry heavy political baggage, including domestic preferences, socio-economic priorities, data rights protection rules and national security concerns. In some cases, these political differences rest on even more fundamental philosophical fault lines. Besides handicapping cooperative efforts, political and philosophical differences will make achievement of overall risk

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* To be clear, although states are responsible under international law for authorization and continuing supervision of national space activities, the legal obligation to remediate its own objects does not necessarily flow from that premise.

reduction through national programs more expensive, less effective and confrontational.

In sum, national programs have inherent legal, economic and political overtones that will inhibit timely, efficient and meaningful risk reduction. Cooperation among the three principal stakeholders for HMDHLEO, Russia, China and the United States, but also including France, Japan, India and ESA, will be necessary to reduce overall risk. But how can unfriendly sovereigns join hands to achieve their shared objective of safe and sustainable space, *before* the next collision?

3.3 Models for International Cooperation

Just as a wide range of public, private and blended approaches are possible for national remediation efforts, three types of cooperative models are possible for international cooperation. Private-public arrangements among governments would either employ a private non-governmental organization (NGO) to facilitate cooperation among participating governments or rely on a purely private source of funding for remediation (i. e., non-cooperative but requiring legal consent from each sovereign government whose objects are to be remediated). The other two types of cooperative models involve governments acting together without a private intermediary, either multilaterally through an intergovernmental organization (IGO) under a United Nations enabling umbrella, or directly under bilateral agreements.

3.3.1 Private-Public

An NGO is a privately held organization that is independent of government involvement (although it may receive government funding) and is operated by voluntary citizens towards a common interest. They are typically non-profit entities. The term as it is used today was first introduced in Article 71 of the newly-formed United Nations Charter in 1945. NGOs can operate at a local, national or international level to achieve objectives in support of the public good. They exist today in a variety of models and have evolved in different ways to best serve the interest they represent.

TCTB is an existing multi-jurisdictional, non-profit, international NGO (INGO) that has been created specifically to enable cooperative planning for remediation of HMDHLEO [23]. TCTB is an acronym for "Three Country-Trusted Broker" which describes its business model in a few words. It would ally stake-holding governments to a shared purpose through separate but interdependent domestic "prime" contracts with TCTB, or under a single contract with the United Nations "back-funded" by participating governments. Cooperation would be achieved through contractual agreements on common but necessary principles (e. g., cost, risk and information sharing, legal consent, protection of sovereign prerogatives, dispute resolution and procurement mechanisms). TCTB would facilitate and lead cooperative planning and could engage and manage competitively selected remediation "subcontractors" using pooled funding legislatively authorized by each participating government. Governments would participate through "firewalls" inside TCTB designed to protect sensitive or proprietary information embedded in the debris targets or remediation technology. TCTB would engender trust among governments through independence (neutrality), transparency and domestic presence. TCTB's private-public arrangement is portrayed in Figure 1. Depicted as a three-country structure, other governments could be added.

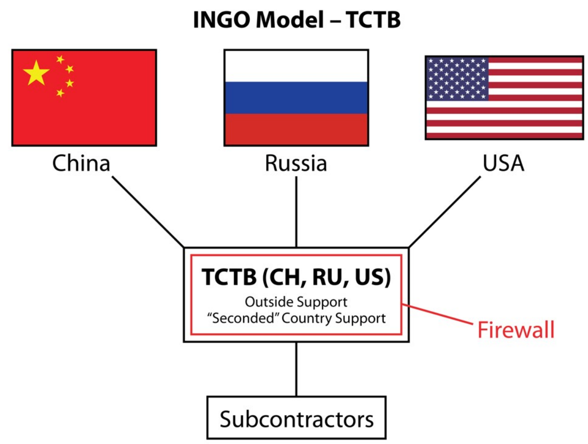

Fig 1 – How TCTB is organized to facilitate cooperative remediation.

