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OVERVIEW OF THE LEGAL AND POLICY CHALLENGES OF ORBITAL DEBRIS REMOVAL

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ABSTRACT

Quite a bit of attention has been paid recently to the issue of removing human-generated, or artificial, space debris from Earth orbit. Much of this attention was sparked by modeling and research done by both NASA and ESA on the space debris population and their conclusion that mitigating debris is not sufficient, that debris-on-debris collisions will continue to generate new debris even without additional launches, and some sort of active debris removal (ADR) is needed. Several techniques for ADR have been proposed and a few, at least from a technical perspective, are plausible enough to merit further research and eventually operational testing. However, all of the proposed techniques present significant legal and policy challenges which will need to be addressed for debris removal to become viable. This paper summarizes the most promising techniques for removing space debris in both low Earth orbit (LEO) and geostationary orbit (GEO), including electrodynamic tethers and ground- and space-based lasers, and discusses several of the legal and policy challenges these techniques pose, including:

- Lack of a separate legal definitions for functional operational spacecraft and non-functional space debris
- Broad international agreement on which types of space debris objects should be removed
- Sovereignty issues related to who is legally authorized to remove pieces of space debris placed in orbit by other launching States
- Establishing a global reference catalog of space debris objects in Earth orbit which is needed for identifying and conducting removal operations
- Instituting transparency and confidence building measures to reduce misperceptions of ADR as anti-satellite weapons development and deployment
- Intellectual property rights and liability with regard to ADR operations

The paper concludes that significant work in the legal and policy fields on these issues must take place in parallel to the technical research and development of ADR techniques, and argues that debris removal needs to be done in an environment of international collaboration and cooperation.

I. PROBLEM STATEMENT

Since the launch of the first satellite in 1957, humans have been placing an increasing number of objects in orbit around the Earth. This trend has accelerated in recent years due to the increase in number of States which have the capability to launch satellites and the recognition of the many socioeconomic and national security benefits that can be derived from space. There are currently close to 1,000 active satellites on orbit, operated by dozens of state and international organizations [1]. More importantly, each satellite that is placed into orbit is accompanied by one or more pieces of non-functional objects, known as space debris. More than 20,000 pieces of space debris larger than 10 cm are regularly tracked in Earth orbit, and scientific research shows that there are approximately five hundred thousand additional pieces between 1 and 10 cm in size that are not regularly tracked [1]. Although the average amount of space debris per cubic kilometer is small, it is concentrated in the regions of Earth orbit that are most heavily utilized, as shown in Figure 1, and thus poses a significant hazard to operational spacecraft.

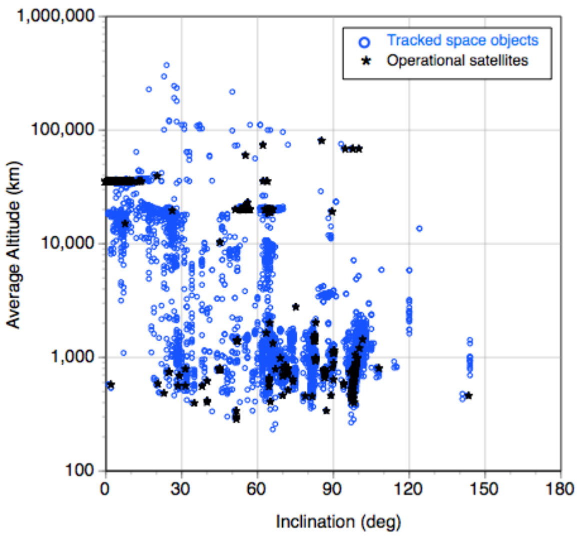

Figure 1: All artificial space objects in Earth orbit [3]

In the late 1970's, two influential NASA scientists, John Gabbard and Donald Kessler, laid the scientific groundwork for what became to be known as the "Kessler syndrome"[4]. They predicted that at some point in the future the population of artificial space debris would hit a critical point where it would pose a greater risk to spacecraft than the natural debris population of meteoroids. According to their models, large pieces of space debris would get hit by smaller pieces of debris, creating hundreds or thousands of new pieces of small debris which could then collide with other large pieces. This "collisional cascading" process would increase the population of space debris at an exponential rate and significantly increase the risks and costs of operating in space.

