Maneuvering Towards Safe and Responsible Rendezvous and Proximity Operations in Space

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Abstract

As space becomes increasingly congested, states operating in close proximity to other states is an inevitability. Strategically valuable space will become more crowded, and naturally, states will try to find creative solutions to fit more satellites into a constrained volume of space. As the commercial market begins to eclipse the defense market in the global space economy, there is a current impetus to normalize operating in close proximity to other satellites, also known as Rendezvous and Proximity Operations (RPO) activities. Normalizing RPO activities helps each state better understand intentions and ultimately avoid miscalculations that would escalate tensions or, worse—start a shooting war in space. As more states become space powers, all of humanity will have to wrestle with this problem. It stands to reason that the United States is best situated to lead the international community in the development of standards of conduct while conducting RPO activities and demonstrating to the world that not only can RPO activities be done, but they can be done safely and responsibly. This first step will improve space sustainability by enabling RPO-enabled commercial ventures to remove debris and extend satellite mission life. For the first time in history, the preponderance of the space market is predominately commercial. Now is the time to leverage a louder private equity voice to define safe and responsible space behavior.

Keywords: space power, space norms of behavior, geopolitics of space

Maniobrando hacia operaciones de encuentro y proximidad seguras y responsables en el espacio

Resumen

A medida que el espacio se vuelve cada vez más congestionado, es inevitable que los estados operen muy cerca de otros estados.

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El espacio estratégicamente valioso estará cada vez más poblado y, naturalmente, los estados intentarán encontrar soluciones creativas para colocar más satélites en un volumen de espacio limitado. A medida que el mercado comercial comienza a eclipsar el mercado de defensa en la economía espacial global, existe un impulso actual para normalizar las operaciones en estrecha proximidad con otros satélites, también conocidas como actividades de Operaciones de Encuentro y Proximidad (RPO). La normalización de las actividades de RPO ayuda a cada estado a comprender mejor las intenciones y, en última instancia, evitar errores de cálculo que aumentarían las tensiones o, peor aún, iniciarían una guerra a tiros en el espacio. A medida que más estados se conviertan en potencias espaciales, toda la humanidad tendrá que luchar con este problema. Es lógico que Estados Unidos esté en la mejor posición para liderar a la comunidad internacional en el desarrollo de estándares de conducta mientras realiza actividades de RPO y demuestra al mundo que no sólo se pueden realizar actividades de RPO, sino que también se pueden realizar de manera segura y responsable. Este primer paso mejorará la sostenibilidad espacial al permitir que empresas comerciales habilitadas por RPO eliminen escombros y extiendan la vida útil de la misión del satélite. Por primera vez en la historia, la preponderancia del mercado espacial es predominantemente comercial. Ahora es el momento de aprovechar una voz más fuerte del capital privado para definir un comportamiento espacial seguro y responsable.

Palabras clave: poder espacial, normas de comportamiento espacial, geopolítica del espacio.

实现安全、负责的太空交会与近距操作

摘要

随着太空变得越来越拥挤，各国在其他国家附近开展行动已成必然。具有战略价值的太空将变得更加拥挤，各国自然会试图找到创造性的解决方案，以便在有限的空间内容纳更多的卫星。随着商业市场在全球太空经济中开始超越国防市场，目前有一种动力将“在其他卫星附近开展的操作”正常化，这也称为“交会与近距操作”(RPO)活动。将RPO活动正常化，有助于每个国家更好地了解意图，并最终避免可能加剧紧张局势（或更糟的是引发太空交战）的误判。随着越来越多的国家成为太空强国，全人类都将不得不努力解决这一

问题。理所当然的是，美国最适合领导国际社会制定行为标准，在开展RPO活动的同时向世界展示：不仅可以开展RPO活动，而且可以安全、负责任地开展这类活动。这第一步将通过使RPO支持的商业企业能够清除太空垃圾并延长卫星任务寿命，进而改善太空的可持续性。太空市场在历史上首次以商业为主。现在，是时候利用更响亮的私募股权声音来定义安全和负责任的太空行为了。

关键词：太空力量，太空行为规范，太空地缘政治

Biography

Dr. Matthew Jenkins is an adjunct professor at George Washington University's Space Policy Institute. He received his Statecraft and National Security doctorate from the Institute of World Politics in Washington, DC. His research specializes in space policy issues.

Acronyms

ADR	Active Debris Removal
ASTRO	Autonomous Space Transport Robotic Operations
COPUOS	Committee on the Peaceful Uses of Outer Space
CUES	Code for Unplanned Encounters at Sea
DARPA	Defense Advanced Research Programs Agency
ESA	European Space Agency
GEO	Geostationary Orbit
GPS	Global Positioning System
GSSAP	Geosynchronous Space Situational Awareness Program
IADC	Inter-Agency Space Debris Coordination Committee
INCSEA	Incidents at Sea Agreement
LEO	Low Earth Orbit
MEV	Mission Extension Vehicle

NASA	National Aeronautics and Space Administration
NG	Northrop Grumman
NRO	National Reconnaissance Office
ODMSP	Orbital Debris Mitigation Standard Practices
OOS	On-Orbit Servicing
ROPE	RPO Operations Profiles for Encounters
RPO	Rendezvous and Proximity Operations
SATCOM	Satellite Communications
SMC	Space and Missiles Systems Center (now SSC Space Systems Command)
SPD	Space Policy Directive
SSA	Space Situational Awareness
TRP	Technology Reinvestment Program
UNCLOS	U.N. Convention on the Law of the Sea
VESPA	Vega Secondary Payload Adaptor

CHAPTER 1

> As more actors come to space, the domain is changing, with an increased risk of collisions, as well as of miscalculations or misunderstandings.
>
> —U.S. Secretary of Defense, Lloyd Austin, 2021

Background

As of 1 May 2023, there were 7,560 operating satellites in space (Union of Concerned Scientists, 2023). The United States operates over 68 percent of those satellites either through government or commercial operations. Nevertheless, the category of "other" space nations is steadily increasing. As the limited volume of valuable space around the Earth becomes more congested, the obligation of space-faring nations is one of safety and responsibility towards each other to avoid the cascading collisions of space debris, known as the Kessler syndrome, impacting global use of space-based capabilities.[1]

As space becomes more congested and the world hurtles closer to this possibility of cascading collisions, there is increased interest in space sustainability worldwide. Even though five international treaties regulate space behavior, none have done anything to influence space sustainability. As such, in 2020, the Trump Administration published a National Space Policy that specifically included the goal to "create a safe, stable, secure, and sustainable environment" in space (Executive Office of the President [EOP], 2020, p. 14). Recognizing that the United States cannot achieve this objective unilaterally, the administration tasked the Secretary of State to "cooperate with like-minded international partners to establish standards of safe and responsible behavior, including openness, transparency, and predictability, to facilitate the detection, identification, and attribution of actions in space that are inconsistent with the safety, stability, security, and long-term sustainability of space activities" (EOP, 2020, p. 5). Fortunately for America and the world, the Biden administration retained those same objectives.

Now, more than ever in space exploration's history, the world needs all states to work together to achieve this vision of sustainability in space. This cooperation starts with earnest attempts to define and codify how states will interact not with space-enabled technology but in space itself. Rendezvous and Proximity Operations (RPO) represent a subcategory of state interaction in space. However, this subcategory presents a critical starting point for developing normative behavior because of the ubiquity and ever-present need for RPO to sustain space-based capabilities for all. Most established or burgeoning space powers have or are developing RPO capabilities to sustain the longevity of satellite systems and verify the purpose and function of sat-

1 The Kessler syndrome is a theory proposed by NASA scientist Donald J. Kessler in 1978, used to describe a self-sustaining cascading collision of space debris in LEO.

ellites from a national security perspective. Private firms are also new players in the field, pursuing commercial ventures enabled by RPO activities that can obfuscate more nefarious state activities in space. As a result, RPO provides a significant and relevant starting point to initiate and establish normative behavior in space, and it is incumbent on the United States to lead the way as the most prominent user of space. There is increased ambiguity and a chance for miscalculation between rival states without broadly understood responsible behaviors for RPO. This thesis offers some safe and professional RPO behaviors, which, if generally accepted, will promote international peace and stability.

The Research Question

How can the United States become a leader in demonstrating safe and responsible behavior when conducting RPO activity? The United States, more than any other nation in the world, relies on space-enabled technologies and capabilities for much of its way of life. To everyday Americans, space is the invisible but ever-present force sustaining both our daily routines and the functions of our society: enabling us to check traffic on the way to work, stream TV or music, monitor vital health information, or conduct secure banking transactions. In acknowledgment of this dependency, the United States has led the world in militarizing space and bolstering rhetoric on the need for space dominance to ensure U.S. national security (Axelrod, 2018). In the last decade, the United States began messaging that space is the next warfighting domain and that the country must prepare to fight a war in space, and others have followed suit (Hirsch 2018).

U.S. messaging on preparing the battlefield in space is more likely to escalate other state activity to match U.S. behavior, increasing the chance of conflict and collision in space that could make the domain unusable for all. This phenomenon is not new or unique to space. IR theorists recognize this as a security dilemma that occurs when one state's efforts to increase its security threaten other states, leading to unnecessary conflict or intensified security competition (Montgomery, 2006). Inadvertent as it may be, the United States cannot afford a kinetic war in space. U.S. policymakers should look to easy wins to de-escalate tensions in the space domain where possible.

This work posits that establishing RPO normative behavior, while not comprehensive, could be that easy win. If done safely, RPO activities stand to improve space sustainability, and one day, these activities will provide a trusted verification mechanism for states who wish to expand safe and responsible behavior for other elements of space affairs. Defining the rules of the road for RPO allows all practitioners to pick a starting point and begin moving toward a safer and more sustainable space future to protect the shared resource that is the province of all.

Assumptions

The United States has the most significant equity in space; therefore, it is in the best interest of the United States to define normative space behaviors and continue to build upon this foundation as technology and usable space geography change. The problem of defining behavior has endured since the 1960s, despite space-faring nations signing several bilateral and multilateral treaties that provided initial steps in this process.[2] It is assumed in this work that states, by virtue of being a signatory on these or future treaties, will, for the most part, comply with the stipulations. Similarly, and much like the laws governing the maritime domain, this work also assumes that though not all space powers are signatories to international treaties and agreements, they all generally comply with the principles laid out in the five international agreements relevant to space. In other words—international customary law. This unity of effort, even absent signed obligation, is a foundational assumption supporting the notion that RPO activities can be meaningfully prescribed and regulated.

This work assumes that no unforeseen technological advances or shifts in space technologies will change the nature or need for RPO activities or the limits of usable space geography. Defining norms for RPO activities is done to help expand the conversation on other elements of space affairs, thereby preventing unnecessary miscalculation between states conducting space operations and promoting peace and stability among the international community. Without a technological shift, RPO activities will remain a burgeoning need for space powers to sustain their capabilities and compete in the military domain for "space dominance."

Building on the last assumption is the notation that states will conduct RPO activities regardless of whether there is an agreement upon the list of responsible behaviors, and the United States has the most to lose in the absence of one. Some may argue that developing norms and regulating RPO activities unnecessarily constrains policymakers' flexibility for strategic action.

The third assumption of this work is that normative behavior for RPO activities can be replicated and will establish a framework for other agreements or treaties concerning the space domain. This concept would enable an Intergovernmental Organization (IGO) or non-partisan organization to use RPO activities to verify other international obligations neglected due to lack of enforcement and verification. The United States, more than anyone, should endeavor to be a world leader in crafting this strategy moving forward, not only for the geopolitical "feather" that it may acquire but because it stands to lose the most from reckless behavior in space—regardless of the intent.

Finally, this work assumes that building a successful model to define safe and responsible RPO activities informs other elements of the space problem. Many challenges plague normalizing space activities, from proliferation to sustainability. The same fundamental impasse vexes all these problems—

2 Norms are the general rule, by which the principles of moral conduct and legally accepted before society are governed. They differ from law, as they do not have the formalized obligation for compliance. In general, a Norm must first exist, then a law follows.

widely accepted norms. By defining the norms for one subcategory of space challenges and enabling increased transparency and confidence through RPO activities, the work assumes that headway can be made to address other challenges in space.

Key Terms and Definitions

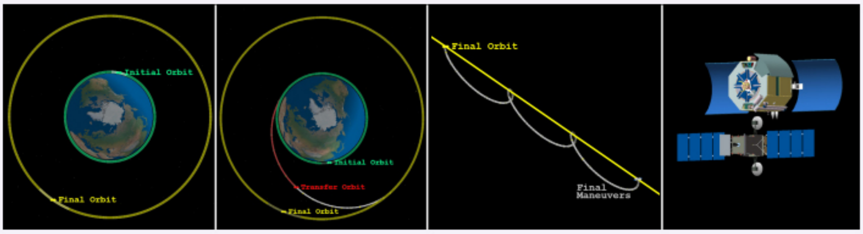
First conceived in the 1800s, RPO generally refers to orbital maneuvers in which two spacecraft arrive at the same orbit and approach at a ***close*** distance (Reesman et al., 2018, p. 2). To expand on this definition, the Aerospace Corporation considers two satellites close to each other when the inter-satellite distances and speeds are on the order of kilometers and meters per second (Reesman et al., 2018, p. 2). Figure 1 below, developed by Dr. Rebecca Reesman and Dr. Andrew Roger, provides additional terminology and definitions that will be used multiple times throughout this work (Reesman et al., 2018, p. 5).

An essential distinction exists concerning RPO activities—cooperative RPO and non-cooperative RPO. As documented in Figure 1, cooperative RPO includes information transfer between two vehicles in space. The International Space Station and the vehicles that arrive to service it are examples of cooperative RPOs. On the other hand, non-cooperative RPO involves the one-way transmittal of information against another vehicle. The United States Geosynchronous Space Situational Awareness Program (GSSAP), declassified by the United States Air Force in 2014, conducts non-cooperative RPO activities (Cheng, 2014). This distinction becomes important when considering state-to-state RPO interactions, as two-way communication may imply consent. Non-cooperative RPO activities do not require both systems to interact. This unilateral action in the conduct of RPO activities increases anxiety among the non-cooperative state because they cannot readily interpret the intentions of the approaching vehicle. Alternatively, cooperative RPO requires two-way communication and interaction during the activity. For this to occur, both parties must be witting participants. This consent is a useful standard for safe and responsible RPO acts.