Other private alternatives have been proposed, including salvage, bounties, and prizes, but all lack paying customers. Salvage would require development of two separate industries, remediation and re-use, and would struggle to overcome legal and economic hurdles to remediation. Privately funded bounties and prizes fail to meet the steep cost and risk challenges of HMDHLEO. Finally, recent commercial activity in LEO will simply not yield sufficient profit margins to enable remediation of the most dangerous government-owned HMDHLEO, even if it could otherwise address the remaining daunting legal and national security challenges.

3.3.2 Public (Intergovernmental Organization)

An Intergovernmental Organization (IGO) is an organization established among sovereign states through formal treaties under international law in furtherance of a shared purpose. In most cases, the United Nations provides the framework for multilateral IGOs. IGOs can be framed around a common interest or region, and the number of members can vary. They can be inclusive or restrictive regarding membership, and broad or narrow in scope. They vary in longevity, degree of formality, granted authority, and internal governance structure. IGOs (or their derivatives) which could be newly created or re-purposed for cooperative remediation include two, the International Debris Removal Satellite organization ("INREMSAT") [24] (new, derived from INTELSAT), and the International Civil Aviation Organization ("ICAO") [25] (existing), both of which have already been proposed by others, and one hypothetical structure, "ADR (new)", which could be established exclusively for the purpose of cooperative remediation. In general, IGOs require lengthy and often contentious gestation periods before operations can begin.

3.3.3 Public (Bilateral)

Direct cooperation among two or more participating governments without forming an IGO, the other purely public alternative, could be implemented on a bilateral basis starting with two governments and then adding more (i. e., "Debris Accords"). The "market" for HMDHLEO has only a handful of stakeholders, which suggests a bilateral approach among a small group of governments might be feasible. Although politically controversial in some circle, the recent Artemis Accords for cooperative exploration of the Moon and deeper space reflects such a model [26]. By analogy, "Debris Accords" could be implemented through bilateral agreements containing mutually acceptable principles for cooperative remediation. "Debris Accords" would not implicate any changes to existing international law, but, like IGOs, they would still require diplomacy among adversaries which might be impossible in today's polarized political environment.

3.4 Key Factors Enabling Cooperation

The unique challenges presented by HMDHLEO, namely, imminent risk, technical similarities, high overall cost, and necessary involvement of a handful of adverse sovereign governments, will frame any cooperative solution. There are five keys to finding the best cooperative path to overcome policy, legal and economic hurdles.

Opportunity versus fault - The first is understanding and overcoming the mismatch between fault and opportunity. Developing an equitable cost and risk sharing formula must be based on future opportunity in space, not mired in past "fault". Any of the models for cooperation noted above are capable of achieving this. Sharing cost and risk based on future opportunity in space that would be enabled by remediation (i.e., cost avoided) is fairer, and would better motivate participants.

Share the burden - Equitably sharing the admittedly high cost and risk of remediation missions among seven governments over the several years it would take makes remediation of HMDHLEO more affordable. For example, assuming a $5B price tag to remediate the 100 most dangerous objects in 10 missions (10 objects per mission, $.5B per mission) over ten years would amount to roughly $71m per year per government, if cost and risk were shared equally among all seven. (Future technical developments accessible through a world-wide competitive selection process may provide viable alternatives to removal from orbit and help mitigate overall cost.) Some governments might choose to provide in-kind sharing (e. g., launch costs, salvage opportunities) and/or subsidies to domestic remediation competitors. Cooperation, coupled with burgeoning capabilities stimulated through national programs, enables efficiency, affordability, and wider opportunity. Moreover, once begun, cooperative remediation would yield recurring cost savings through repetition (economy of scale) and enable adjacent markets.

Remove politics as much as possible - IGOs under a United Nations umbrella and bilateral government-to-government agreements are not immune to politics and bureaucracy. Employing an apolitical INGO like TCTB to help governments accomplish a shared purpose could overcome the inevitable political differences and necessary bureaucratic structure that would complicate and prolong any inter-governmental negotiation.