Although the exact tipping point at which this collisional cascading will occur is still a matter of debate, research and modeling done by both NASA and the European Space Agency (ESA) show that the growth of the space debris population will accelerate, largely due to debris-on-debris collisions [5]. The voluntary space debris mitigation guidelines developed by the Inter-Agency Debris Coordination Committee (IADC) and endorsed by the United Nations will reduce some of this growth. But ultimately, actively removing space debris will be necessary to deal with the problem in the long-term [6].

This paper summarizes the techniques being proposed for performing active debris removal (ADR), and outlines some of the major legal and policy issues they raise. These non-technical issues are an important consideration for successful ADR operations, and demonstrate that the topic of ADR cannot be approached from a purely technical standpoint. Legal, policy, and economic concerns are deeply imbedded in the notion of ADR, and will have important effects on its success. More importantly, a technically feasible solution may not be a politically feasible solution. A sub-optimal technical solution may be required to satisfy these other concerns. Thus, multidisciplinary and international perspectives should be included from the very beginning when considering ADR.

II. Summary of ADR Technologies and Techniques

There are currently a number of technologies and techniques being proposed and considered for ADR. Most of these techniques exist only as theoretical concepts and have not been operationally tested or proven. As shown in Figure 2, they can generally be broken down into by orbital regime, target object size, and whether or not the target object is cooperating.

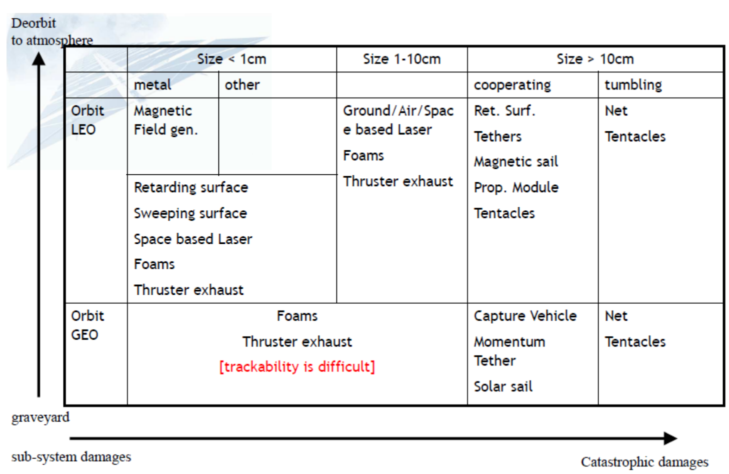

Figure 2: Summary of ADR technologies and techniques [7]

A. Removal of debris in low Earth orbit (LEO)

LEO is commonly defined as the region of Earth orbit below 2,000 km in altitude [8]. This region is home to the vast majority of the space debris objects, a significant number of active spacecraft, and all of the spacecraft carrying humans in Earth orbit. Space debris in this region will re-enter the Earth's atmosphere through a process known as natural decay. The upper atmosphere exerts a drag force on satellites in LEO which over time causes them to lose energy and altitude and eventually fall out of orbit and into the atmosphere. The length of time it takes for objects to re-enter is a function of their altitude as shown in Figure 3, namely, the higher the altitude, the longer their orbits will take to naturally decay.