Within the category of RPO lies two significant subcategories—On-Orbit Servicing (OOS) and Active Debris Removal (ADR). On-orbit servicing requires two satellites to be in the same orbit, in proximity and typically includes docking or grabbing (Cheng, 2014). Successfully employed, OOS has the potential to increase satellite mission life by orders of magnitude through fuel transfers and mission payload upgrades. An example that personifies the value of OOS is the knowledge the world has of the universe from NASA's Hubble telescope, which has been serviced by the space shuttle four times over its life, providing enhanced capabilities and longer life (Hubblesite, n.d.).

The other subcategory of RPO activity is ADR. ADR is a proposed method for removing defunct satellites or residual spacecraft components before their orbits decay on their own (Bonnal et.al, 2013, p. 51). While less

Rendezvous and Proximity Operations



Initial configuration.	The transfer orbit, which effects rendezvous.	Example of a maneuver that corresponds to proximity operations.	Final configuration just before docking.

Definitions:

Rendezvous: matching the plane, altitude, and phasing of two (or more) satellites.

Proximity operations: two (or more) satellites in roughly the same orbit intentionally perform maneuvers to affect their relative states.

Docking: subset of proxmimity operations, where one satellite intentionally performs maneuvers to physically contact another satellite.

Cooperative RPO: information (position, velocity,health/status, etc.) transfer is two-way via crosslinks, ground contact, etc. Example: docking with the ISS.

Non-cooperative RPO: information transfer between vehicles is one-way only. Example: active debris removal.

Figure 1: Rendezvous and Proximity Operations Terms & Definitions

commonplace than OOS, the concept of ADR has the same potential to change how states interact. ADR can dramatically improve the long-term sustainability of space—if properly enabled. The challenge ADR faces today is that existing international treaty law dictates that the launching state owns the debris, so any attempt to remove it would likely require consent from the launching state. Even still, ADR and consent to do so is worth pursuing. With the ability to remove defunct satellites and debris from space, sustainable space becomes a very realistic possibility.

Scope and Delimitations

This study does not provide a detailed overview of the orbital mechanics associated with conducting RPO activities. Instead, it provides a brief overview of the significant RPO activities that serve to recenter our attention to the benefits of the activities. The work then examines how states have handled operating in the proximity of other states on the high seas. The work then attempts to identify the significance and potential benefits of establishing normative behavior and ends with a conversation on moving forward. Ultimately, the work is structured with the hope that it highlights the potential benefits of delineating safe, professional, and responsible RPO activities and how these benefits outweigh the reticence some may have with them. Further, this work aims to advance the discourse on how states can help define normal behavior in RPO and more easily assess intention when states or corporations deviate from established normative behavior.

Summary

With a few exceptions, most RPO activities are shrouded in mystery, thereby increasing the chance of misinterpretation of intent. This risk space is the primary reason for this study. States will continue to refine their ability to execute RPO activities, which is good for the international community. With the ability to successfully leverage safe and professional RPO activities, a gamut of space-based commerce emerges and the ability—should states be open to it—to leverage RPO activities as a means for verification to improve transparency and confidence in space activities of all space-faring nations.

CHAPTER 2

Rendezvous and Proximity Operations Origins

The concept of Rendezvous and Proximity Operations (RPO) first originated in science fiction literature as the world came to understand its place in the cosmos in the mid-1800s (Hacker, 1974, p. 374). However, it was not until a young, self-taught Ukrainian, Yuri Vasil'yevich Kondratyuk, published a manuscript in 1916 or 1917 that the concept became well-known. In his work, Kondratyuk elucidates a concept of two parts separating in orbit. One of the parts lands on the surface of a celestial body, only to rejoin with the other part later when back in orbit (Hacker, 1974, p. 377).

As initially envisioned in the manuscript from the early 1900s, this concept is the foundational concept American and Soviet space programs used in the 1960s to place humans on the Moon. The United States first exercised rendezvous operations on December 15, 1965, when Gemini 6A and 7 achieved zero relative motion and maintained approximately 110 meters separation (NASA, 2021). The first successful docking operation was later carried out by Gemini 8 on March 16, 1966, with an unmanned Agena target vehicle (NASA, 2021). NASA would go on to use this same approach for the Apollo missions and, having mastered the art, put humankind on the Moon.

Subsequently, almost every Space Shuttle mission would have at least one RPO objective (Goodman, 2006). Today, the International Space Station is serviced by manned and unmanned missions routinely using the same RPO concepts refined almost 70 years ago.

RPO Moves Away from Manned Flight

While RPO activities had become commonplace in manned spaceflight, it was not prevalent in unmanned missions. At least to this point, RPO activities had been primarily overseen by a human in the loop. This is true for Agena, Apollo, Mir, the Space Transport System, and the International Space Station. However, it was only a matter of time before computers and technology matured to the point where systems could autonomously conduct RPO activities without the assistance of humans.

RPO changed dramatically in the mid-2000s in a way that raised eyebrows. In 2007, DARPA funded a Boeing mission called Orbital Express, the first successful demonstration of "a safe and cost-effective approach to autono-

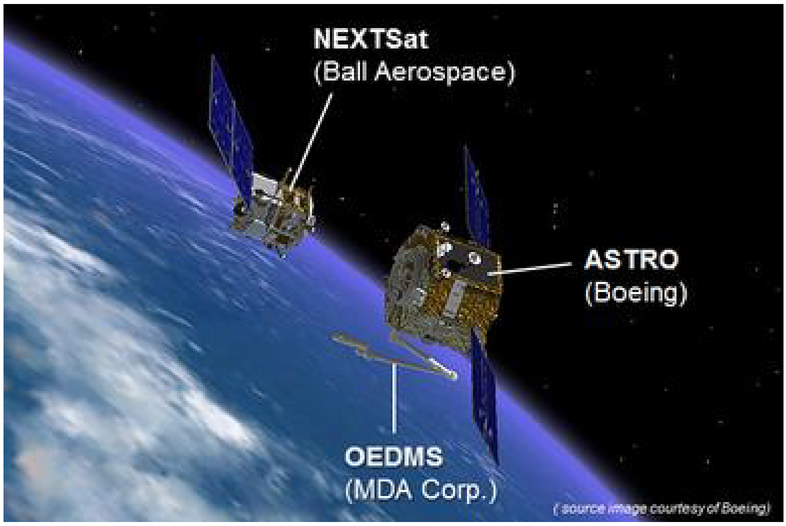


Figure 2: Artistic rendition of Orbital Express and component manufacturers

mously service satellites in orbit" (Boeing, n.d.). The mission consisted of two vehicles (Figure 2). The first was Autonomous Space Transport Robotic Operations (ASTRO). ASTRO released and grabbed a serviceable prototype satellite called NextSat, built by Ball Aerospace. In a series of experiments, ASTRO would transfer fuel between the two vehicles and replace critical flight components, including a flight computer. The United States showed the world that it was willing to begin reaching out and touching satellites. The world took notice.

Having witnessed the success of the American missions, China would use similar grappling techniques less than seven years later in a series of experiments to advance its research and development of OOS capabilities. Launched on July 19, 2013, China's SY-7, CX3, and SJ-15 (Payloads A, B, C, respectively) were designed to demonstrate RPO activities and the use of a robotic arm release to catch a servicing payload. SY-7 would release a smaller satellite (Payload A) on October 18, 2013 (Secure World Foundation [SWF], 2023). The three systems would interact numerous times, coming within a few kilometers of each other and demonstrating their ability to execute RPO activity safely. The Chinese are also refining their ability to conduct RPO activities in Geosynchronous Orbit (GEO). The Chinese SJ-17 mission, launched in 2016, roams around the GEO belt and is most likely used for inspection purposes by the Chinese (SWF, 2023).

In both cases, the United States has responded strongly in condemnation of the activities. Why? With payloads A, B, C, it is not clear. However, with SJ-17, the drift rate and distance from other systems were particularly alarming. In February 2018, SJ-17 began a drift at four degrees per day—in GEO. By any definition, this was faster than most inspection systems would traverse the GEO belt (usually under two degrees per day). The United States, clearly surprised by the Delta-V elocity capability of the system, was even more surprised at the proximity operations subsequently conducted. In July, the system came to within 1.5 km of Cina-Sat1C (SWF, 2023). As previously discussed, the United States generally sees anything inside of 10 km as close in GEO. China has demonstrated the ability to conduct RPO activities in both LEO and GEO for all the world to see. However, the lack of understanding of intentions plays a significant role in the overall anxiety of the United States and other countries to this day.

The renewed interest in RPO activities is not limited to China. Russia, too, has taken steps to demonstrate its ability to conduct similar activities. Launched in September of 2014, The Russian OLYMP/LUCH relay satellite has since "drifted" around the GEO belt in what analysts believe is a campaign to eavesdrop on other satellites (Weeden, 2015). To date, LUCH has "snuggled" with over a dozen GEO satellites, most of which are commercial satellite systems (Roberts, 2022).[3]

Not satisfied with only GEO demonstrations, Russian's LEO RPO activities in early 2020 caused much consternation for U.S. defense leaders. In January, COSMOS 2543, released on-orbit from COSMOS 2542, conducted a series of burns to come within approximately 20 kilometers of USA 245. While a single conjunction would probably not be noteworthy, when USA 245 was maneuvered away, COSMOS 2543 conducted maneuvers to remain close. Believed to be an inspection system, the sun angle in the conjunction provided COSMOS 2543 a fantastic, illuminated view of 245. The United States denounced COSMOS 2543 as an anti-satellite weapons system. It condemned Russia for "hypocritical advocacy of outer space arms control, with which Moscow aims to restrict the capabilities of the United States while clearly having no intention of halting its own counter-space program" (USSPACECOM, 2020).

The United States does not know with high confidence what the mission of 2543 is or what Russia intends to do with it. The challenges faced by all space actors in interpreting intention and understanding the true use of a satellite continue to plague the space community at large. This problem is made more difficult by the dual-use nature of space systems.

Dual-Use Conundrum

The most common argument made for the strong rhetoric around the unique nature of space is that satellites and the boosters that deliver them to orbit are widely regarded as "dual-use" technology. While there is some truth to this uniqueness, the reality is that many of the technologies the world's citizens use today have their origins in development through the defense sector. The Global Positioning System (GPS), the Internet, digital cameras, and touchscreen devic-

3 "Snuggled" is a colloquial term in space operations used to refer to two satellites that operate in close proximity for an extended period of time.

es were all developed under the umbrella of security and defense (Fiott, 2014).

Originating from defense and security, dual-use technologies require a specific definition. As defense items, the United States has export control laws that define dual-use technologies as an item that has civil applications as well as terrorism and military or weapons of mass destruction (WMD)-related applications (Title 15 §730.3). Even though the definition highlights the link between military and civil use, the practical developmental application in most cases is distinctly different. The military's GPS receivers are not nearly as lovely as private citizens' iPhones and Android devices. The same is true for tablets and cameras. However, for space applications, this is different. A commercial communication satellite looks like and is used exactly the same way as a military communications satellite. Sometimes, they are even the same satellite. For example, the Wideband Global SATCOM satellite was designed on a Boeing commercial 702 bus and leverages commercial antenna technologies widely used. Why?

The answer is two-fold and partly cause and effect. The Clinton administration's Technology Reinvestment Project (TRP) was envisioned and designed to propel the development of commercial technologies critical to the military. This effort ultimately achieved its objective—creating a single unified industrial base for commercial and military technological development. This cooperation would, in turn, spur innovation throughout industry, give U.S. firms a new edge in international competition, and help ease the post-Cold War conversion of the defense industrial base. Today, commercial derivative aircraft operate in the U.S. and allied militaries worldwide, and space is no exception.

In theory, this is good news for taxpayers and users. Research & Development costs spread over a more extensive base represent smaller end unit prices for systems. The WGS system mentioned above was intended to be quick and cheap. In fact, it was a "Gapfiller" until the Defense Department could field its future SATCOM architecture. The real challenge that faces the United States today is that this same ubiquity presents numerous policy problems when trying to clarify friendly or adversarial forces in space. Much like the United States does, other defense organizations leverage commercial systems for military purposes. Iridium, Inmarsat, and GPS are three examples.

In short, this diplomatic concept of dual-use does little good in helping the larger space community solve challenges in space. The reality is, and always will be, rockets that launch scientific instruments can launch anti-satellite weapons. Satellites that can transmit can also jam other satellites. Satellites that can service other satellites can also cripple them. RPO activities require satellites to operate closely. This dual-use ambiguity has always perplexed policymakers—and continues still. Regardless of the difficulty it presents, there is no reason to shy away from the discussion. On the contrary, this challenge gives us the reason for having discussions in earnest on normalizing space behavior precisely because the dual-use nature of space systems is not like to change—period. The added nuances of RPO activities make the need for clarified rules all the more urgent as states will continue to deliberately maneuver close to each other with "dual-use" satellites, and other states will wonder what their intentions and actual use are.

The Problem with Intentions

Space powers may well be developing their RPO capabilities for mission life extension—or they may not. Just as dual-use technologies hamstring productive dialogue about a better path forward, one of the other difficulties in space operations has always been the ability to interpret and understand intentions. Using the Orbital Express Mission again in this paper, the technology stands to open a door for on-orbit servicing as it demonstrates hardware replacement and refueling. However, the Defense Advanced Research Projects Agency (DARPA) developments probably signal other states that its true purpose is not as altruistic as they suggest. Robotic arms absolutely can help do great things, as the arm on the International Space Station has demonstrated again and again. However, they also enable nefarious activities that raise significant concern for space practitioners.

Without prior coordination, it is nearly impossible to know another state's purpose or aim as their satellite approaches. Two satellites can approach each other at ballistic velocities fast enough to obliterate each other literally, but it could be completely innocent and simply a function of conjunction angle. Today there is no obligation to communicate with other states. There are occasions when states will attempt to contact each other and alert them of impending conjunctions. However, this is usually to notify the other party that an uncontrollable space object is approaching. Very rarely do states inform one another of RPO activities. Instead, militaries and space observation organizations see it via radar or optical telescope and are left to draw their own conclusions about what is going on. The lack of communication, more often than not, leads to increased anxiety, escalated tensions, and almost always strong rhetoric denouncing each other (Clark, 2021).