Maximize transparency and trust - The fourth key to cooperation is maximizing transparency and trust among participating governments. This would be challenging working through an IGO or bilaterally but could be more easily achieved through a non-sovereign, multi-jurisdictional, single purpose INGO like TCTB.

Streamline to meet the urgent need - Finally, limiting remediation planning discussions to include only those topics related to the shared objective (e. g., cost, risk and information sharing, legal consent, target selection methodology, procurement plan, dispute resolution mechanism and protection of sovereign prerogatives) could avoid bureaucratic and diplomatic entanglements that could delay or prevent concerted action. By definition, a private INGO has no political agenda.

3.5 A Cooperative Path Forward

Timely cooperation will be necessary to meet the existential challenge of HMDHLEO, but any cooperative formula must preserve sovereign prerogatives and serve the best interests of each participating government without getting bogged down in political or bureaucratic entanglements. Where the only common ground among the three key protagonists is a desire to reduce risk in space in order to better fulfill their respective (and conflicting) national destinies in space, an INGO is the best alternative.

INGOs act globally but operate locally. Thus, while no cross-border agreements, changes to international law or establishment of any new cooperative legal structure would be required to implement TCTB's solution, domestic regulations must be wisely applied in each jurisdiction to avoid derailing the shared purpose.

If effective, efficient remediation of the most dangerous objects in space is to begin *before* the next collision, in addition to continuing and broadening national efforts, and as an integral complement to cooperative space traffic management and debris mitigation initiatives for new space objects, cooperative planning for remediation of HMDHLEO among key stake-holder governments needs to start now. Looking even further ahead, successful remediation of HMDHLEO through a contract-based private-public INGO could lead to remediation of other debris, in space or on Earth, using the same model. In truth, realizing a sustainable future in any shared space depends on cooperation.

TCTB already exists with citizen partners in each of the three major jurisdictions and can be engaged now under a single United Nations contract, or through separate domestic agreements. In Russia, TCTB will be represented by a Russian legal entity to be formed for that purpose. In China, TCTB is led by Harmonize Space, a Chinese consulting entity for space-related matters, and in the United States, TCTB is a Limited Liability Company (LLC) organized under Texas law. TCTB's partners collectively possess broad experience in international and space law, procurement law and planning, international mediation, management systems, governance structures, and public-private collaboration which, when coupled with TCTB's novel creative vision, can provide a bridge for stake-holder governments to work together to plan for and accomplish the shared goal of real remediation while setting aside philosophical and political disagreements on unrelated matters. Costs of planning through TCTB would be negligible.

TCTB has published a detailed road map to guide cooperative planning among stake-holder governments, which is found in a series of papers contained on its website [27]. The papers provide more detailed descriptions of the "Trusted Broker" model (think Red Cross or international mediation) and the legal, political, national security, economic and funding hurdles that have prevented remediation to date; the planning process; a cooperative methodology for object selection and remediation technology; an analysis of alternative structures for cooperation; and cooperative principles in the form of fully-drafted contract clauses.

6. Conclusions and Recommendations

Remediation deserves the world's attention, but results will not be attainable overnight. Development of national capabilities and planning for international cooperation will take several years before missions are possible.

Two actions could be taken now, one national and one international, to get started.

In the United States, funding could be allocated by Congress to NASA for remediation *planning*, including development of commercial capabilities via the AMC model. Other countries could also establish funding and specific programs for technical demonstrations to advance remediation technologies.

On an international level, the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) could sponsor a set of *planning* meetings between TCTB and the Inter-Agency Space Debris Coordination Committee (IADC) representatives for China, Russia and the United States to begin exploring cooperative remediation. IADC representatives could act as government focal points to coalesce whole-of-government views on key questions (e. g., cost, risk and information sharing, legal consent, target selection methodology, procurement plan, dispute resolution mechanism and protection of sovereign prerogatives), in seeking common ground among adversaries.