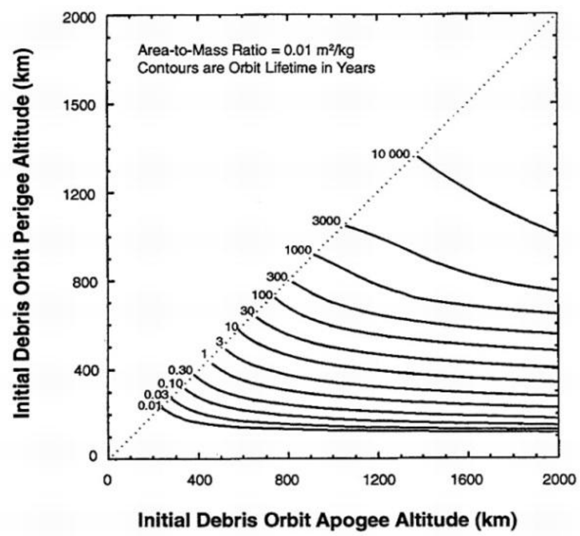

Figure 3: Orbital lifetime as a function of altitude [9]

Most ADR technologies in the LEO regime take advantage of this natural decay process and perform their function by accelerating natural decay, either by increasing the atmospheric drag on the space debris object or moving the debris object to a lower altitude orbit. For smaller pieces of debris, one of the most promising ADR techniques uses lasers, either ground- or space-based. These lasers are fired at a piece of space debris and exert a change in velocity (delta-V), either through ablation or solar radiation pressure, that change the object's orbit [10]. Repeated firings over one or more orbit revolutions can be used to lower the object's orbital altitude and speed up its re-entry into the Earth's atmosphere.

The primary challenge with enhanced drag techniques is controlling the atmospheric re-entry to ensure that the object does not endanger people or infrastructure on the ground. Laser techniques are also mostly limited to debris objects smaller than 1 cm.

Larger pieces of space debris can primarily be removed through rendezvous operations. An ADR spacecraft can rendezvous with the targeted piece of debris and attach to it using nets, grapples, tentacles, or harpoons. The removal spacecraft would then fire its maneuvering thrusters to move both objects into a lower orbit. The removal spacecraft can then separate from the target debris and, if remaining fuel allows, maneuver again to rendezvous with another debris object and repeat the process.

The ADR spacecraft could also attach a de-orbit aid, such as a thruster or a tether, to the target debris object and use that aid to remove it. One of the primary difficulties of these types of techniques is docking or attaching to the target debris object, which may be tumbling or structurally unstable.

Orbiting "collection media" can also be used to remove small pieces of debris in LEO. These consist of spacecraft with large surface areas coated in or made of substances that can absorb the momentum of debris impacts, such as foam or rotating panels. As small pieces of debris impact these collection media, they become trapped. At the end of its mission, the removal spacecraft de-orbits, taking all the trapped pieces with it. This technique is only viable for debris smaller than 1 cm.

B. Removal of debris from geostationary Earth orbit (GEO)

After LEO, the second most crowded region of Earth orbit is GEO, which is a region 35,786 km above the Earth. More than 1,200 objects are being tracked in this region, of which approximately 375 are active satellites located in a narrow belt around the Equator [11]. At this altitude, the Earth's atmosphere is non-existent and there is no practical natural decay process. Most debris removal strategies in GEO have the goal of moving debris objects into a post-mission disposal (PMD) orbit at the end of their operational lifetime, which is at least 235 km above the active

GEO belt [8]. The techniques for doing this are similar to those used in LEO, with the notable exception that it is much more difficult to remove small objects in GEO because they are extremely difficult to track from the ground. Debris removal of large objects in GEO is made easier by the fact that most objects are in similar orbits and less delta-V is needed to maneuver between multiple objects.

It is possible to remove a GEO object by bringing its orbit down in altitude to the point where it will re-enter the Earth's atmosphere. However, this requires a large amount of delta-V and is generally only practical using constant thrust propulsion techniques, such as ion engines or solar sails. Removing GEO debris via the Earth's atmosphere also requires moving the debris object through all lower orbital regimes, potentially creating opportunities for collisions with other objects.