There is a need today for more open communication between states for safety reasons and debris mitigation. As states continue to conduct RPO activities, increased communication about the intention of the approach can help in several ways. First, if both parties know what is happening, neither party will misinterpret it for something it is not. Communication prevents inadvertent escalation of hostilities. Second, if both states know what is happening and why, neither side will conduct unnecessary defensive maneuvers, thus spending valuable propellant on getting away from a possible collision.[4] Establishing communication channels

4 It is both possible, and likely that defense system operators may choose to move rather than be approached, but the communication can help to deconflict burn direction and duration and make sure nothing else is endangered from the defensive maneuver.

and a standard lexicon will help build a repeatable, widely understood, ingress and egress dictionary that all states can use. This lexicon would be analogous to aviation terminology that is ubiquitous regardless of airspace or country sovereignty.

Regardless of the intention behind an approaching satellite, communicating intention only increases the overall safety of the encounter. When it comes to civilian encounters, there is literally no incentive not to do it. Alternatively, if the intentions are military in nature, it is reasonable to assume that states would not choose to follow this guidance. In this scenario, all parties better understand a state's intentions precisely because they do not participate and are not declaring intentions. Understanding what other aircraft in the air or other cars on the highway are going to do is a problem mankind has solved before through signals and or voice communication. The abstraction of space beyond our eyes should not limit our effort to do the same.

The Impetus for Action

In aggregate, the dual-use nature of satellites and the inability to understand intentions confound what is already a considerable problem in LEO and a growing one in GEO—orbital debris. Satellites' mission lives are limited. Some are limited by fuel, others are limited by power, and still others by consumables. When their useful life is over, more often than not, they are simply abandoned. Some states will actively try to deorbit systems if they can, others will allow their orbits to decay naturally over time, and some forget about the defunct satellite.

This apathy leaves the strategic space geography in a very congested state. The European Space Agency's (ESA) Database and Information System Characterizing Objects in Space (DISCO) notes that since the launch of Sputnik-1, there have been nearly 10 million objects tracked (Figure 3) (European Space Agency [ESA], 2021). With no current ability to conduct RPO

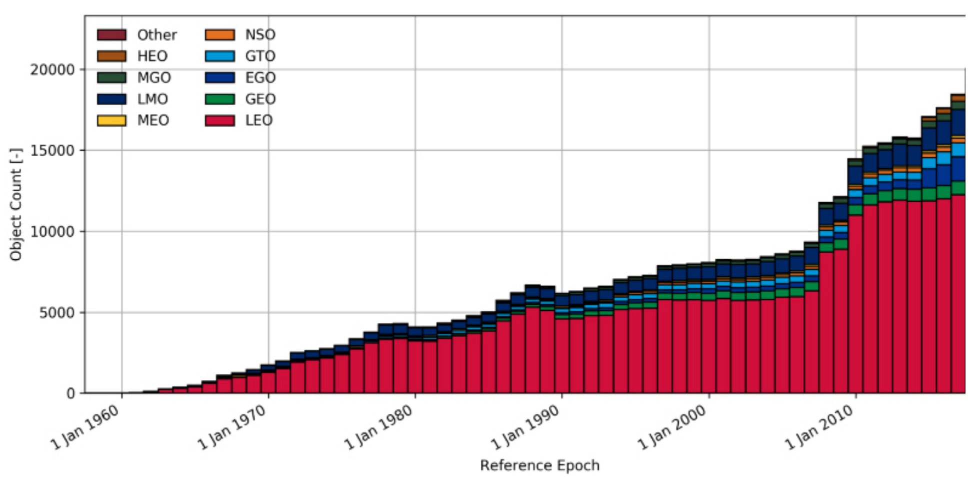


Figure 3: Object Count Over Time

activities to remove objects and inherent uncertainty about the intention of approaching satellites, the debris problem will continue to be an issue. Undoubtedly, it will result in a more significant issue for space sustainability in the not-too-distant future. Nevertheless, civilian companies are making great strides to prove the mission utility of RPO activities to solve these problems today.

Pit-Stops at 22,000 Miles Above the Earth

A unique capability recently demonstrated and being perfected presently is refueling in space. This concept is relatively straightforward. A servicing satellite and a client satellite conduct RPO activities until which time the two can dock. The servicing satellite can transfer fuel, extending a mission for many more years and enabling greater revenue to the client satellite. Alternatively, if properly configured, the servicing satellite can transfer cryogenics to the client satellite to keep sensitive payloads active longer and enable extended mission life for systems otherwise limited by small stores of coolant.

The American company, Northrop Grumman (NG), has twice demonstrated this method to service satellites. Instead of a robotic arm, the company used specially designed service receptacles to fuel on-orbit missions. In February 2020, NG's MEV-1 successfully docked with Intelsat 901 just outside its GEO orbital slot. To prove the company could service a system without removing it from its mission (and thus losing revenue), on April 12, 2021, NG's Mission Extension Vehicle-2 (MEV-2) successfully docked with a GEO communications satellite (Intelsat 10-02 (I.S. 10-02) while at its assigned orbital slot (Figure 4) (Northrop, 2021). The success of MEV-2's OOS objective opens the door for a new business model for companies looking to acquire and use satellite-based capabilities without necessarily committing to multiple vehicles and, by extension, expensive launches.

The risk, of course, is that what can reach out and grab can also be used for nefarious purposes. There is no getting around it, and it is time to accept that risk. There is no denying this is the greatest threat RPO activities can pose, and it is what naysayers will continue to claim as justification for denouncing

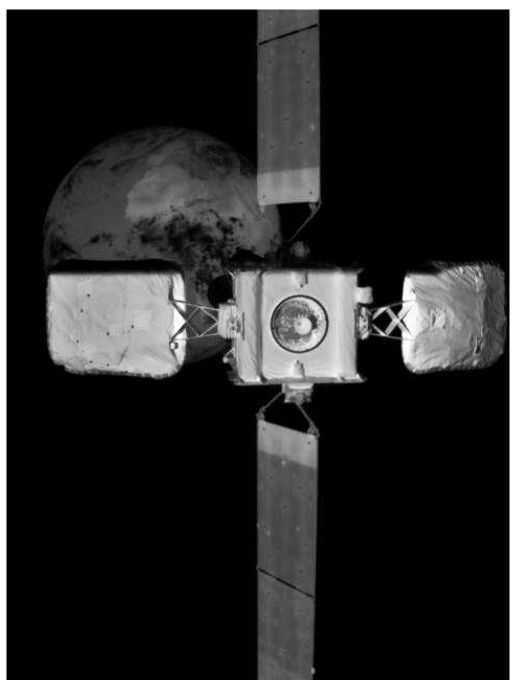


Figure 4: Northrop Grumman's -Z view of Intelsat 10-02 taken by MEV-2's infrared wide field of view camera at 15m away.

RPO activity as dangerous. While there is always an inherent risk that dual-use technologies can be used for harmful purposes, both ASTRO and MEV have demonstrated that the business benefits can far outweigh the low probability of bad actors using RPO as a means to conduct "space wars."

Summary

In 2021, Russia and China have likely caught up to, or are very close with, the United States in terms of RPO capabilities (Defense Intelligence Agency, 2022). However, it should be noted that the United States is still the most active country conducting RPO missions—both militarily and commercially—in the world. Commercial companies are beginning to truly appreciate the value of OOS and starting to consider how architectures that more readily enable it. The United States has demonstrated OOS through grapple and docking. Each method, though different, leverages the same phases of RPO to get close enough to achieve the desired results. Other countries see the value and want the same capabilities for their expensive investments.

What makes RPO contentious? Why is the United States, the world leader in both rendezvous and proximity capabilities, issuing public statements decrying other nations conducting RPO activities? The answer lies in both hubris and, thus far, unsubstantiated fear. The U.S. constantly uses the "dual-use" card to assert that what can be used for good can also be used for nefarious purposes. Is this a legitimate concern? Alternatively, is it simply another "missile gap?"

States have long operated in close proximity in space, and even during the height of the Cold War, they were not willing to engage satellites directly. The fear is based on a lack of demonstrated conduct. Large space powers are not politically incentivized to change their behaviors. Countries like the United States and Russia have been doing whatever they please, but it has substantially impacted the long-term sustainability of space. Through responsible RPO activities, states stand to gain more than they stand to lose.

Further, defining cooperative RPO as the responsible way to do it will help improve overall situational awareness for all states. Cooperative RPO requires pre-coordination. It allows states to talk and define their interaction before it happens.

Today, the vast leap in the ability to conduct satellite imaging has revealed most, if not all, satellite features to other states. There is no reason to believe that inspector satellites will reveal some other feature that has not already been revealed. Cooperative RPO activities allow states to gain better confidence in the true purpose of satellites, potentially increase mission life (and thus revenues), and build a foundation for improved transparency and confidence measures that can be expanded in time to address other problematic areas. In the end, enabled by increased knowledge, states are better positioned to assess the intent of non-cooperative, hazardous activities. The larger the cohort that agrees, the easier international bodies can hold each party accountable for RPO activities continued safe and responsible conduct.

CHAPTER 3

> ... reservation exclusively for peaceful purposes of the sea-bed and the ocean floor ... beyond the limits of present national jurisdiction, and the use of their resources in the interests of mankind (UNGA, 1967).
>
> —Arvid Pardo, 1967

Stalemate in the Global Commons

When it comes to establishing rules in space, there are generally two camps. The first camp widely subscribes to the belief that no rule put in place would be followed, and as such, if the United States attempted to follow it, it would leave the country at a strategic disadvantage. This same group feels that rules in space are largely unenforceable and would not be advantageous to deliberate on or attempt to implement. This argument centers on a belief that compliance would limit U.S. strategic options or create some mythical Achilles heel for the United States in space. Proponents of this school of thought write about the United States' high risk and increasing danger in space (Kramer, 2021) (Broad, 2021).

The alternative school of thought—a more liberal international relations approach—believes that space, much like the sea did for the British empire, can bring increased national wealth and prestige opportunities. Commercial business has often been the driver for international agreements because such agreements open the world up for increased commerce. This school of thought essentially believes that revenue opportunity exists, so rules should be established to ensure that everyone plotting a course across the black seas of space can do so peacefully (Greason et.al, 2019). Naturally, the two schools of thought have been largely unable to reconcile their differences and produce meaningful progress for rules of the road in space.

Regardless of which school of thought the reader subscribes to, the reality is that any attempt to legislate the entire *problem* of space is unlikely. The problem is three-dimensional and multivariable, and for most policymakers, the abstraction of outer space makes it all the harder to envision a way forward. This difficulty should not surprise anyone. There are many lessons to be learned from the world, and mankind has answered many of these same questions for the other great shared domains of the world—the oceans.

Examination of the legislation developed to establish and oversee the rules of the road of the sea may, on the surface, be counter-intuitive when considering how the United States might best develop space rules of the road. However, carefully reflecting on the governing principles for using the maritime domain reveals more similarities than differences. The world's oceans are vast, and by comparison, vessels that traverse them are minuscule. The same is true of space. Moving across vast oceans can be done in innumerable ways, but paths have evolved naturally that have been proven to be most efficient. In space, satellites can go in different directions and routes, but to do so comes at a high cost. Thus, logically, certain orbits have been defined over time, thereby allowing the most efficient space use. However, the interrelationship is much more nuanced than merely dimensional comparisons.

The reality is that no nation controls the sea. As much as one might desire, controlling an entire ocean is implausible, let alone all the oceans around the world. However, states can positively influence bodies of water through presence and action. Early theorists such as Alfred Thayer Mahan wrote ardently to document how but stopped short of saying one could control the entire sea. He wrote that the sea "presents itself as a great highway ... a wide common, over which men may pass in all directions, but on which [they] choose certain lines of travel [more] than others."

Mahan's definition reaffirms the natural tendency to choose specific paths across vast oceans and introduces us to the word *commons*. The term has been adopted by subsequent theorists and writers when referring to places no one nation owns but all nations use. Widely used to describe the oceans, some space analysts have argued that the terminology should apply when describing space, and others have cautioned against the legal pitfalls of its use (Silverstein et. al, 2021; Jonhson et. al, 2019). Seeing the value in treating space as a common allows analysts to try and adapt maritime norms towards the space domain. This adaptation enables policymakers and everyday citizens to envision the what and the how more easily-supported by thousands of years of historical experience on the seas. The antagonist's argument suggests that the term commons carries legal connotations not supported by existing international legislation (Johnson et. al, 2019). Regardless of which school of thought subscribed to, the truth remains that nations worldwide actively use space-based and enabled capabilities. Some of these capabilities come from organic space systems; others use international agreements to leverage standardized systems put in orbit by other states. Whatever the mechanism, the fundamental requirement for two states to operate in the same proximity and shared space is common to maritime and space operations.[5]

The United States has long asserted that no one nation can own space. The Trump administration's National Space Policy reaffirmed this proclamation recently when it declared that "All nations have the right to explore and to use space for peaceful purposes and for the benefit of all humanity, in accordance with applicable law" (EOP, 2020, p. 3). This overarching policy objective remains valid for the world's high seas outside territorial waters. Additionally, the same policy paper notes that the

5 This work uses shared space in reference to orbits—shared by all, owned by none.

United States considers the space systems of all nations to have the right to pass through and conduct operations in space without interference—another commonality with the world's oceans. Given the similarities, it seems only prudent to try and learn the lessons the world's statesmen have to teach us about international agreements that serve to advance the safe and responsible behavior of states in a global common—the oceans of the world. Rhymes in Time

The argument has been made many times before that those operating in space can learn a lot from the centuries of maritime operations of the world. Many works draw parallels between the maritime domain and the space domain and how best the United States can learn the lessons of Mahan and Corbett. However, for whatever reason, U.S. policymakers cannot agree to top-level treaties or arrangements that serve to guide our behavior in space. This disagreement is valid for the seas as well. The United States is not a signatory to the most prominent international agreement regulating marine and maritime activity. The United Nations Convention on the Law of the Sea (UNCLOS), signed by 167 states, is the overarching legal framework the world uses to settle maritime disputes and establish rules of the road. Despite its objection to provisions to parts of the UNCLOS, the United States has participated in nuanced agreements that serve its purpose. Bifurcation or even nuanced agreements could serve as a lesson for space policymakers moving forward because these nuanced agreements have served, over time, to protect American interests on the high seas.

