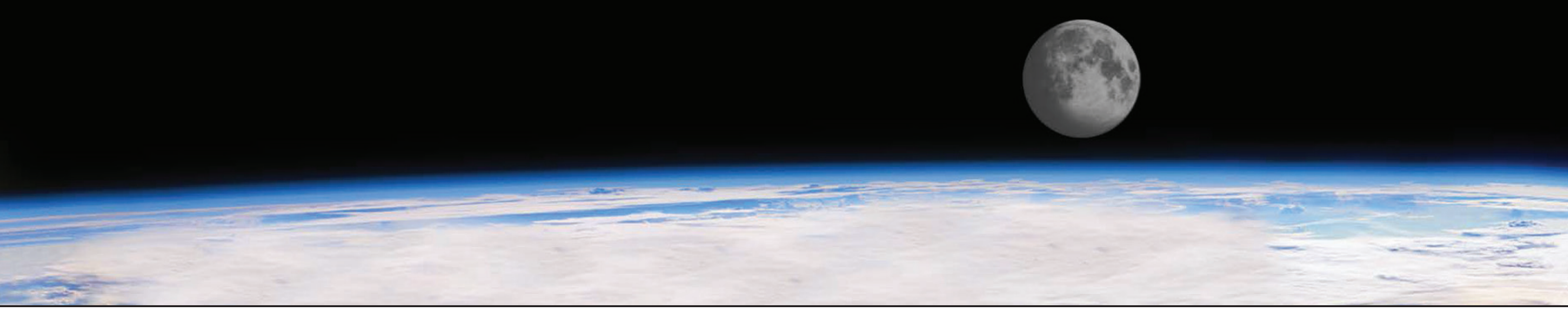

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Orbital Debris Remediation Through International Engagement

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Foreword

There is broad international agreement that orbital debris constitutes a serious and growing threat to space operations in Earth orbit, prompting spacefaring nations to approve mitigation guidelines in international forums. Although there is more to be done to encourage implementation of these guidelines, work has already begun on the next step: remediation. As technical barriers to on-orbit cleanup are overcome in both government and private-sector efforts, political and legal barriers will loom larger and become time-consuming challenges. This paper suggests an approach that could surmount these barriers within the current environment of international treaties and efforts to establish behavioral norms.

Debris Mitigation Standards: The Story So Far

Today's orbital debris mitigation standards are the result of a gradual evolution on both domestic and international fronts. The current U.S. guidelines were developed in the late 1990s in a collaborative effort between the Department of Defense (DOD) and NASA, and adopted by the National Security Council as national guidelines in December 2000.[1] Immediately thereafter, the U.S. began the long process of gaining international acceptance of the guidelines to encourage existing and emerging spacefaring nations to use best practices that would help control the growing debris problem. This effort was eventually successful in establishing voluntary international guidelines very similar to those followed by the United States.

Global adoption of best practices for mitigation is ongoing, but even broad success in this area would not provide a full solution to the debris problem. The next step, removal of debris, has been discussed for decades without advancing to the implementation stage due to technical and affordability limitations. Policy and international law concerns were identified, but these remained in the background as the formidable technical challenges pushed the testing and deployment of remediation systems well into the future.

Operational debris removal systems may no longer be such a distant prospect. Advances in robotics, satellite bus design, automated rendezvous and docking, and low-mass orbital maneuvering systems, coupled with a variety of efforts to reduce launch costs, may make debris remediation practical in the next 10 to 15 years. Using the same technologies, commercial space operators have demonstrated an interest in developing satellite servicing capabilities in even shorter timeframes.[2,3] Meanwhile, NASA conducted risk-reduction demonstrations for satellite refueling aboard the International Space Station starting in 2011[4] and in December 2016 awarded a contract for a satellite servicing demonstration spacecraft, Restore-L, to be flown in 2020.[5] If practical technological solutions are starting to appear on the horizon, it's not too early to give attention to hurdles in policy and international law that need to be surmounted if remediation efforts are to be successful. The two most significant hurdles are 1) international law that treats salvage in space differently from salvage at sea, and 2) remediation technologies and operations that look like and could double as antisatellite (ASAT) systems.

To Salvage or Not to Salvage?

Given the degree of importance assigned to the debris problem today, it may seem surprising that there were no consequential actions to promote good practices on the international scene throughout the Cold War, even in the period from the mid-60s to the mid-80s when numerous space treaties and principles were enacted. While debris was a concern, it was not seen as an imminent threat requiring broad actions by the major players. No practical cleanup technologies were available. Furthermore, the U.S. and the Soviet Union were not inclined to seek compromises that involved sharing sensitive information about space system operations and plans for debris-causing tests.