III. OVERVIEW OF MAJOR ADR POLICY AND LEGAL ISSUES

A. There is no legal distinction between functional satellites and non-functional space debris

In its Terms of Reference, the IADC defines space debris as "all man-made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional" [8]. This same definition was adopted the Committee on the Peaceful Uses of Outer Space (UN COPUOS) in its Space Debris Mitigation Guidelines [12].

However, the term "space debris" does not appear in any of the treaties which form the foundation of international space law, and there is not a clear legal distinction between a function satellite and non-functional space debris. Under the existing legal regime, both are considered to be space objects. This non-distinction presents a barrier to removal in that there can be disagreement between States over the status of an object. A large satellite could be non-functional for years or decades in a crowded orbit and thus be considered by some a prime candidate for removal, but to the Launching State it could represent a potential backup or hibernating capability.

Within other regimes, notably the maritime regime, legal statutes and procedures exist for both declaration and determination of abandoned or worthless objects as such. This enables actors in those regimes to deal with objects which become hazards to navigation, perhaps through removal or destruction.

Although Article IV of the Convention on Registration of Objects Launched Into Outer Space (hereafter known as the Registration Convention) does provide a mechanism for the Launching State to notify the United Nations Office for Outer Space Affairs (UNOOSA) of the change in status of a space object [13], this is far from universal state practice.

B. There is no consensus on which types of objects should be prioritized for removal

Space debris can be broken down into three general categories, based on size, as outlined in Figure 4. Collisions between a spacecraft and debris larger than approximately 10 cm in size can cause total destruction, generate thousands of pieces of debris, and cannot be shielded against. Collisions with objects between 1 and 10 cm can be lethal to a spacecraft, but are less likely to generate debris. Collisions with objects smaller than 1 cm can be shielded against and are unlikely to generate significant debris.

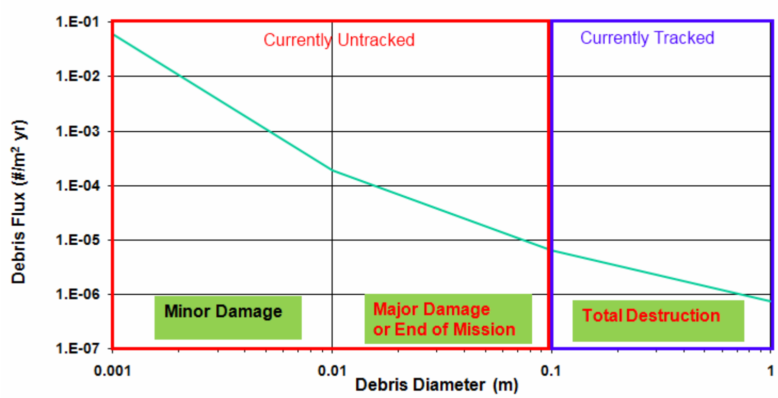

Figure 4: Categories of space debris [14]

If the objective is to prevent exponential growth in the size of the space debris population, and thus reduce the long-term risk to spacecraft, then debris objects with the most mass should be targeted for removal. These objects are the sources of future space debris, and removing them will remove the sources of future space debris.

However, if the objective is protecting operational spacecraft in the near-term, then priority should be given to removing small objects in heavily trafficked orbits, particularly those objects between 1 and 10 cm in size. These objects are not currently tracked using Space Situational Awareness (SSA) techniques and thus spacecraft are unable to maneuver to avoid collisions with these small objects, like they are for the larger objects.

Active removal of large space debris objects requires different technologies and techniques compared to removal of small debris objects. Given the likelihood of limited funding for debris removal operations, it will probably be necessary to prioritize removal of one category over the other in the near term.

Within the categories of large or small objects, there are additional arguments over which objects should be prioritized for removal. This is an important consideration to maximize the benefit of costly ADR operations.

The more massive an object is, the greater the amount of debris it can generate if involved in a catastrophic collision. Thus, several prominent space debris scientists argue that mass times collision probability ($M \times P_c$) is the best metric for determining which large debris objects should be removed [6],[14].