Déjà vu

The present debate around safe and responsible behavior has been heard before—and solved. In the 1960s, a series of incidents, including close approaches of surface ships, low overflight of aircraft, and shouldering operations, all raised the overall anxiety of the United States and the Soviet Union. As the Cold War tensions elevated and the Soviet Navy moved to a blue water Navy, the frequency of close encounters between U.S. ships and Soviet ships increased.

On June 24, 1966, the Soviet *Anemometr* and the USS *Banner* collided (Winkler, 2005). In the same year; the U.S. State Department listed 36 soviet *harassment* incidents against American ships. In the spring of 1967, as Soviet destroyers shadowed the U.S. task group, the two countries ran into another series of contacts. On May 10, 1967, *Besslednyy* turned toward the USS *Hornet*. The U.S. destroyer, USS *Walker*, worked to block throughout the morning until finally, at 1106, the two ships took evasive action to avoid contact. Unfortunately, it was too late. The two ships made glancing contact and rubbed for about a minute (Navyhistory, 2021). The next day, a different Soviet destroyer (DDGS 025) took over for the *Besslednyy*, and while conducting shouldering ops, it also collided with the *Walker* (Navyhistory, 2021). American policymakers felt something had to be done in order to avoid misinterpretations and escalation.

The Soviet Union felt the same way, and on November 10, 1970, the Kremlin agreed to an American offer to discuss safety-at-sea talks (Winkler, 2005, p. 367). As part of the American delegation meeting in Moscow in May 1971, a senior Soviet Officer explained why. As the Soviet Navy grew from a coastal defense force to a blue-water navy, it did not have the experienced captains it needed. This inexperience could lead to junior officers inadvertently creating an incident with grave consequences for both countries (Winkler, 2005, p. 367). The engagement led to implementation of the Incidents at Sea Agreement (INCSEA), signed into force on May 25, 1972 (State Department, n.d.).

INCSEA has subsequently served to do precisely what it was designed to do. The United States and the Soviet Union agreed to the INCSEA to reduce the risk of misunderstandings by providing measures to help avoid collisions, protocols for maintaining safe distances from surveillance ships, prohibiting interference in formations, or simulating attacks on the other party's ships or aircraft. In October 1973, as conflict broke out in the Middle East, both countries operated approximately 150 warships in relatively close proximity on the Mediterranean Sea. Both sides still worked to avoid interference and used signaling techniques identified in the treaty to prevent inadvertent incidents (Winkler, 2005, p. 369).

Even after the Cold War ended, the INCSEA served as the molding document to help shape similar guidance. The treaty was a precursor that shaped an eventual agreement in 1998 between the United States and China that reflected many of the same tenets of INCSEA (LaGrone, 2014). Other efforts continue to refine the rules of the road for the rest of the world.

Even Unofficial Can Be Official Enough

The most recent attempt to clarify the maritime rules of the road was a 2014 proposal at the Western Pacific Naval Symposium to establish the Code for Unplanned Encounters at Sea (CUES). The United States has signed the CUES agreement, along with twenty other states. CUES is a series of non-binding rules of the road to prevent an escalation of tensions between different militaries at sea. A lot of international arrangements are, in fact, non-binding. However, CUES offers clarifications that help avoid unnecessary angst among navies at sea. Specifically, CUES defines both safety and communications procedures to help develop cooperation and transparency concerning the use of the sea (USNI, 2014). The United States implemented and executed the provisions laid out in CUES in a series of exercises with the PLA in 2014 and 2015 (*China Daily*, 2014).

In the end, the unofficial CUES has helped teach the navies of the signatory countries more about the operating frameworks of the others. In addition, it has and continues to build confidence in the actions of each state. At the same time, CUES has not done anything to decrease the tension of the activities on-going in the South China

Sea. However, it does help both countries establish normative behavior and, by extension, help inform deviations from expected behavior. As each state does something inconsistent with the rules of the road, responses are developed proportionately to the action. Ultimately, agreements like this go a long way to decrease the risk of misinterpretation and overreaction by the parties and are critical in ensuring the oceans remain open and accessible to all those that sail them.

Summary

Countries have found a way to operate in proximity of each other for centuries at sea. While there have been conflicts, by and large, the world's oceans and seas have been a place of peaceful coexistence. Even though blue water navies possess high-tech and lethal weapons like destroyers, aircraft carriers, submarines, and frigates—they do not attack each other at will. Despite the potential for nefarious behavior, states have largely cooperated with international agreements that govern maritime behavior. More importantly, even non-signatories have complied, because it has been widely accepted as "normal"—this is the lesson to be taken from the maritime domain when thinking about space operations.

Ships of war can be dual-use, and as humanitarian assistance around the globe has proven—they are. States use maritime assets to project power around the globe and do so without violence. If the United States believes that their space assets are strategic, we should treat their interactions with other states similarly. States should desire to continue to define how they interact with each other in the deep black seas of space. The world knows how to do it; it just must believe the benefit of doing so will be greater than the loss of some perceived advantage. However, the benefits of cooperative RPO activities are numerous.

With the commercial sector now accounting for most launches and satellites in space, perhaps it is time to reassess the defense fears that have prohibited the United States and others from letting down their guard and defining rules of the road. By defining safe and responsible behavior, states stand to boost the revenues for domestic companies and ultimately work to enable a more sustainable future for space powers around the world.

CHAPTER 4

> This is further evidence of Russia's continuing efforts to develop and test space-based systems, and consistent with the Kremlin's published military doctrine to employ weapons that hold U.S. and allied space assets at risk.
>
> —Gen John Raymond, 2020

Commercial Implications of RPO activity

Today, several countries are working through the early Research & Development (R&D) phase of on-orbit servicing and active debris removal concepts. The United States, China, and Russia have all demonstrated technologies that could be used for either application. Private companies who see a potential business model have also invested in demonstrations to refine the concept and present a viable technical approach to investors who may be interested. The problem, of course, is that it is all voluntary, and today there is no political will on the part of states to fund the development of this technology (COPUOS, 2012). The time for change may have arrived as purely state-sponsored space is on a rapid decline. From 2010–2019, commercial spacecraft constituted 55.6% of the total population (Disrens et al., 2019) (Figure 5). As the commercial sector takes on a more prominent role, there has never been a better time to discuss space sustainability and how it impacts investors.

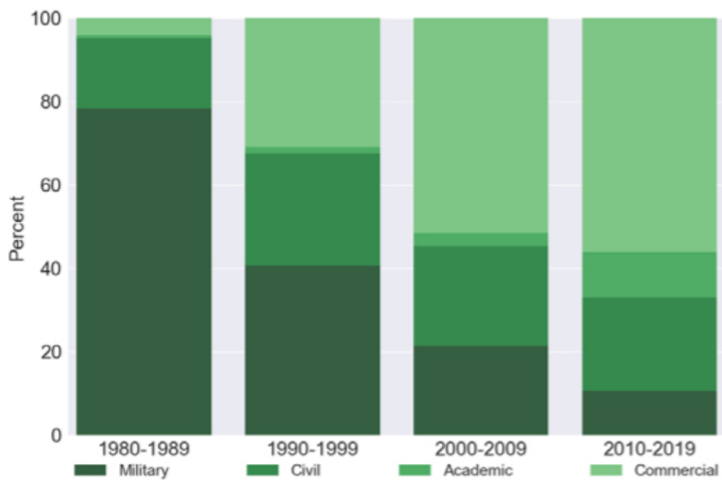


Figure 5: Percentage of spacecraft launched per decade by organization type

In 2020 alone, the global space economy was valued at over $371B. Forty-four percent of that was commercial satellite services (revenue generated from on-orbit satellites). On-Orbit servicing concepts stand to improve the longevity of these profits by extending mission life, and as such, the commercial market has an incentive to invest in the development of the technology. Further, when it comes to active debris removal, any effort to improve operational satellite safety translates to longer mean mission life and should equally be desired by the commercial community. Why the emphasis on the commercial? Quite simply, economics will drive any change to the existing approach to space operations legislation. Commercial companies in 2023 accounted for 52 percent of all launches and almost 50 percent of the global market share. As such, commercial space now have a chance to exercise a prominent voice to advocate for and work to ensure a more sustainable space (Bryce Tech, 2023).

States and commercial companies have made great strides toward improving the sustainability of space. Today, states and private companies alike work towards improving debris mitigation programs. As a result of the U.S. Space Policy Directive-3 (SPD-3), NASA—in coordination with the Secretaries of State, Defense, Commerce, and Transportation, and the Director of National Intelligence—worked to develop the U.S. Government Orbital Debris Mitigation Standard Practices (ODMSP) (Federal Communications Commission [FCC], 2020). The European Union published a draft Code of Conduct for Outer Space that included provisions to "minimize the possibility of accidents" (Council on Foreign Relations [CFR], 2021). Together, along with other overarching guidance, companies aim to minimize the debris generated, but the effort is simply not enough to overcome the number of objects sent into orbit.

Active Debris Removal and On-Orbit Servicing

The need for ADR is increasingly apparent to anyone paying attention. There are already more than 28,000 routinely tracked objects orbiting the Earth. Most of these objects (85%) are considered debris (Figure 6) (EOP, 2021, p. 1). That is to say that there is a vast ocean of objects orbiting the Earth that are not operational and no longer serve a purpose. A large amount of debris comes from any number of the approximately 560 known breakups, explosions, and collisions of satellites or rocket bodies. These have left an estimated 900,000 objects larger than 1 cm and a staggering 130 million objects larger than 1 mm in commercially and scientifically valuable Earth orbits (Krag, 2021). Without a change in direction, the continued pace of launches presents a real possibility of a future with unusable orbits around the Earth.

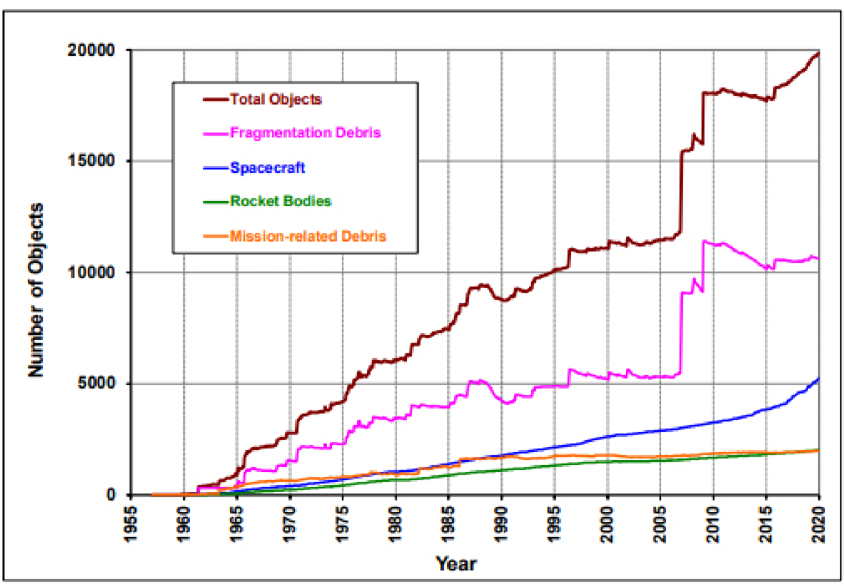


Figure 6: Number of Space Objects over Time

Orbital debris exists throughout the space environment surrounding the planet, and they naturally tend to be more densely located in the orbits humans use the most. The LEO region contains the highest estimated mass of debris, at about 3,000 metric tons (Liou, 2017). Collectively, there are over 8,000 metric tons of orbital debris from LEO to geosynchronous orbit (GSO), which is around 35,800 kilometers in altitude (Figure 7) (ESA, 2021).

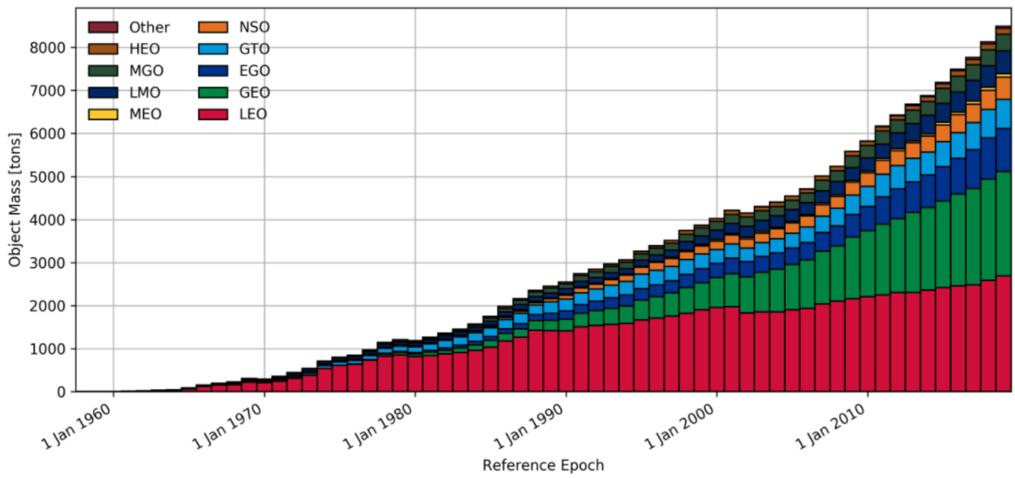


Figure 7: Mass Evolution in Orbits Over Time

The debris generation creates an unsustainable model, if proactive steps are not taken to deliver a future where residual debris is not simply ignored. The risk is substantial. Even relatively small pieces of debris are traveling at ballistic speeds, and when impacts occur, the results can be catastrophic. As a result of this increased probability of collision, the global space community is actively working through the R&D phase of the technology required to remove debris and enable a sustainable space environment actively.

Switzerland's ClearSpace-1 is the first mission specifically designed to remove debris from orbit. The mission, planned to launch in 2025, is being developed as a service contract designed to establish a new market for in-orbit servicing and debris removal. ClearSpace-1. Both NASA and ESA have acknowledged that the only way to stabilize the orbital environment is by actively removing large debris items. ClearSpace-1 will demonstrate the new project called Active Debris Removal/In-Orbit Servicing—ADRIOS.

The mission will target Vega Secondary Payload Adaptor (VESPA) upper stage (Figure 8) (ESA, 2019). Vespa is, in fact, a piece of orbital debris. Following a 2013 launch, VESPA has quietly waited in orbit (800 km x 660 km) and presents a perfect opportunity to demonstrate the technology ClearSpace-1 is working to prove. Vespa's mass is roughly the same as a small satellite, and the shape is simple enough to facilitate early demonstration of the technology's readiness.