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References
[1] J.-C. Liou, N.L. Johnson, and N.M. Hill, Controlling the growth of future LEO debris populations with active debris removal, *Acta Astronautica,* Vol 66, Issues 5-6, March-April 2010, pp 648-653, https://doi.org/10.1016/j.actaastro.2009.08.005
[2] C. Bonnal, D. McKnight, C. Phipps, C. Dupont, S. Missonnier, L Lequette, M. Merle, and S. Rommelaere, Just in time collision avoidance - A review, *Acta Astronautica*, Vol. 170, May 2020, pp. 637-651, https://doi.org/10.1016/j.actaastro.2020.02.016
[3] Commercial Removal of Debris Demonstration (CRD2), *Japanese Space Exploration Agency,* https://www.kenkai.jaxa.jp/eng/research/crd2/crd2.html (accessed 01.08.22)
[4] J. Rainbow, UK funds studies to remove two spacecraft from LEO, *SpaceNews*, October 26, 2021, https://spacenews.com/uk-funds-studies-to-remove-two-spacecraft-from-leo/ (accessed 01.8.22)
[5] S. Erwin, Space Force selects 125 industry proposals for on-orbit servicing technologies, *SpaceNews*, 2 May 2022, https://spacenews.com/space-force-selects-125-industry-proposals-for-on-orbit-servicing-technologies/ (accessed 01.08.2022)
[6] A solution to the problem of space junk, European Commission, https://ec.europa.eu/research-and-

innovation/en/projects/success-stories/all/solution-problem-space-junk (accessed 01.08.22)

[7] A. Cavaciuti, J. Heying, J. Davis, In-Space Servicing, Assembly, and Manufacturing for the New Space Economy, Aerospace Corporation Center for Space Policy and Strategy, July 2022, https://csps.aerospace.org/sites/default/files/2022-07/Cavaciuti-Davis-Heying_ISAM_20220715.pdf

[8] N. Adilov, P.J. Alexander, and B.M. Cunningham, Economic dynamics of orbital debris: Theory and application, First International Orbital Debris Conference, December 2019, https://www.hou.usra.edu/meetings/orbitaldebris2019/orbital2019paper/pdf/6072.pdf (accessed 01.08.22)

[9] N. Adilov, B. M. Cunningham, P. J. Alexander, An Economic "Kessler Syndrome": A Dynamic Model of Earth Orbit Debris, preprint January 2018, https://www.researchgate.net/publication/326656441_An_Economic_Kessler_Syndrome_A_Dynamic_Model_of_Earth_Orbit_Debris

[10] B. Weeden, Overview of the legal and policy challenges of orbital debris removal, *Space Policy*, Vol 27, Issue 1, February 2011, pp. 38-43, https://doi.org/10.1016/j.spacepol.2010.12.019

[11] B. Weeden, The evolution of U.S. national policy for addressing the threat of space debris, 678th International Astronautical Congress, 26-30 September 2016, https://swfound.org/media/205624/iac-16a683-weeden_evolution_us_space-debris_policy-paper.pdf

[12] J. Foust, 'What the hell happened?': The rise and fall of commercial suborbital tourism companies, *SpaceNews*, 13 June 2017, https://spacenews.com/what-the-hell-happened-the-rise-and-fall-of-suborbital-space-tourism-companies/

[13] A.G. Smart, The demise of the Google Lunar X-Prize, *Physics Today*, 31 Jan 2018, https://physicstoday.scitation.org/do/10.1063/pt.6.2.20180131a/full/

[14] L. Kay, The effect of inducement prizes on innovation: evidence from the Ansari X Prize and the Northrop Grumman Lunar Lander Challenge, *R&D Management*, Vol 41:4, September 2011, https://doi.org/10.1111/j.1467-9310.2011.00653.x