However, there are two concerns with this approach. The first is the calculation of collision probability, which can vary depending on the model and technique used and thus can be open for debate. The second concern is a political one: under this metric, almost all the highest priority objects are defunct satellites and large rocket bodies placed in orbit by Russia [6]. Thus, without international agreement on the technique used to determine the priority of objects selected for removal, adopting this method could lead to the perception that the objects are being selected for removal based on political motivation. This motivation could be to label certain States as "bad actors" to achieve ulterior geopolitical ends, justify intelligence gathering, or sabotage missions under the cover of debris removal.

Orbital mechanics also drives consideration of which objects should be targeted for removal. A spacecraft which is performing the removal would need to maneuver to match orbits with its various targets. Maneuvers, especially changes in inclination, require expenditure of fuel. Thus, space debris objects which have high $M \times P_c$ values but are isolated from other objects might present an expensive target, compared to debris objects with lower $M \times P_c$ values that are clustered with other debris objects with notable $M \times P_c$ values.

C. Only the Launching State is allowed to remove an object from space, and the Launching State is not always known

Article XIII of the Treaty on the Principles Governing the Activities of States in the Exploration and use of Outer Space, including the Moon and Other Celestial Bodies (hereafter known as the Outer Space Treaty), states [15]:

> *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..*

Article I of the Convention on International Liability for Damage Caused by Space Objects (hereafter known as the Liability Convention) further defines the term Launching State as [16]:

> *(i) A State which launches or procures the launching of a space object;*
>
> *(ii) A State from whose territory or facility a space object is launched;*

Thus, these two Treaties stipulate that a space object is under the jurisdiction and control of the Launching

State in perpetuity, and leads to the conclusion that any attempt by a third party to remove that object could be seen as a breach of sovereignty.

Approximately one-third of the space debris currently in orbit is owned by the United States, one-third by the Commonwealth of Independent States (Russia), and one-third by the People's Republic of China. Thus, under international law, unilateral ADR activities by any one of these States would only be able to remove a portion of the orbital debris threat.

It is possible that with proper prior consultation, a third party could obtain permission from the Launching State to remove a debris object. However, a protocol for doing so does not currently exist and would need to be developed.

In order to determine and record the Launching State for a space object, Article II of the Registration Convention stipulates that the Launching State shall [13]:

> *"...register a space object by means of an entry in an appropriate registry which it shall maintain. Each launching State shall inform the Secretary-General of the United Nations of the establishment of such a registry."*

Unfortunately, compliance with this requirement is not homogeneous across all Launching States. Although most States do register their satellites and rocket bodies placed in orbit with UNOOSA (which maintains the UN Registry of Space Objects), it is not universal state practice to register all objects including debris. Additionally, the Launching State is only required to provide basic information on an object's orbit when registering, and this information is not sufficient to allow for the object to be tracked with any precision nor located in orbit at a future date.

It is left to others, historically governments and militaries, to develop SSA capabilities to track objects in space and develop and maintain catalogs of their positions. The U.S. military maintains the most complete catalog of space objects, which currently contains over 16,000 entries [17]. However, there are 5,000 or more additional objects which are tracked by the U.S. military which are not included in the catalog [14]. Entry into the U.S. satellite catalog requires that an object be tagged to a specific launch event, and that has not been done, and likely cannot be done, for these 5,000 objects.

Because the Registration Convention also does not make any requirement to notify the Registrar or register debris that is created at later points in an object's lifespan, virtually all of these un-cataloged pieces of debris do not exist in the UN Registry and thus, they do not have a clearly defined Launching State. This leads to a situation of legal ambiguity with regard to who would be allowed to remove these objects from orbit.

D. There is no reference catalog of space debris objects

As mentioned previously, the UN Registry of space objects does not contain all of space debris objects, or even those currently being tracked via SSA, and those debris objects that are in the UN Registry lack the positional information necessary to enable their removal. Thus, it falls to the SSA providers who track space objects and maintain catalogs to provide the orbital positions of space debris objects, usually in the form of element sets or ephemeris.