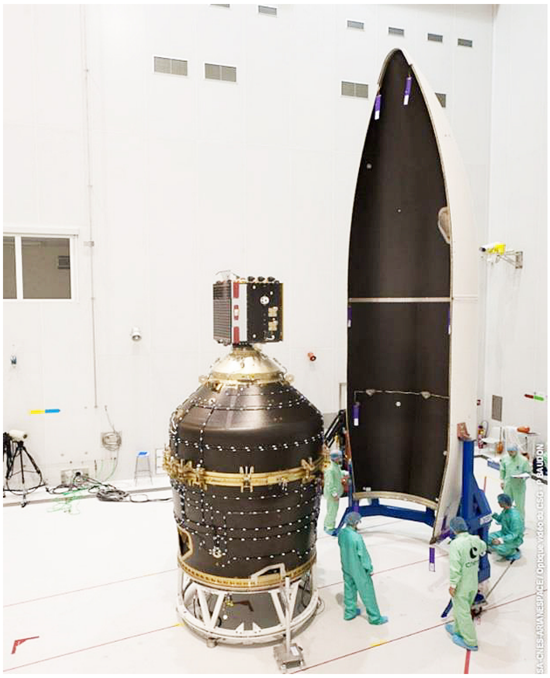


Figure 8: VEGA Launch Vehicle Adaptor mated to satellite

The ClearSpace-1 "chaser" will be launched into a lower orbit and will execute RPO until it catches up to and captures Vespa with the four robotic arms protruding from the Z-axis of the spacecraft. After capture, the chaser satellite will conduct a series of burns until it re-enters the Earth's atmosphere, where the combined set of satellites will be destructively deorbited (Figure 9) (ESA, 2019). If successful, this model could be used for a reoccurring business solution for sustainable space operations.

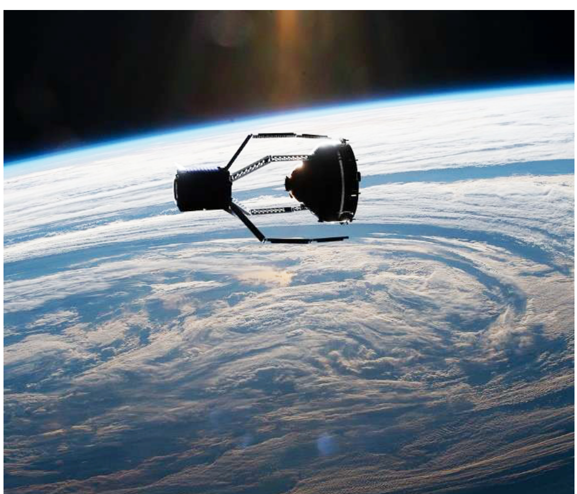


Figure 9: ClearSpace1 Artistic Rendition

Military Implications

The most common argument made for the rhetoric around the unique nature of space is that satellites and the boosters that deliver them to orbit are widely regarded as "dual-use" technology. In short, this is a diplomatic concept that refers to technologies that can be used both for peaceful and military aims. Rockets that launch scientific instruments can launch anti-satellite weapons. Satellites that can transmit can also jam other satellites. This very ambiguity has always perplexed policymakers. Add to this calculus the nuances of RPO activities, and the need for clarified rules becomes much more urgent.

The fact that RPO activities today cannot be evaluated for intent allows military flexibility in execution. The lack of boundaries is exploited routinely by all states, most prominently the United States. Today, the U.S. Space Force's GSSAP program conducts routine RPO activity to image and evaluate GEO-based satellites' capabilities. GSSAP provides an unobstructed view of resident space objects from a close distance and serves to enhance U.S. Space Command's (USSC) space situational awareness (SSA) (USSF FactSheet, n.d.). Alternatively, more easily understood—its job is to inspect other satellites. In 2016, the U.S. Air Force used GSSAP to inspect the Navy's Mobile User Objective System (MUOS-5). The system had encountered an anomaly on-route to its orbital slot, and GSSAP provided the ability to go and inspect the system to see if anything external was anomalous (Gruss, 2016).

Other states have similar systems and perform similar operations. In 2016, the Chinese launched SJ-17 and subsequently used it to inspect other satellites such as ChinaSat 5A and 20. In July of 2018, SJ-17 came to within 1.5 km of ChinaSat 1C for what analysts believed was an inspection mission (SWF, 2023, p. 03-10). All these missions are analogous to the missions conducted by the U.S. GSSAP system. Secure World Foundation categorized their activities as "consistent with research and demonstration of RPO technology for on-orbit servicing, inspection, and SSA" (SWF, 2019, p. 1-7).

Russia, too, conducts RPO missions regularly. In 2014, Russia launched OLYMP/LUCH. While believed to be a communications system, Russia has made close approaches to more than a dozen different commercial satellites for what analysts believe is a data intercept mission (SWF, 2023). This mission was in GEO, but Russia has also conducted RPO activities in LEO, some of which have received international attention. In 2020, COSMOS 2543 made a series of close approaches to USA 245 with the closest approach of 20 km (SWF, 2023, pp. 2-09). The US defense establishment publicly denounced the encounters as "threatening behavior," even though GSSAP has come within 10 km of Russian systems (Kahwaji, 2019). This inconsistency between actions and messages by the United States continues to plague any attempt to develop norms in space.

Ultimately, the major takeaway is that countries will continue to refine their RPO concept of operations and technology, and they will do so by watching the United States. For its part, the United States continues to use RPO activity extensively. RPO has helped the United States improve its knowledge of Russian and Chinese satellites through close inspection passes. It stands to reason, therefore, other countries will want this same military capability. Why? The answer is simple—uncertainty. Today, there are no rules that require states to divulge the mission of their systems. While the Registration Convention requires states to identify their "general purpose," nothing requires them to reveal secondary missions or "alternative" payloads. As such, states have a defense interest in knowing what satellites are, and they will continue to conduct RPO missions to improve their knowledge about them.

Summary

Improvements in codifying the road rules for RPO operations can only enhance the overall safety of these RPO missions, whether for commercial or military purposes. By cooperatively defining inspection profiles with all states, there will be less risk of misinterpretation, leading to a lower chance of escalation that would render space a battlefield. Additionally, if states could make it to a point where standardized RPO activities became the norm, there would be increased transparency and higher confidence in satellites missions. This improved confidence should go a long way in allaying dual-use concerns among states.

The commercial value of on-orbit servicing is evident. Moreover, in 2020 the commercial sector of space activity exceeded the military/defense sector for the first time. This market share should provide the impetus for serious consideration of RPO activity rules of the road. Extending mission life, updating payloads to accommodate rapidly changing technology, and fixing defective hardware all stand to reduce the need for launches, and by extension, the debris launches create. Additionally, with satellites living longer, fewer assets will require disposal, which will help manage the long-term viability of space as an operating domain.

While the ADR concept is today not economically viable, various initiatives could be undertaken to create an incentive to conduct debris removal missions. As discussed elsewhere in this work, whether it is a tax or some other mechanism, steps can be taken to hold companies and states financially responsible for the objects they send into orbit. Space may not be a global commons, but we all share the responsibility to take care of it. Understanding the value economically and politically in developing and codifying rules enables increased confidence in actions taken in space. If states are more comfortable operating in close proximity, we can begin to focus on the technical requirements to ensure the long-term sustainability of space for future generations.

CHAPTER 5

> A key reason why the space race is accelerating is that technology is advancing so rapidly ... a second reason is the absence of "binding commitments on what the operating norms are going to be in space ... and without that, we're very likely to have a space war.
>
> —Carey Smith, Parsons CEO

No Real Rules in Space

The real challenge the U.S. and the world face today is that existing legislation does not have anything to say about RPO activities. To date, states have been left to their own devices to define and conduct the activities however they see fit. The United States and Russia refined RPO activities through the early manned space programs. Alternatively, China has refined its RPO approach through a series of satellite experiments over time. Regardless of the how, none of the approaches violated any international agreement. However, all countries conducting RPO activities have issued strong rebukes of each other for doing what they do. If no one is breaking the law, why are they all pointing fingers? The truth is, the gray space leaves room for confusion, which causes anxiety and fear.

Current Legislation

Operating in space has always been relatively unregulated compared to airspace, territorial waters, and physical land borders. Ironically, this lack of regulation is not a reflection of a lack of states attempting to define and enforce them.

In January 1957, the U.S. Ambassador to the United Nations petitioned to secure space's peaceful use. Henry Cabot Lodge, addressing the U.N. General Assembly, implored that outer space's future development would be devoted exclusively to peaceful and scientific purposes (Vlasic, 1995). In September of that year, the U.N. General Assembly adopted Resolution 1148(XII), which called for an inspection system to ensure that "the sending of objects through outer space will be exclusively for peaceful and scientific purposes" (United Nations [UN], 1957, p. 871). In 1958, the U.N. adopted Resolution 1348(XIII), "recognizing the common interests of mankind in outer space and recognizing that it is the common aim that outer space should be used for peaceful purposes only…." (1958, p. 5).

Most importantly, U.N. Resolution 1348 established the Committee on the Peaceful Use of Outer Space (COPUOS), laying the groundwork for the first international space treaty. In 1963 the COPUOS submitted resolution 1962 named the "Declaration of Legal Principles Governing the Activates of States in the Exploration and Use of Outer Space" (UN, 1963). This resolution continued to advocate for peaceful uses for space but did no more than subsequent legislation to categorize what that term means. In the years that followed, the declaration played a prominent role in laying the groundwork for the subsequent Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies. This treaty was signed on January 27, 1967; this treaty is widely known as the Outer Space Treaty (OST) of 1967.

The Outer Space Treaty

The Outer Space Treaty is the first genuine attempt to hold stakeholders accountable for what they do in space, but ambiguous definitions continue to challenge its practical use by states. Article VII stipulates that each state party to the treaty that launches or procures the launching of an object into outer space […] is internationally liable for damage to another State party to the treaty or to its natural or juridical persons such object or its component parts on the Earth, in air space or in outer space (UN, 1967). It sets a valuable baseline, yet like other attempts to establish norms in space, it still does not define what peaceful means. The OST's vagueness allows for interpretations that permit military activities that can be defined as non-aggressive or defensive; in fact, "except for stationing of nuclear weapons and [other] weapons of mass destruction, all other forms of military activity are permitted in outer space" (Oppenheim, 2013, p. 770).

Article IX of the OST spells out the general provisions that stipulate that state use of outer space [...] shall be guided by the principle of cooperation and mutual assistance and shall conduct all their activities in outer space [...] with due regard to the corresponding interest of all other parties to the treaty (UN, 1967, p. 15). This provision lacks the specificity to distinguish between state action and civilian action. It also lacks clarity on specific space missions, making any potential for future arbitration on the matter unlikely.

The Liability Convention

In September 1972, the United Nations attempted to remedy these deficiencies by clarifying state liability by adopting the liability convention after fragments from a Soviet space object struck a Japanese cargo ship off Siberia's coast, causing damage to the ship and injuring five sailors (Diedriks-Vorschoor et al., 2008). The liability convention provided that a "launching State shall be absolutely liable to pay compensation for damage caused by its space objects on the surface of the Earth or to aircraft in flight" and liable for damage in space due to its faults, "or faults of persons for whom it is responsible" (UN, 1971, p. 25). However, this too has its limitations.

The provisions of the liability convention only apply to member states. Article VII notes that it applies to states, not nationals. So, private companies seeking arbitration would require state intervention to leverage this convention. As more private companies are launching and operating satellites, the antiquity of the convention limits its ability to serve the needs of corporations instead of states. Additionally, Article XIX is clear that the claims commission is not a mandatory mechanism.

Any compensatory judgments would be a recommendation unless both states agreed—which seems unlikely.

The Registration Convention

In 1975, the COPUOS put forth the registration convention that called for all states party to the resolution to register the objects they launch to ensure that the damaging party can be traced back to the registration. The COPUOS designed the provisions to ease any tensions by requiring states to register the space object's general function (UN, 1974). The resolution was ratified in September of 1976 and included the requirement to disclose the general function but did not require any disclosure of alternate or ulterior functions for which it might be used (UN, 1974). The dual-use nature of space systems limits the overall effectiveness of this provision.

Even with the requisite registration, and the other articles of the OST, the world is no closer to having any legal precedence that codifies RPO norms. Even 45 years later, no legally binding legislation has followed. The United States and the world have not agreed to any international agreement that would standardize RPO activities, and, as recent testing has proven, it would seem there is little appetite to move in that direction.

Summary

No real legislation has been put forth in almost 50 years that would serve to adapt these provisions and laws to modern technology or the changing dynamic that emerged with the growth of private space companies. While at the time of their drafting, it was true that states were the primary actors in space; yet today, the number of satellites owned by private companies dwarfs the number of satellites owned by state governments. This reality complicates international bodies even more. Companies are not signatories, and, in reality, companies may well accept the financial risk associated with their activities over trying to adapt to any emerging legislation that would impact their profitability and business model. All these things, and other reasons as well, have driven space legislation to languish. This stagnation—along with the fact that the United States has the most space-dependent economy, defense system, and way of life—is why the United States must take the lead and establish norms and standards of behavior that could help other states to adopt them or, at the very least, normalize RPO activities to the point where they become part of customary international law.

CHAPTER 6

Strategic Ambiguity Is Not Helpful

The economic model for Active Debris Removal (ADR) and On-Orbit Servicing (OOS) suggests there is potential; challenges stand in the way in any case. First, there is disagreement among states on what constitutes debris. Additionally, when considering third-party participation for commercial RPO activities, there is no agreed-to definition of how to safely approach and execute the mission. Other definitions need to be agreed upon before states can begin to put together a coherent framework through which ADR and OOS are not only economically viable but desired. For instance, assuming all parties can agree on whether something is debris and should be removed (not necessarily a given), what is the best way to remove it while being transparent and building confidence that the industry is a safe one.

Additionally, treating RPO activities the same, regardless of orbit, limits flexibility in developing options that help advance the tradecraft—it is not a one-size-fits-all concept. For instance, assuming identical standoff distances for each orbit limits the potential for solution space in them. Spacecraft in LEO are traveling vastly faster than those in GEO. Orbits closer to the gravitational sources (Earth in this case, but the same theory applies for other celestial bodies) need to travel faster to balance the higher gravitational pull found at the lower altitudes. Therefore, it is perfectly reasonable to have a different concept of operation for RPO activities in LEO than for activities in GEO, where the encounter would be comparatively slower.