The Outer Space Treaty (OST) of 1967[6] established the Cold War's only rules governing the treatment of orbital debris. Article IX, which is primarily concerned with contamination from extraterrestrial matter, is generally interpreted to be applicable to orbital debris as well, due to language that directs "appropriate international consultations" prior to engaging in activities that could cause "potentially harmful interference with activities of other States Parties." To address the sensitivities of the two superpowers—each worried that the other would try to abscond with its satellites—the OST granted perpetual ownership of space objects to their launching state, even after the objects are deactivated and become uncontrolled junk. Although this is an obstacle to effective cleanup efforts, most active spacefaring nations (including the U.S.) are reluctant to suggest changes to the OST despite the fact that Article XV permits any signatory to offer amendments.

Article VIII specifies that ownership stays with the original owner, no matter where a space object is found or whether it is brought back to Earth. Any State Party to the OST attempting to salvage space objects that it doesn't own or have jurisdiction over must do so with the permission of the owner. Since Article VI makes State Parties responsible for the actions of their non-governmental entities, private sector salvage operators must play by the same rules when space objects of foreign ownership are involved.

Eventually, as space operations become more sophisticated and active removal becomes a practical way to address the debris problem, the space salvage restriction will need to be addressed in some manner to allow actions akin to salvage at sea. Diplomats in the 1960s were not thinking about establishing a business-friendly environment for space salvage, and diplomats today will not do so unless the required technologies, a plausible business case, and political feasibility are within sight.

Increasing Concern after the Cold War

Greater attention to the debris problem developed in the late 1980s through the 1990s, both domestically and internationally, as the number of spacefaring countries—and space objects to be tracked—was poised to grow.[7] As noted earlier, DOD and NASA developed the debris mitigation standard practices that would become national guidelines at the end of 2000. They were built around four objectives:

1. Control of debris released during normal operations;
2. Minimizing debris generated by accidental explosions during and after mission operations;
3. Selection of safe flight profile and operational configuration to limit the probability of creating debris by collisions; and
4. Postmission disposal of space structures to minimize impact on future space operations.

Of particular interest to this discussion is the last of these, and the three methods outlined for end-of-life disposal: atmospheric reentry (within 25 years), maneuvering to storage orbit, and direct retrieval.

The U.S. proposed these guidelines to the international community through NASA's participation in the Inter-Agency Space Debris Coordination Committee (IADC), an organization founded in 1993 that currently includes 13 of the world's most active civil space agencies. The IADC published its own version of the guidelines in 2002.[8] The essential elements are the same as the U.S. version, with additional background information, definitions, and some technical details. The IADC presented this version to the U.N. Committee on the Peaceful Uses of Outer Space (COPUOS), which deliberated on it for five years before issuing its own version,[9] which was endorsed by the U.N. General Assembly a few months later.[10] Once again, the COPUOS version retained the same essential elements, although it dropped the more technical points in the IADC guidelines. The U.N. document does not mention the 25-year limit to postmission low Earth orbit (LEO) lifetime, and does not specify disposal orbits, instead simply stating that non-operational space objects "should be disposed of in orbits that avoid their long-term presence" in LEO or geosynchronous Earth orbit (GEO). (Other orbital regimes are not mentioned). In this area, the U.N.

guidelines are less stringent than those of the U.S. government, and in no area are they more stringent.

"Rules of the Road" Proposals

The international space community has long recognized the difficulty in formulating a treaty on space debris, which has been opposed by major spacefarers, including the United States. As an alternative to the long and delicate process of creating a legally binding treaty, interested parties have proposed adoption of voluntary "rules of the road" to guide behaviors in space, with orbital debris mitigation (but not remediation) prominent among those behaviors. The calls for action have increased in recent years in the wake of several debris-creating incidents, most prominently the January 2007 Chinese antisatellite test, the February 2008 intercept of a disabled U.S. satellite, and the February 2009 collision of an active Iridium satellite and a defunct Russian Cosmos.