There are many different entities that track space objects and maintain various catalogs. The U.S. and Russian militaries currently maintain the most complete catalogs. The European Space Agency uses space surveillance data from several European radar and optical sensors, as well as data from the United States and Russia, to maintain a partial catalog of geosynchronous objects [11]. The International Scientific Optical Network (ISON), consisting of more than 20 observatories in 10 countries, also maintains a catalog of deep space objects [18]. The Astronomical Institute at the University of Bern (AIUB), maintains a catalog of high area-to-mass debris objects in deep space orbits [19].

None of these catalogs are exhaustive, and there are discrepancies in the numbers of debris objects, names, and orbits between them. Thus, a single, reference catalog that can be used to determine which space objects should be removed does not exist, should there be an agreed-upon metric for choosing.

E. ADR operations can pose a hazard to normal space activities

All ADR techniques require some level of interaction with a space debris object, and this poses inherent risks. The harsh space environment can degrade the materials and structures of objects, making them fragile to physical contact or sudden acceleration. Debris objects such a rocket upper stages or spacecraft can have residual fuel or energy sources, which could explode if disturbed.

Even for benign debris objects, ADR requires precision tracking and orbit estimation to enable either rendezvous or targeting. Rendezvous operations, and in particular uncooperative rendezvous, are complicated procedures made more difficult by their remote nature.

ADR spacecraft which conduct repeated or continual maneuvers to collect multiple pieces of debris may require special traffic management procedures. Their owner-operators will likely be required to continually publish updates of the spacecraft's position. These continual updates may drive special conjunction assessments to screen the ADR spacecraft's orbit against other objects to warn against unintentional collisions.

Lasers fired into space for ADR present a special challenge. Although none of the laser ADR concepts utilize "weapons-grade" lasers that could destroy a spacecraft, accidently illumination of spacecraft by low power lasers could still damage or degrade optical sensors. The U.S. military currently has procedures in place that require all Department of Defense (DOD) lasers being fired into space to register with a Laser Clearing House (LCH) [20]. The LCH screens these DOD laser firings against the satellite catalog and determines if they will pose a danger to spacecraft.

Wide-scale laser ADR activities will likely involve a number of laser sites around the globe and hundreds to thousands of firings into orbit. LCH procedures will need to be developed and implemented to ensure these laser firings do not endanger spacecraft, and perhaps more importantly to assuage satellite operators' concerns.

F. The dual-use nature of ADR operations can cause instability and mistrust

An increasing number of States utilize spacecraft in Earth orbit for national security purposes, and over the last fifty years space has played a significant role in international security and stability. These important missions include ballistic missile launch detection and warning and treaty verification. An increasing number of States are also using space capabilities to augment their military power through satellite communications, precision navigation and timing, and intelligence collection.

Thus, many States view interference with their space assets or capabilities as serious national threats. Many of these threats come in the form of anti-satellite (ASAT) capabilities, which can be used to deceive, deny, degrade, disrupt, or destroy space capabilities [21].

Although ADR operations are not inherently ASAT activities, many of the technologies and techniques which are candidates for ADR operations could also be used to damage or destroy a spacecraft. In the past, some of these techniques have been included in ASAT programs, although most have not made it past the theoretical stage [22].

The development of ADR technologies and techniques by one State, particularly by classified programs, could be interpreted by other States as development of ASAT capabilities. This could prompt those States to develop their own ASAT capabilities or pursue other mechanisms to counter the perceived threat, which could in turn lead to an arms race or instability in the space domain.

Actual ADR operations in orbit could also be a significant source of concern. Many States lack the SSA capacity to determine what is happening in orbit. Even among those States which do possess some SSA capacity, it can still be difficult to determine the exact cause of a spacecraft failure or malfunction. Thus, ADR operations that are done unilaterally by one State or covertly could create misperceptions and mistrust that could lead to instability, and potentially conflict.