Finally, once all the definitions are solidified, establishing rules for interactions in each orbital regime, one can begin to identify conditions that would be anomalous, and each state would be better equipped to determine intentions and assess threatening behavior. Without these definitions, the space community continues to be unable to evaluate the intent of another satellite in close proximity. This risks misinterpretation and inadvertent escalation. Ultimately, if states felt threatened enough, it could lead to offensive counter space activities that may very well have been unnecessary. Instead, it is in everyone's best interest to understand the challenges laying ahead and start to offer constructive dialogue on the path forward. The following section examines some of these challenges and offers potential options to address them moving forward.

One Man's Junk Is Another Man's Treasure

As a viable business option, ADR faces a few significant challenges, and, as usual, they are not necessarily technical. Defining what is and what is not debris is a challenge, though a challenge that could certainly be overcome. The Inter-Agency Space Debris Coordination Committee (IADC) defines it as "all man-made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional" (UN, 2011, p. 11). This distinction is not limited to satellites but applies to all the associated hardware that gets them to their operational positions. It ranges from spent rocket bodies to release mechanisms. Large things, like rocket bodies, are easy to track and generally pose a lower threat. However, smaller objects present a different challenge. Emanuelli et al. (2014) broke up the debris into categories based on size, risk, and how easily they are tracked (Figure 10). It provides a helpful comparison to note the sheer number of small objects that the world cannot accurately track.

Size	Potential Risk	Detection	Number	Mass Fraction
> 10 cm	Complete destruction	Tracked	21 000	>95 %
1 – 10 cm	Partial/ Total destruction	Partially Tracked	500 000	<5%
<10 cm	Damage, can be shielded	Not tracked, statically assessed	>100 million	

Figure 10: The classification of space debris

Of course, the IADC definition does not address passive satellites and carries a connotation of "useless" things. There have been instances where satellites thought to have been passivated have come back online and maneuvered (Axe, 2017). Whether this is deliberate or serendipitous is a subject of debate, but the fact remains, distinguishing between things like this and true "junk" is a task that must be completed. The IADC definition provides a practical framework from which to begin. It covers most objects in space, and any attempt to interact with them is likely to be much less contentious. To that end, it is best to start with the IADC definition, identify the objects that meet the criteria, and then begin to assess courses of action to deal with them appropriately. If ADR missions could prove the viability and demonstrate the ability to do it safely and responsibly, then there is reason to believe in accomplishing bigger endeavors to improve the sustainability of space.

Agreeing on what is and is not debris is the first step, but other challenges make it difficult to proceed. The most significant challenge to ADR is that there is no legal obligation to remove debris, nor are there legal provisions allowing entrepreneur spirits to remove it in hopes of a viable business model. As it exists today, Space Law includes five major treaties, and only two have anything to say about debris removal issues.

- The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space—the Outer Space Treaty (OST) of 1967
- The Convention on International Liability for Damage Caused by Space Objects of 1973 (the Liability Convention), defining the liable party as "the launching State."

The main weaknesses of these two treaties are that they do not clearly explain who must remove their satellites or their fragments. More importantly, neither legislation obligates a state to do so at all (Kallender-Umezu, 2012). Further, no legal precedence or legislation defines the roles of a third party that might attempt to remove the debris. It is not difficult to envision a scenario where a third party could remove "debris" that was not, in fact, debris. International agreements must be made to define the interaction between ADR entities and their interaction with other state objects, starting with consent to remove the object in the first place. A coordinated RPO activity would follow this consent to approach, contain, and deorbit the debris safely and responsibly.

Another challenge that limits the viability of ADR concepts today is that any U.S. component on spacecraft is constrained by International Traffic in Arms Regulations (ITAR), which requires specific high-level approval to obtain an ITAR-free classification. That said, the United States launches an array of satellites that perform sensitive missions from intelligence collection to communication, and it is unlikely that they, or other states, would be amenable to third-party interference with even their defunct satellite systems. This reticence will undoubtedly hamper any effort to conduct ADR as many satellites in orbit are American-made or support a sensitive mission.

Where Do We Go From Here?

None of the aforementioned challenges are insurmountable. All of them are addressable through increased transparency and coordinated confidence-building measures by states participating in space activities. The first thing that would be immensely helpful is a series of internationally conducted technology demonstrations. Participation from various states allows each state to become familiar with the process and technology used to conduct ADR and increase confidence in our collective ability to safely approach, restrain, and deorbit systems. Ultimately, these demonstrations could lead to widely accepted rules of the road for ADR activities and lead to a published (agreed to) guidebook for all states and private entities to follow when conducting debris removal operations.

To overcome the legal challenges that would prohibit normalizing these ADR activities, there needs to be an intergovernmental organization that will define and coordinate the remaining gray areas related to ADR. Once the definition is appropriately set up, other solutions can be implemented. To establish an effective legal & political framework related to an ADR service market, there needs to be:

- International agreement and transparency on which objects are selected for removal, and who should remove debris (Weeden, 2010)
- The clarification of the liability regime:
    - Identification of the proportion of debris for which each State is responsible
    - Development of protocols/agreements between Launching State and third-party removal entities
    - Defining who is responsible if a 3rd party is damaged during the removal process
- International agreement on the

implementation of ADR activities, with binding rules and regulations

- The creation of an Intergovernmental Organization (IGO) that will coordinate ADR missions

The IGO would coordinate ADR missions and is a critical, non-partisan entity that serves to diffuse state anxieties. Surrey Satellite Technology Ltd. (SSTL) (2013) envisioned an IGO coordinating mitigation and remediation activities and ultimately contracting for ADR missions. This concept is good, but it would require authorities to legislate and implement binding rules and regulations—a constant challenge for the space community. Assuming for a moment that there is sufficient confidence after the demonstrations that states want to be a part of this body, the IGO would go a long way to helping assuage fears of nefarious intentions that ADR practices could enable. Additionally, if all ADR activities would need to be coordinated with the IGO, any activities noticed by states that were not coordinated now become deviations from safe and responsible and leave the intentions of such activities to be more easily defined.

Who Pays for It?

Launching satellites today is not an inexpensive endeavor. The graph below shows the launch cost in current year dollars for the various launch systems over time (Figure 11). The good news is that the cost is decreasing rapidly. Today, boosters like SpaceX's Falcon rocket can boost missions to space for under $62M (about $2,720/kg) (Jones, 2018, p. 2). This decrease is excellent and promises to entice more private companies and other states to venture into the cosmos. However, the truth remains that both states and companies spend a large sum of money on building and launching a satellite into space. Today, there is not a cost incentive to spend more money to remove it.

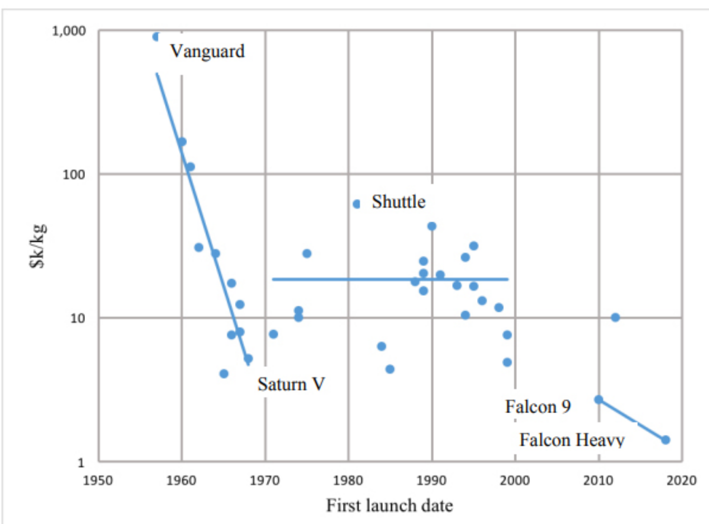


Figure 11: Launch Cost Over Time

In 2020, the demand for space launches totaled \$5.3B around the globe (Bryce Tech, 2021). For the same year, \$12.2B in revenue was generated for satellite launches. Most of this revenue came from commercial satellite launches (84%), a category of launch that is not regulated in the Liabilities Convention or the OST. Companies launching satellites into GEO will take necessary steps to dispose of satellites at the end of the mission, but it is not necessarily a given at that altitude. Satellites in low LEO will naturally deorbit over time; those in higher altitudes can take decades. Without some economic incentive or forcing function, it is unlikely that companies will aim to do anything different.

In 2009, Dunstan and Werb (2019) proposed a fund for debris removal they called the Orbital Debris Removal and Recycling Fund (ODRRF). Each satellite operator and launching state contributes to the ODRRF. Their contribution is a function of the threat criteria determined by the ODRRF as they evaluate the value of the space debris. This same entity would oversee the fund's administration and provide other services. The ODRRF would assist companies with re-registration and oversee removal actions to guarantee payment to the private companies (Baudet et al., 2016, p. 21). After the debris is removed, the private companies receive payment from the ODRRF. This initiative is analogous to the loss insurance already carried by many commercial space telecommunications companies today.

Ultimately, this approach faces challenges, too. Participation in a fund like the ODRRF would require top-level direction. Structuring the program to ensure that money is reallocated to the shareholders at the end of life could help garner their support for the early allocation of money in the mission. The ODRRF would have to account for mission life as a variable in the equation. Shorter mission lives will not generate the revenues as the decade-long telecommunication missions in GEO. The value of disposal must be accounted for in the early planning phases of the mission. This means users, or regulators, must specify the estimated value at disposal as a requirement for the companies to build. There is no reason this conceptual framework cannot work, and it would go a long way to helping ensure the long-term sustainability of space.

Rules to Abide By

Assuming states agree to an IGO that arbitrates what is classified as debris and coordinates between parties on its removal, the same rules can apply to servicing. First, two states, or companies, must agree on the technical approach used to service satellites or remove debris. This agreement will inform mission design and enable safe conduct in orbit.

Next, states must agree on proximity definitions. Close in GEO is not the same as close in LEO. The relative speed differences make the approaches challenging. Defining proximity, approach checkpoints, and contingency options should something become anomalous will help build confidence in the conduct of RPO activities. The United States conducts the most RPO activities in space—by far—so it should take the lead in helping define the terms and building an international demonstration team to prove out and refine the methodologies. A non-defense entity should run this demonstration; perhaps NASA or even a commercial company would be better. A non-militarized demonstration sets the stage for a non-military frame of mind that enables countries to see the commercial viability of RPO.

Finally, there needs to be increased cooperation among states in tracking and communicating satellite positions in space. The United States is finally making a concerted effort to define and build out Space Traffic Management (STM) as a framework (SR-253, 2021). Along with other states and even commercial companies, cooperative STM will bring a host of other sensors worldwide that provide improved frequency and geographic diversity. This improved capability will allow all participants to understand orbital information of satellites and enable improved accuracy in position knowledge and respective distances between satellites. With this improved knowledge, states could work out arrangements to move satellites even closer and more frequently. The increased resolution would enable the commercial capabilities that permit debris removal and mission life extension, drastically changing the life-cycle models used by satellite manufacturers today. This improved knowledge would also enable states to make more efficient use of the usable space left around the world as the margin for error becomes smaller.

Summary

The United States is uniquely suited to temper its anxiety and drive towards constructive clarification and road rules for RPO activities. First, America has the most satellites in the world—by far. Additionally, every day Americans use satellite-enabled technology more than all other states and rely on it for everything from banking to integrated control systems. Finally, the United States conducts more RPO activities than any other state in the world. Given all of that, there is absolutely no reason not to believe that the United States is best situated to define safe and responsible behavior in space and demonstrate it as well.

The United States can leverage various technologies to prove the concepts, increase overall confidence in their effectiveness, and define how RPO activities can become standard practice through the vast commercial base available. Through an improved clarification on safe and responsible behavior, the United States can help flush out improved standards of conduct that will better inform future endeavors to make space safer and more sustainable. There is no real downside to attempting such an effort. Any effort to codify safe and responsible RPO activities does not limit strategic flexibility. If anything, the effort better enables strategic flexibility. If states have improved situational awareness, and if RPO activities are cooperative, then deviations from the rules of the road make attribution and accountability all the easier. This increase in knowledge and precision affords additional protection to high-value assets in space, both in understanding the purposes of other satellites close by and in the form of removing debris that would otherwise inadvertently threaten mission success.

CHAPTER 7

> To seek invulnerability is to fall
> into the strategical vice of trying
> to be superior everywhere,
> to forfeit the attainment of
> essential for fear of risking the
> unessential, to base our plans on
> an assumption that war may be
> waged without loss, that it is, in
> short, something that it never
> has been and never can be.
>
> —Julian Corbett

How Can America Lead?

As previous sections of this work have noted, the challenge moving forward is not technical. The United States conducts RPO activities all the time and has demonstrated On-Orbit Servicing (OOS) technologies several times. The real challenge moving forward is instead a political one. This challenge is, without question, substantial. The United States, more than any other nation in the world, has a large and fractured space community. A U.S. Government Accountability Office (GAO) report (2016) identified 60 organizations spanning the DoD, the Executive Office of the President, the Intelligence Community, and civilian agencies that share space interests or responsibilities. Of these, eight organizations, including Space Systems Command (formerly Space and Missile Systems Center) and the National Reconnaissance Office, have space acquisition management responsibilities; eleven have oversight responsibilities, and six are involved in setting requirements for defense space programs (GAO, 2016). This complex and nebulous relationship is made more difficult by the nine different committees in congress that exercise some form of oversight over space activities (Gleason et al., p. 11).

The idea that the United States could reach a quick consensus, let alone the rest of the world, is improbable. The challenge of addressing all space behavior is onerous, and history has shown that more parties do not always lead to solutions. The UN Committee on the Peaceful Use of Outer Space (COPUOS) took nearly a decade to garner consensus on the Guidelines for the Long-Term Sustainability of Outer Space Activities—a voluntary, non-binding set of guidelines. How then can states make decisions on essential activities in space? There are several ways to deal with this challenge. The first method is one of top-down national leadership. Robin Dickey (2021) points out that this type of approach has the benefit of raising attention leading to policy momentum and providing a high-level outlet for coordinating among various agencies. The challenge inherent in expecting the Executive Branch to issue national-level guidance is that it frequently will be vague. However, with the proper support, a downward-directed approach may well be required to start a movement that can build momentum over time.