[15] Blended public-private models in other industries include Federally Funded Research and Development Centers (FFRDC) like Sandia National Laboratories (https://www.sandia.gov) (accessed 08.11.22) which was formed to help manage the United States' nuclear stockpile, and neutral parties like Critical Path Institute (C-Path) (https://c-path.org) (accessed 08.11.22) which stands between industry and the regulatory community to streamline development and regulatory approval of new lifesaving medical technology. C-Path is a non-profit spin off from Silicon Valley research pioneer SRI International, an independent, non-profit organization which recently also spun off LeoLabs. The United Kingdom's successful experience with Private Financing Initiatives (PFI), where the government retains ownership of a public asset while private industry provides a service in managing it, is to the same effect. The Skynet program, a space-related PFI project where private industry provides communications services for the United Kingdom's military communications satellites, is described at https://en.wikipedia.org/wiki/Skynet_(satellite)#Skynet_5 (accessed 08.09.22)

[16] M. Kremer, J.D. Levin, and C.M. Snyder, Advance Market Commitments Insight from theory and experience, *National Bureau of Economic Research*, working paper 26775, February 2020, https://www.nber.org/papers/w26775

[17] C.F. Bolden, Jr, Reflections on Commercial Cargo and Crew Missions, *NAE perspectives*, 16 November 2020, https://www.nationalacademies.org/news/2020/11/reflections-on-commercial-crew-and-cargo-missions

[18] E. Berger, The numbers don't lie – NASA's move to commercial space has saved money, *Arstechnica*, 20 May 2020, https://arstechnica.com/features/2020/05/the-numbers-dont-lie-nasas-move-to-commercial-space-has-saved-money/

[19] L. Grush, How the SpaceX crew dragon mission could shape the future of commercial space, *The Verge*, 21 May 2020, https://www.theverge.com/21255700/spacex-crew-dragon-mission-launch-nasa-commercial-space-travel-tourism

[20] J.-C. Liou, "An Active Debris Removal Parametric Study for LEO Environmental Remediation", *Advances in Space Research*, Vol. 47, Issue 11, pp. 1865-1876, https://www.sciencedirect.com/science/article/abs/pii/S0273117711000974

[21] M. Stevenson, D. McKnight, H. Lewis, C. Kunstadter, R. Bhatia, Identifying the Statistically-Most-Concerning Conjunctions in LEO, AMOS Conference, September 15, 2021, https://amostech.com/TechnicalPapers/2021/Poster/Stevenson.pdf

[22] D. McKnight, R Witner, F. Letizia, S. Lemmens, L. Anselmo, C. Pardini, A. Rossi, C. Kunstadter, S. Kawamoto, V. Aslanov, J.C. Dolado Perez, V. Ruch, H. Lewis, M. Nicolls, L. Jing, S. Dan, D. Wang, A. Baranov, and D. Grishko, Identifying the 50 statistically-most-concerning derelict objects in LEO, *Acta Astronautica*, Vol 181, April 2021, pp.

282-291, https://doi.org/10.1016/j.actaastro.2021.01.021
[23] TCTB has been recognized as an NGO by the United Nations Economic and Social Council (ECOSOC).
[24] Proposal for an Operational and Regulatory Framework to Ensure Space Debris Removal, McGill Institute of Air and Space Law, September 2020, https://iaass.wildapricot.org/resources/Documents/Discussion%20Paper%20-%20Proposal%20for%20an%20Operational%20and%20Regulatory%20Framework%20to%20Ensure%20Space%20Debris%20Removal%20(6).pdf
[25] S. Kaul, International Cooperation in Space Exploration: Managing the Low Earth Orbital Issues, GLEX 2021,1,1,1,2,2, x62001, St. Petersburg, Russia, July 2021, https://iafastro.directory/iac/paper/id/62001/ext/abstract-pdf/GLEX-2021,1,2,2,x62001.brief.pdf?2021-03-04.10:47:22
[26] The elements of NASA's "Artemis Program" are more fully described at https://www.nasa.gov/specials/artemis/ (accessed 08.08.22)
[27] TCTB's website is at threecountrytrustedbroker.com (accessed 08.08.22)