G. There are unresolved questions as regard to liability from ADR operations

Article III of the Convention on International Liability for Damage Caused by Space Objects (hereafter known as the Liability Convention) states [23]:

> *In the event of damage being caused elsewhere than on the surface of the Earth to a space object of one launching State or to persons or property on board such a space object by a space object of another launching State, the latter shall be liable only if the damage is due to its fault or the fault of persons for whom it is responsible.*

This requirement for establishment of raises several questions for ADR. If the Launching State is removing the space object, and in the process of disturbing the object it fragments, is the Launching State liable for any damage those fragments cause to other space objects in the future? There does not exist a standard of care for ADR operations, and thus it may be impossible to currently establish whether or not the removal operations were done in a negligent manner.

If the ADR is being performed by a third party, this creates additional complexities if the removal spacecraft incurs damages in the process of the removal, or if they damage other spacecraft as a result of the removal operations.

The re-entry of space debris objects into the Earth's atmosphere introduces the possibility of these objects causing damage on the surface of the Earth or to aircraft in flight. However, Article II of the Liability Convention states [23]:

> *A launching State shall be absolutely liable to pay compensation for damage caused by its space object on the surface of the Earth or to aircraft in flight.*

Thus, if a third-party is performing the debris removal via a technique that accelerates the process of natural decay, there could be a situation where a removed object causes damage during atmospheric-re-entry. Under the current law it is uncertain whether the Launching State has any recourse against the party that performed the removal, or whether the party performing the removal has a requirement to control the object's atmospheric re-entry to ensure that it does not cause any damage in the process.

H. Removal of debris objects raises significant concerns with regard to intellectual property rights

Several ADR techniques require close approach or orbital rendezvous between a removal spacecraft and the target debris object. These techniques also require characterization of the target debris object to determine stability, spin state, structural integrity, and potential methods and points of attachment.

This characterization of a debris object that is a non-operational spacecraft or a spent rocket stage could reveal patents, trademarks, or trade secrets with regard to materials science, design, or payload configuration. Divulging these intellectual property items to the third party that is performing the removal could be a major concern for the debris object's Launching State. The third party performing the removal could see the potential economic value of this intellectual property as part of their business model for doing the debris removal. If space debris objects are removed and either re-used in orbit or returned to the surface of the Earth, this could cause additional concerns.

Without development of some version of maritime salvage law for outer space, the legal issues regarding intellectual property could prevent many of the most promising economic incentives for commercial ADR operations. This could stifle innovation and increase costs, reducing the likelihood that the large-scale ADR operations become a reality.

V. Conclusions

Further technical research and development on ADR techniques and technologies required, and is underway by scientists and engineers around the world. In particular, many of the more promising ADR technologies and techniques need to be validated through on-orbit demonstrations and experiments.

While some of these technical challenges are indeed difficult, the legal and policy issues outlined in this paper are no less important. It can be argued that these non-technical challenges are in fact more important. Given that serious work by engineers and scientists on solving the technical challenges has already begun, it would follow that policymakers and lawyers should begin tackling the non-technical challenges as well.

Although it is too early to provide complete answers to many of the legal and policy issues raised in this paper, there are some concrete steps that can be taken to address some of these issues:

- International research and agreement on the need for and objective of ADR, including metrics to determine priority of debris objects to be removed
- Dialog on the issue of heterogeneous space debris catalogs and SSA data sharing
- Development of best practices with regard to safe orbital rendezvous and laser operations
- Legal scholarship and debate on the legal separation between functional spacecraft and non-functional space debris, third party removal permission protocol, resolving the ambiguity of un-cataloged debris objects, and clarifying the issues with intellectual property rights and liability
- Development of specific Transparency and Confidence Building Measures (TCBMs) for ADR which will reduce the chances for misperceptions and mistrust

An international ADR technology demonstration mission could be useful for not only evaluating technical concepts, but also on evaluating potential solutions for these policy and legal issues.

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