Alternatively, Dickey (2021) notes that a single agency lead can be effective as well. Senior military leaders have already noted that the Department of State (DoS) should be the lead agency for developing rules and norms of behavior (Burt, 2021) (SASC, 2021). The State Department has the expertise to help develop international norms agreements. Through a national policy decision, the department could be directed to lead the way in identifying rules of the road and working to garner other state support for norms related to RPO activities.

Finally, taking civil constructs and expanding them is a creative way to approach an old problem. The Artemis Accords offer a framework for the United States to leverage. Signed by 36 states, the Artemis Accords established a practical set of principles to guide space exploration cooperation among the signatory nations. The United States must lead in creating transparency and confidence-building measures (TCBMs), not just among allies but all space-faring states. Though it is not a legally binding agreement in its current form, the Artemis Accords include sections that address numerous issues that have long plagued space's formal normalization. Section three commits the signatories to use space for peaceful purposes, and section four follows committing the signatories to transparency (NASA, 2021). It should go without saying that transparency is critical for any internationally binding legislation for states. Having already gained some momentum in the international arena could prove beneficial in getting other states to agree. The Accords offer a reinvigorated framework to focus America again on attempting to build out a definitional agreement on terms and start the journey to building robust TCBMs that will build, over time, confidence in our cooperative use rendezvous and proximity operations.

Regardless of which approach is selected, the complexity of the U.S. space community will make reaching consensus a challenge. Ideally, a top-down leadership approach would be taken by an administration. The National Space Council could inform this directive to provide the technical merit to the directive and help avoid the general vagueness of national-level guidance. Ultimately, the national-level approach forces the disparate entities and institutions in the United States to synchronize and move forward. A solidified outward-facing solution to other states will help to avoid confusing and counterproductive themes and messages. In the end, this approach is the one most likely to focus America's effort into developing *a singular set of guidelines* to inform global conversations on a standard solution moving forward.

Not Rules, Guidelines

Trying to develop a one-size-fits-all solution for RPO writ large would be a wasted effort. Each orbital regime carries with it unique characteristics that states can use to their advantage. Satellites operating in Low Earth orbit (LEO) can take advantage of surveying the entire globe in a matter of days. Given the high accuracy associated with the relatively low altitude, LEO is the most used and the most vulnerable orbit regime. LEO is increasingly congested, making operating there more complicated than it has historically been. At the same time, satellites operating at geosynchronous orbits (GEO) and beyond are relatively low threat areas but require substantially more energy to get there. In GEO (approximately 35,786 km altitude), a satellite's orbital period equals one revolution of the Earth, making it appear as if the satellite is fixed relative to Earth's surface.[6] This relationship places a premium on orbital locations there, which can provide 24/7 telecommunications fixed contact.

As these two orbits have vastly different utility and density, RPO activities in each should be viewed differently. Close approaches in LEO are frequent, and as such, the intent is harder to gauge. Alternatively, satellites conjunctions in GEO often are deliberate—even if for *peaceful* purposes.

Tangible Policy Recommendations

The United States can take the lead in RPO activity, not just in doing it, but in helping shape how the world does RPO. First, in agreement with the more considerable effort to declassify overly classified things, the Executive Branch should publish an Executive Order dictating what the United States accepts as best practices for RPO. The United States has spent years refining its method, and it is readily available information should the defense apparatus choose to divulge it. This information would not reveal critical capabilities or vulnerabilities and, as such, only stands to increase the global understanding of what the world's largest space power thinks about RPO as a matter of formal policy. Publication of this policy document would serve to inform the military and civilian sector on what is acceptable.

Second, the United States, led by the Department of State, needs to publish a cooperative RPO Obligatory Program for Encounters (ROPE) that, among other things, explains safe ingress and egress, acceptable relative velocities by orbit, and distance from the client satellite. ROPE would also specify an acceptable methodology of docking, grappling, or other capture methods based on system size and type. All have been demonstrated successfully by multiple countries. Standardization stands to significantly decrease ambiguity on what states are doing when conducting RPO activities. ROPE would also provide specific actions approaching satellites must take at various distance gates to demonstrate positive control, minimum Delta-V elocity for emergency maneuvers, and communications link connectivity.

6 Note: In this work, while there are differences, the terms Geostationary and Geosynchronous are used synonymously.

Advocating wide acceptance of the ROPE, the United States should develop a joint, international venture to demonstrate it in all orbital regimes and flush out improved orbit unique profile requirements. The demonstration should use a common operating picture, widely available to all countries (e.g., spacetrack.org is a commonly used one) so each participating state can see and monitor the activity. As part of the demonstration, each state should be operating in their domestic control centers to prove the ability to coordinate remotely and establish communication plans and language that facilitates the ingress, possible capture, and egress of the cooperation encounter. The demonstration ultimately serves to increase overall confidence by providing standardized approach methods and profiles. By extension, states who choose not to participate, or do not follow, should be called out by all space-faring states.

Audrey Shaffer (2017) correctly notes that defining norms is not likely to deter hostile states from doing hostile activities. States, or even private actors who intend to violate rules, will do so regardless of existing rules, norms, or legislation. However, this should not be a detractor from an attempt to do the right thing. The specifications defined in ROPE will enable improved space situational awareness, enable multilateral observations to monitor anomalous behavior, and, if necessary, take appropriate actions to maintain flight safety.

Third, The United States should publish executive mandates to require all future high altitude (upper limits of LEO and above) satellites to be OOS compatible. Whether this is software-defined radios that improve mission utility over time or integration of refueling capability that extends mission life, this compatibility will actively help mitigate debris by reducing the total number of launches and decommissioned systems. Accommodations should naturally be made for low-LEO systems in the form of disposal obligations. This directive does not stand to burden satellite manufactures. The technologies have been demonstrated and are relatively form-fit-function replacements for other components on satellites. However, the long-term benefits to improve the sustainability of space will manifest in tangible decreases in man-made orbital debris.

Finally, the United States should advocate for creating an IGO with the express charter to improve space coordination and sustainability. This IGO, unlike the COPUOS, should have the authority to arbitrate disagreements, hold states accountable for non-compliance, and seek to codify, in legislations, rules that would be built off ROPE. Expanded further, the IGO would be responsible for developing economic approaches that would economically incentivize debris mitigation—not just best practices. Working with both the technology and financial sectors, revenue potentials exist for debris removal that would be useful for future applications (e.g., asteroid mining).

Summary

The world's space powers will continue to conduct RPO activities regardless of what American policymakers want. After all, imitation is the highest form of flattery. Countries understand the value of RPO because America has shown them. Commercial ventures like those enabling OOS and ADR are here, and they stand to generate significant revenue for the private sector. All countries have an inherent interest in ensuring the respective missions are executed safely, and, as the world's leader in RPO activities, launches, and the number of satellites, it stands to reason that the United States has the largest dog in this proverbial fight.

Today, non-governmental and governmental organizations are trying to formulate rules of the road to enable quiescent RPO operations. The concept of mission enhancements resulting in longer life for satellites is a good one. The concept of removing the incredible amounts of debris that man has put into orbit is an even better one. Both concepts combine to enable a more sustainable future for space-faring nations of today and tomorrow. If the United States is committed to a sustainable space environment, as laid out in the National Space Policy, there is absolutely no reason the United States should not be the country working to codify how all states conduct RPO activities.

By agreeing to terms, orbital regime offsets, and safety zones, each country is less likely to misinterpret activities and thus inadvertently escalate geopolitical tensions in space. AAD and OOS activities will be conducted regardless of agreement, most likely by the United States. The time to let go of unfounded fears has come. Enabling states and private companies to refine and normalize RPO activities is now the responsible thing to do. That does not mean all states will do it. However, even if legislation is never ratified, leading the way in developing widely accepted definitions and concepts will be an essential step forward for the United States in normalizing RPO activities.

Appendix

RPO Obligatory Program for Encounters (ROPE) Notional Tenets and Elements

1. **Applicability:** While the Elements identified herein are intended to be compulsory, voluntary adaptation, at a minimum, is highly encouraged to reduce risk and improve Long-Term Sustainability (LTS) of space. All tenets identified below reinforce the work codified in the LTS measures published by the United Nations Committee on the Peaceful Uses of Outer Space. Ideally, these should be adopted as a future amendment to the LTS measures. Recognizing that those measures are voluntary, the tenets below reinforce the measures and add technical specificity and accountability to states engaging in RPO encounters.

2. **Two-Party ROPEing Agreement:** Before conducting any On-Orbit Servicing (OOS) or Active Debris Removal (ADR) encounter, Servicing Satellites and Client Satellites shall establish consent prior to any encounter. This legally binding agreement identifies the date, time, purpose, and flight profile. The agreement will specify burn profile and declare min/max Delta-V , when possible, to help with approach, egress, and contingency planning. In addition, it would identify break-off points and contingency measures in the event of an anomaly. This agreement would enable either the servicing or the client satellite to call "knock it off" at any time. In addition, it would include language for arbitration, should it be required.

3. **Defined Approach Profile Risk Categories:**

    a. **Safe Ingress:** The preferred RPO method. Defined herein as cooperative encounters with active systems capable of positive control. Safe Ingress includes declared min/max Delta-V capabilities. It consists of both primary and backup sensors (could be EO, LIDAR, or both). Cooperative implies both systems are using sensors to measure relative distance and velocity.

    b. **Low-Risk Ingress:** Less Preferred RPO method. Defined herein as non-cooperative encounters with passive stable systems. It also includes encounters where one of the systems does not have positive control or sensors to support the approach and departure of the other. In this scenario, the other system does have both positive control and sensors.

    c. **Medium-Risk Ingress:** Undesired. Defined herein as non-cooperative encounters when one of the systems is active and capable of positive control and one of the systems has an anomaly that impacts ACS, GNC, or other subsystems that would support maintaining positive control. Both parties must agree to the risk. This agreement would include the release of liability of damage.

4. **Notice To Space Operators (NOTSO):** For each engagement, a NOTSO shall be published on an open-source, widely available, and used space tracking resource. This could use existing open sources, like space-track.org. The NOTSO shall include purpose, intention, epoch, and points of contact. Analogous to a NOTAM, the NOTSO informs non-participating parties of future activities that may impact their operations. This facilitates increased space situational awareness for all space operators, not just the systems, states, or companies involved in the operation. NOTSOs shall be published no later than 24hrs prior to the event and updated 12hrs, 6hrs, 3hrs, and at T-0.

5. **Pre-Mission Definition of OOS method and Provider:** When possible, systems shall be designed with OOS in mind. This means defining the capture method and building modular systems that are accessible to the servicing satellite. Additionally, operating entities (states or corporations) shall have in place agreements with the Servicing Satellite provider to improve interface design, increase commonality where possible, and encourage early system design OOS considerations

6. **Capture Method Definitions:** The capture method shall be considered as a function of vehicle mass. Heavier objects are likely to include positive control mechanisms (e.g., ACS). However, smaller category systems such as CubeSat have limited Delta-V , and as such, their ability to support an encounter will be limited. The capture method shall be considered before launch and designed into the system.

    a. **Grapple:** Defined herein as a robotically articulated, multi-degree of freedom capture arm. This method shall be used when the client satellite has a low mass and is unlikely to present significant stability challenges for the servicing satellite. Additionally, this method would be preferred for low risks and med risk encounters.

    b. **Docking:** Defined herein as a deliberate attempt to attach two systems mechanically. This method shall be used for cooperative encounters and when both systems have positive control.

7. **Ingress Vectors:** If either the servicing vehicle or the client vehicle is limited to only an electro-optical sensor suite, all approaches should be made in optimal lighting conditions. Approaches made in terminator or eclipse present performance challenges for some sensors that unnecessarily increase the risk of the encounter. If both systems are equipped with other sensor suites such as LIDAR, the encounter should be conducted at a time that optimizes multi-sensor observation from non-participating systems to aid in enhanced situational awareness.

8. **Capabilities Verification Maneuvers:** Each servicing system shall conduct maneuvers during the ingress to verify positive control, communications links, and full system capability. This shall be done at a sufficient distance so as not to present any danger to the client satellite. This shall be done in

optimal lighting conditions so both parties can witness the demonstration and agree to proceed.

9. **Egress Vectors:** All departures shall be made in a manner that does not increase the risk of the encounter, and that will provide the greatest separation distance in the least amount of time.

10. **Declared Delta-V Requirement:** Servicing vehicles must have a declared min/max Delta-V . This ensures the client satellite can accurately model ingress and egress before the encounter and develop optimized approach vectors to support the operation. The declared values are not required to be the max capabilities of the system but rather the min/max Delta-V that will be used in operation.

11. **Defined Communication Plans:** For each encounter, both parties must have a communications plan. Herein defined as agreed to primary and backup comm frequencies and infrastructure, a shared sequence of events for contacts, and active voice communication throughout the duration of the operation.

12. **Contingency Plans:** Each encounter shall identify ingress and egress checkpoints that facilitate safety of flight maneuvers if required.

13. **Non-Compliance Accountability:** Any state or private company that deliberately ignores the provisions herein defined will receive a public acknowledgment by the aggrieved state, corporation, or international intergovernmental organization and shall be labeled as having conducted willfully unsafe and reckless operations in space. This includes any RPO activity in which consent of the other party has not been provided. States are encouraged to engage the involved parties through appropriate channels to adjudicate issues that arise from compliance. With the parties' consent, the outcome of these exchanges should be presented to the UNCOPUS to enable shared knowledge of reckless and unsafe activities by all committee member states. These conversations would ensure this behavior is documented in the committee reports and provide a long-term accounting of violations.

    a. **Exceptions:** Any deviation from the provisions deemed accidental by virtue of vehicle anomaly or loss of control are exempt. This determination would be made on the part of involved states, corporations, or international intergovernmental organizations.

13. **Non-Applicability Exclusions:** Systems that do not possess the means to maneuver are exempt from the provisions herein. This can include deactivated systems, CubeSats, spent rocket bodies, or other space objects. However, suppose any approach to an inoperable system is made. In that case, it is the responsibility of the Servicing System to follow the provisions laid out, submit the proper NOTSOs, and ensure communication with the owner of the non-maneuverable system has consented to and is participating in the RPO activity.