The debris population will continue to grow even in the absence of future launches due to collisions, particularly in LEO…

The International Code of Conduct for Outer Space Activities,[11] proposed by the European Union, addressed space debris, mentioning it several times throughout the document. The preamble recognized that "space debris affects the sustainable use of outer space, constitutes a hazard to outer space activities and potentially limits the effective deployment and utilization of associated outer space capabilities." In space operations, subscribing states are asked to commit to:

- avoid, to the greatest extent possible, any activities that may generate long-lived space debris;
- adopt and implement, in accordance with their own internal processes, the appropriate policies, and procedures or other effective measures in order to implement the [U.N. Space Debris Mitigation Guidelines];
- take all reasonable measures to minimize the risks of collision; and
- notify, in a timely manner, to the greatest extent possible and practicable, all potentially affected Subscribing States on the outer space activities conducted which are relevant for the purposes of this Code [i.e., real or potential space hazards].

There was related activity at the U.N. in the Working Group on Long-Term Sustainability of Outer Space Activities under COPUOS. Its multiyear work plan, approved in 2011, was intended to identify best practices in a variety of areas designed to keep space accessible and usable for all nations.[12] Its proposed guidelines on space debris and space operations (Expert Group B) largely mirrored the U.N. Space Debris Mitigation Guidelines and suggested practices in data sharing. No guidelines were proposed for space debris removal.[13]

Toward Remediation

Clearly, the emphasis to date has been on preventing the creation of debris and on international cooperation in tracking what is in orbit. But debris cleanup has not been completely neglected, as this 2009 conference finding indicates:

> Space debris remediation, i.e., active debris removal from orbit, was identified as the next necessary step... mitigation alone cannot maintain a safe and stable debris environment in the long-term future. Active space debris remediation measures will need to be devised and implemented. This is the main message from [the 5th European Conference on Space Debris].[14]

Research at NASA, presented to the IADC and other space community forums, has found that the debris population would continue to grow even in the absence of future launches due to collisions, particularly in LEO. The only way to stabilize the population is through a combination of strong adherence to existing mitigation guidelines (which has not yet been achieved) and active removal of at least five objects per year that have relatively large mass and high probability of collision. Based on these criteria, modeling techniques have been used to create a list of hundreds of priority objects among the existing population of inactive satellites and spent rocket bodies.[15] Researchers in spacefaring nations have proposed various means for interception and deorbiting of large objects, usually involving robotic attachment of small engines. Some proposals involve encounters with multiple objects on a single mission.[16]

The ASAT Problem

In addition to complications in international law on space object ownership, the other major obstacle is the inescapable fact that debris remediation technologies and operations look like and could double as ASATs. Any system that can conduct tracking, rendezvous, and manipulation of a satellite can destroy it or at least disrupt its functions. (Capturing an active satellite would be easier than capturing an inoperative one that may be in an uncontrolled spin.) International mistrust and possible obstructionism must be overcome if effective remedial operations are to be established.

This problem has appeared in various forms for many years. In negotiations with the USSR on ASAT arms control during the Jimmy Carter administration, the Soviets raised objections to the forthcoming space shuttle, which they labeled an ASAT weapon system.[17] More recently, experiments in autonomous proximity operations by the Air Force (XSS-11), NASA (DART), and DARPA (Orbital Express) were interpreted by some to have at least secondary objectives in ASAT development.[18]

As retrieval becomes feasible, it may be preferred over the practice of routinely maneuvering satellites out of the way of debris in an environment of increasing traffic…

A closely related problem is the emergence of new kinds of private-sector operations in orbit, such as research platforms[19] and the already-mentioned robotic servicing of satellites. These are planned for deployment within the next decade, but no regulatory regime exists in the U.S. or elsewhere to oversee these types of commercial on-orbit activities. The U.S. has regulatory procedures in place to address launch, reentry, spectrum use, slot assignments in GEO, and debris mitigation, but not on-orbit actions such as proximity operations or debris removal. It is possible that international objections will be raised on the grounds that spacefaring nations are not fulfilling their obligations under Article VI of the OST:

> States Parties to the Treaty **shall bear international responsibility** for national activities in outer space, including the Moon and other celestial bodies, **whether such activities are carried on by governmental agencies or by non-governmental entities**, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty. **The activities of non-governmental entities in outer space,** including the Moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty [emphasis added].

Objectors may not wait for the establishment of commercial satellite servicing before raising their complaints. Objections may be sincere or opportunistic, driven by operational safety concerns, fear of ASATs, or simply a desire to negatively portray other countries' actions.

This is a problem facing not just debris remediation, but all manner of orbital activities that go beyond the limited practices of the past half century. Innovators in these areas will need to work together to exhibit transparency, engaging with existing and emerging spacefarers in consultations about startup plans and rules of behavior.

Possible Solutions

For a long time, the conventional wisdom was that small debris should be the primary objective for cleanup because it exists in very large numbers, it can't be tracked, and it's capable of doing considerable damage. But cleaning up the small stuff was a challenge with no feasible technical solutions on the horizon. Meanwhile, dead satellites and rocket bodies were seen as presenting a lesser threat because they could be tracked and avoided, so retrieval was a lower priority. This view was changing even before the 2009 Iridium-Cosmos incident as the population of derelict spacecraft and the likelihood of collision in orbit increased. With development of retrieval capabilities, the old logic reverses: nonfunctional satellites and rocket bodies can be tracked, intercepted, grappled, and removed from orbit before they are impacted and become thousands of pieces of untrackable debris. As retrieval becomes feasible, it may be preferred over the practice of routinely maneuvering satellites out of the way of debris in an environment of increasing traffic.

Government and/or commercial entities contemplating retrieval operations must be able to choose their objectives well in advance. If this involves seeking permission on a case-by-case basis from foreign governments, without the benefit of established procedures, it will be an expensive and time-consuming process that is likely to limit the available objects and undermine the already fragile economics of this activity. If the parties to the OST continue to object to any attempts to update its language, then no remedy will be available in the OST's amendment process to accommodate a modern approach to salvage in space.

Fortunately, a remedy may be available under the Registration Convention.[20] Article IV requires signatories to provide a basic set of information to a U.N. registry soon after the launch of a space object. It also requires notification when an object is no longer in space, having been deorbited or otherwise removed. There is no requirement to report anything about the object during the time between its placement in space and its removal. But although it's not required, signatories may provide input during the on-orbit life of a space object. Article IV states, in part:

> Each State of registry may, from time to time, provide the Secretary-General of the United Nations with additional information concerning a space object carried on its registry.

The nature of the "additional information" is not specified in the Convention, but it could include notification that an object, though still in orbit, is no longer functioning and is not expected to be reactivated. Another possibility is that an active satellite could change ownership through a commercial or intergovernmental transaction, transferring the responsibility for that satellite to another nation.

If the Convention's signatories agree that action is needed to enable debris cleanup, they could create a separate category in the registry for expired satellites and rocket bodies, labeling them "available for salvage." To date, expended hardware has been allowed to remain in orbit for many years, posing a collision hazard and fragmentation risk. As remediation techniques become available, signatories could be encouraged to put their space objects on the "available for salvage" list as they expire. In doing so, they would signal that "if you haul it away, it's yours" but would retain ownership responsibilities until a successful retrieval mission was performed. If an object is salvaged, then the original owner is relieved of responsibility (and potential liability) for that object; if no retrieval is attempted, the outcome is no different than under the current treaty regime.

More detailed considerations would need to be worked out as this process is established: At what point are ownership and liability transferred to the salvager (e.g., first contact in orbit; completion of retrieval mission)? If the

Text of Article VIII of the Outer Space Treaty

A State Party to the Treaty on whose registry an object launched into outer space is carried **shall retain jurisdiction and control** over such object, and over any personnel thereof, while in outer space or on a celestial body. **Ownership of objects launched into outer space, including objects landed or constructed on a celestial body, and of their component parts, is not affected by their presence in outer space or on a celestial body or by their return to the Earth.** Such objects or component parts found beyond the limits of the State Party to the Treaty on whose registry they are carried **shall be returned to that State Party**, which shall, upon request, furnish identifying data prior to their return. [emphasis added] salvager is a private entity, how and when is treaty responsibility transferred to the salvager's country? Is this accomplished by prior arrangement between countries? How should it be reflected in the private entity's license and/or contract?

The salvage list should be open to all interested parties. Governments and commercial entities willing and able to attempt retrievals should be encouraged to report in advance any intended retrievals to avoid conflicts between pursuers of the same object. Salvage objectives should not be "reserved" for a particular operator—at least, not until a retrieval mission is underway—because this could lead to a situation similar to the "paper satellites" problem at the International Telecommunication Union, in which reservations are granted for actions that will never be completed.

Emerging players will not tolerate it if the established players try to limit their access to space because the orbits are too full…

Launching states would be under no obligation to put their satellites on the salvage list. Sensitive national security assets, or satellites that the launching state intends to retrieve or service itself, would retain the traditional space object ownership status. However, launching states that own objects on the high-priority retrieval list (i.e., mass and probability of collision are relatively high) should be encouraged by COPUOS or some other appropriate body to make them available for salvage.

The Registration Convention does not have as many adherents as the OST, but still covers the majority of space actors. (The only OST signatories with noteworthy space activities that are absent from the Convention are Luxembourg—a supporter of space servicing that is home to two large commercial satellite fleet operators—and Israel.)[21] If the signatories support this new procedure in the interest of promoting debris cleanup, and experienced spacefaring nations like the U.S. and Russia set an example by making their expired satellites available, then the ownership problem is solved and salvage in space is enabled without amending the OST. But there still remains the perception that debris remediation is a cover for ASAT capabilities.

Turning Threats into Benefits

The physics and technologies involved in debris cleanup will never allow it to be completely divorced from any connection to ASATs. However, if the salvage list procedure described above is employed, the practice of satellite retrieval can be less controversial, become accepted as the norm, and perhaps stimulate a market for used satellites as debris remediation is accompanied by repair and refueling services. To pave the way for this, and to stave off criticism, the U.S. government could develop guidelines for proximity operations in space analogous to the orbital debris mitigation guidelines created in the 1990s.

Like the debris mitigation guidelines, the proximity ops guidelines should be reflected in licenses issued by the U.S. to organizations involved in such operations, fulfilling obligations under Article VI of the OST. Also, the U.S. guidelines should be offered up as a model in international forums such as UNCOPUOS or as an addendum to a space code of conduct. This would be a multiyear process, as was the case with the debris mitigation guidelines, but if successful the effort could prove its value in promoting growth in commercial space activities, reducing the debris threat, and easing tensions regarding international behavior in space.

The details of the U.S. guidelines would emerge from extensive interagency discussion and debate. At a minimum, the guidelines could include a prohibition against interference with nonhostile satellites that have not been offered up for salvage or put under contract for retrieval. Other guidelines may include:

- Prior public notification of launch or orbital maneuvers to initiate satellite servicing and retrieval missions;
- Prior notification to satellite owners of operations in the vicinity (e.g., within 1 km or 5 km) of their space assets; and
- Immediate alert of any servicing or retrieval mission that does not go as planned and may create a hazard for others.

Potential objectors should be shown that the benefits of debris cleanup—and all the other capabilities that the same technologies bring—outweigh the risks. As more nations become spacefarers and orbital traffic increases, emerging players will not tolerate it if the established players try to limit their access to space because the orbits are too full. Rather, the space lanes will need to be tended by a conscientious global community in a coordinated effort to keep them safe for operations, in the best interests of all players. Active removal of derelict spacecraft and other debris will have to be part of that effort in the not-too-distant future. Responsibility for coordination of the effort may reside with existing international organizations, but also could be managed by an international business collective similar to the Satellite Data Association, which has proven that critical operational issues affecting both government and non-government sectors can be addressed through cooperation among competitor-colleagues.

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One possible boon to small and emerging spacefarers could be development of a used satellite market. Refurbished satellites may be available for a fraction of the price of new projects, and pre-owned spacecraft serviced in orbit may be readied for reuse quickly. A benefit for all operators, especially those with large constellations in crowded orbits, would be the ability to contract with a commercial service to retrieve expired satellites (if they can't be repaired or refueled) and thereby eliminate the potential liability associated with their long-term presence in orbit. For large GEO constellations, the availability of on-orbit servicing, including boosting spacecraft to disposal orbits, could prevent the loss of significant revenue by eliminating the need to expend stationkeeping fuel and shorten service life.

If space development is to advance beyond what has been done during the past half century, it will be essential to deploy manned and/or robotic systems that can rendezvous, capture, repair, refuel, reposition, and retrieve orbiting payloads throughout cislunar space. This will be true across the civil, commercial, and national security space sectors. For example, NASA researchers have proposed a Space Harbor based on ISS engineering that would provide large-scale, LEO-to-GEO satellite servicing, which they believe to be "an essential economic pre-condition and next parallel or sequential step on the road toward exploration beyond LEO."[22] Commercial companies have their own plans, and may benefit from related government research and demonstrations. To prohibit such activities would mean halting further space development. To move ahead, the global community must accept these activities and establish behavioral norms that dispel fears and tensions. Just as with aircraft, ships, and ground vehicles that transit the globe, it would be unwise to ban or excessively restrict these activities just because they have the potential to function as weapons.

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