References

15 CFR 730.3–"Dual Use" and Other Types of Items Subject to the EAR., Title 15 § 730.3 (2017). https://www.ecfr.gov/current/title-15/part-730/section-730.3

Axe, D. (2017, October 30). *Russia's 'Killer Satellites' Re-Awaken*. Thedailybeast. Com. https://www.thedailybeast.com/russias-killer-satellites-re-awaken

Axelrod, T. (2018, August 23). *Pence: Trump's national security will be as 'dominant' in space as it is on Earth*. The Hill. https://thehill.com/homenews/administration/403316-pence-trumps-national-security-will-be-as-dominant-in-space-as-it-is/

Basham, K. (2021, April 12). *Northrop Grumman and Intelsat Make History with Docking of Second Mission Extension Vehicle to Extend Life of Satellite*. https://news.northropgrumman.com/news/releases/northrop-grumman-and-intelsat-make-history-with-docking-of-second-mission-extension-vehicle-to-extend-life-of-satellite

Baudet, L., & Ruffiot, M. (2016, February 3). *Active Debris Removal: From the main barriers to the definition of a business model*. https://chaire-sirius.eu/documents/dac7ab-ruffiot-baudet-2016-active-debris-removal-from-the-main-barriers-to-the-definition-of-a-business-model.pdf

Bonnal, C., Ruault, J.-M., & Desjean, M.-C. (2013). Active debris removal: Recent progress and current trends. *Acta Astronautica*, *85*, 51–60. https://doi.org/10.1016/j.actaastro.2012.11.009

Broad, W. J. (2021, January 25). How Space Became the Next 'Great Power' Contest Between the U.S. and China. *The New York Times*. https://www.nytimes.com/2021/01/24/us/politics/trump-biden-pentagon-space-missiles-satellite.html

BryceTech—Reports. (2021, July 20). *2021 State of the Satellite Industry Report.* https://brycetech.com/reports

Boeing Integrated Defense Systems. (2006, May 12). *Orbital Express*. https://web.archive.org/web/20060512144505/http://www.boeing.com/ids/advanced_systems/orbital.html

Burt, D., MajGen. (2021, May 3). *Schriever Spacepower Series*. Mitchell Institute for Aerospace Studies. https://mitchellaerospacepower.org/event/space-power-forum-maj-gen-deanna-burt/

Cheng, J. (2014, February 24). *Air Force unveils secret space surveillance satellites*. Defense Systems. https://defensesystems.com/articles/2014/02/24/air-force-gssap-spy-satellites.aspx

China Daily. (2014, December 13). *China, US navies implement code of conduct*. http://www.chinadaily.com.cn/world/2014-12/13/content_19077725.htm

Clark, C. (2021, October 28). *US, China, Russia Test New Space War Tactics: Sats Buzzing, Spoofing, Spying*. Breaking Defense. https://breakingdefense.com/2021/10/us-china-russia-test-new-space-war-tactics-sats-buzzing-spoofing-spying/

Committee on the Peaceful Use of Outer Space. (2012, January 27). *Active Debris Removal—An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space*. https://www.unoosa.org/pdf/limited/c1/AC105_C1_2012_CRP16E.pdf

Corbett, J.S. (1911) *Some Principles of Maritime Strategy.* The latest edition, edited by Eric Grove, was published by the Naval Institute Press in 1988. All references in this paper are to the 1988 edition.

Defense Intelligence Agency. (2022). *Challenges to Security in Space: Space Reliance in an Era of Competition and Expansion* https://www.dia.mil/Portals/110/Documents/News/Military_Power_Publications/Challenges_Security_Space_2022.pdf

Dickenson, J. Gen. (2021, April 20). *Hearing before the SASC United States Strategic Command and United States Space Command in review of the Defense Authorization Request for Fiscal Year 2022 and the Future Years Defense Program*. https://www.armed-services.senate.gov/hearings/to-receive-testimony-on-united-states-strategic-command-and-united-states-space-command-in-review-of-the-defense-authorization-request-for-fiscal-year-2022-and-the-future-years-defense-program

Dickey, R. (2021, July 20). *Building Normentum: A Framework for Space Norm Development | The Aerospace Corporation*. Aerospace Corporation. https://aerospace.org/paper/building-normentum-framework-space-norm-development

Diederiks-Verschoor, I. H. P., Kopal, V., & Diederiks-Verschoor, I. H. P. (2008). *An introduction to space law* (3rd rev. ed). Kluwer Law International; Sold and distributed in North, Central, and South America by Aspen Publishers.

Diserens, Lewis, H.G. Prof., & Fliege, J. Prof. (2020). *NewSpace_and_its_Impli-*

cations_for_Space_Debris_Models.pdf. https://eprints.soton.ac.uk/443465/1/NewSpace_and_its_Implications_for_Space_Debris_Models.pdf

Dunstan, J., & Werb, B. (2009, December 8-10). *Legal and Economic Implications of Orbital Debris Removal: A Free Market Approach*. International Conference on Orbital Debris Removal, Reston, VA. https://techliberation.com/wp-content/uploads/2009/12/Legal-and-Economic-Implications-of-Orbital-Debris-Removal-A-Free-Market-Approach.pdf

Emanuelli, M., Federico, G., Loughman, J., Prasad, D., Chow, T., & Rathnasabapathy, M. (2014). Conceptualizing an economically, legally, and politically viable active debris removal option. *Acta Astronautica*, *104*(1), 197–205. https://doi.org/10.1016/j.actaastro.2014.07.035

European Space Agency. (n.d.). *Space Safety Analysis and Prediction*. Retrieved October 18, 2021, from https://www.esa.int/Safety_Security/Space_Debris/Analysis_and_prediction

European Space Agency. (2019, September 19). *ESA commissions world's first space debris removal*. https://www.esa.int/Space_Safety/Clean_Space/ESA_commissions_world_s_first_space_debris_removal

Executive Office of the President. (2018, June 18). *Space Policy Directive-3, National Space Traffic Management Policy*. https://trumpwhitehouse.archives.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/

Executive Office of the President. (2020, December 9). *National Space Policy*. Office of Space Commerce. https://www.space.commerce.gov/policy/national-space-policy/

Federal Communications Commission. (2020, August 25). *Mitigation of Orbital Debris in the New Space Age*. Federal Register. https://www.federalregister.gov/d/2020-13185

Fiott, D. (2014). *The Three Effects of Dual-use: Firms, Capabilities, and Governance*. European Union Institute for Security Studies (EUISS). http://www.jstor.org/stable/resrep06836

Gleason, M., Dickey, R., & Byrne, J. (2021, January 19). *The Space Policy Primer: Key Concepts, Issues and Actors | Aerospace Center for Space Policy and Strategy*. https://csps.aerospace.org/papers/space-policy-primer-key-concepts-issues-and-actors

Goodman, J. L. (2006). History of Space Shuttle Rendezvous and Proximity Operations. *Journal of Spacecraft and Rockets*, *43*(5), 944–959. https://doi.org/10.2514/1.19653

Greason, J., & Bennett, J. (2019, June 5). *The Economics of Space: An Industry Ready to Launch*. Reason Foundation. https://reason.org/policy-study/the-economics-of-space/

Gruss, M. (2016, August 18). Air Force sent GSSAP satellite to check on stalled MUOS-5. *SpaceNews*. https://spacenews.com/air-force-sent-gssap-satellite-to-check-on-stalled-muos-5/

Hacker, B.C. (1974). The Idea of Rendezvous: From Space Station to Orbital Operations in Space-Travel Thought, 1895–1951. *Technology and Culture 15*(3), 373-388. https://www.muse.jhu.edu/article/892735.

Hirsch, S. (2018, May 29). *There is no* "*War in Space.*" Air & Space Forces Magazine. Retrieved May 10, 2024, from https://www.airandspaceforces.com/article/there-is-no-war-in-space/

Holger Krag. (2021, July 16). *A sustainable use of space*. Science. https://www.science.org/doi/10.1126/science.abk3135?utm_source=TrendMD&utm_medium=cpc&utm_campaign=TrendMD_1&

Johnson, C., Weeden Brian, & Hertzfeld, Henry. (2019). *How Simple Terms Mislead Us: The Pitfalls of Thinking about Outer Space as a Commons* [dataset]. https://doi.org/10.1287/5f4e34c9-55a8-4667-b696-4d50c9931b3e

Jones, H. W. (2018). *The Recent Large Reduction in Space Launch Cost*. 10. https://ttu-ir.tdl.org/server/api/core/bitstreams/d4074c60-2e50-4e92-a49b-e2fbc2be4b91/content

Kahwaji, R. (2019, April 10). The Stellar Dance: US, Russia Satellites Make Potentially Risky Close Approaches. *Breaking Defense*. https://breakingdefense.sites.breakingmedia.com/2019/04/the-stellar-dance-us-russia-satellites-make-potentially-risky-close-approaches/

Kallender-Umezu, P. (2012). *G-SEC WORKING PAPER No.30 A Market for Cleaning Up Space Junk?* https://www.kgri.keio.ac.jp/en/docs/GWP_30.pdf

Kramer, M. (2020, August 4). *The U.S. is at risk of attacks in space*. Axios. https://www.axios.com/space-attacks-us-vulnerable-russia-satellites-3f169464-0abe-4ceb-aab9-7b5f2db29a0a.html

LaGrone, S. (2014, June 17). Code for Unplanned Encounters at Sea. *USNI News*. https://news.usni.org/2014/06/17/document-conduct-unplanned-encounters-sea

Liou, J.C. (2017, February 10). USA Space Debris Environment, Operations, and Research Updates. *54th Session of the Scientific and Technical Subcommittee*. https://ntrs.nasa.gov/api/citations/20170000496/downloads/20170000496.pdf

Montgomery, E. B. (2006). Breaking Out of the Security Dilemma: Realism, Reassurance, and the Problem of Uncertainty. *International Security*, *31*(2), 151–185. https://doi.org/10.1162/isec.2006.31.2.151

National Aeronautics and Space Administration. (2021, September 22). *National Space Science Data Coordinated Archive*. https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1966-020A

National Aeronautics and Space Administration. (n.d.). *Servicing Missions*. HubbleSite. Retrieved May 10, 2024, from https://hubblesite.org/home/mission-and-telescope/servicing-missions

National Aeronautics and Space Administration. (n.d.). *Artemis Accords*. Retrieved April 1, 2024, from https://www.nasa.gov/artemis-accords/

Naval Historical Foundation. (2016, June 30). *Shouldering Incident Reminiscent of Sea of Japan Bumpings | Naval Historical Foundation*. https://www.navyhistory.org/2016/06/shouldering-incident-reminiscent-of-sea-of-japan-bumpings/

Oppenheim, J. (2013). *Danger at 700,000 Feet: Why the United States Needs to Develop a Kinetic Anti-Satellite Technology Test-Ban Treaty*. Brooklyn Journal of International Law, *38*(2), 761–795. Academic Search Premier. http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=86440510&site=ehost-live

Reesman, R. & Rogers A. (2018). *Getting In Your Space: Learning from Past Rendezvous and Proximity Operations* (p. 18). The Aerospace Institute. https://aerospace.org/sites/default/files/2018-05/GettingInYourSpace.pdf

Schaffer, A. (2017). The Role of Space Norms in Protection and Defense. *Joint Forces Quarterly*, *87*(4th QTR), 5.

Silverstein, B., & Panda, A. (2021, March 9). *Space Is a Great Commons. It's Time to Treat It as Such*. Carnegie Endowment for International Peace. https://carnegieendowment.org/2021/03/09/space-is-great-commons.-it-s-time-to-treat-it-as-such-pub-84018

Surrey Satellite Technology LTD. (2013). *Service Oriented Approach to The Procurement/Development Of An Active Debris Removal Mission* (SESH 0221674; p. 80). https://nebula.esa.int/sites/default/files/neb_study/1175/C4000108122ExS.pdf

Union of Concerned Scientists. (2023, May 1). *UCS Satellite Database*. https://www.ucsusa.org/resources/satellite-database

United States Space Command Public Affairs. (2020, July 23). *Russia conducts space-based anti-satellite weapons test*. United States Space Command. https://www.spacecom.mil/Newsroom/News/Article-Display/Article/2285098/russia-conducts-space-based-anti-satellite-weapons-test/http%3A%2F%2Fwww.spacecom.mil%2FNewsroom%2FNews%2FArticle-Display%2FArticle%2F2285098%2Frussia-conducts-space-based-anti-satellite-weapons-test%2F

Weeden, B. (2010). *Overview of the Legal and Policy Challenges with Orbital Debris Removal*. 61st International Astronautical Congress, Prague. https://swfound.org/media/23301/iac-10.a6.4.4-presentation.pdf

Weeden, B. (2015, October 5). *Dancing in the dark redux: Recent Russian rendezvous and proximity operations in space*. The Space Review. https://www.thespacereview.com/article/2839/1

Weeden, B., Samson, V. (Ed.). (2022). *Global Counterspace Capabilities*. Secure World Foundation. https://swfound.org/media/207350/swf_global_counterspace_capabilities_2022_rev2.pdf

Winkler, D. F. (2005). The Evolution and Significance of the 1972 Incidents at Sea Agreement. *Journal of Strategic Studies*, *28*(2), 361–377. https://doi.org/10.1080/01402390500088395

United Nations. (1957, August 29). *U.N. Doc DC/SC.1/66, Fifth Report of the Subcommittee of the Disarmament Commission* (DC/113), Annex 5.

United Nations. (1958). *A/RES/1348(XIII) Question of the peaceful use of outer space, 13th Session (1958-1959), UN General Assembly* (UNA(01)/R3). https://digitallibrary.un.org/record/206866

United Nations. (1963). *A/RES/1962(XVIII) Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space* (UNA(01)/R3). https://digitallibrary.un.org/record/203965

United Nations Office of Outer Space Affairs. (1967, October 10). *Outer Space Trea-*

ty. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html

The United Nations 26th Session. (1971). *Convention on International Liability for Damage Caused by Space Objects.* https://digitallibrary.un.org/record/192067

United Nations. (1974). *RES 3235 (XXIX), Convention on Registration of Objects Launched into Outer Space.* https://www.unoosa.org/oosa/oosadoc/data/resolutions/1974/general_assembly_29th_session/res_3235_xxix.html

United Nations. (2011). *Towards Long-term Sustainability of Space Activities: Overcoming the Challenges of Space Debris* (A/AC.105/C.1/2011/CRP.14). https://www.unoosa.org/pdf/limited/AC105_C1_2011_CRP14E.pdf

United States Department of State. (1972, May 25). *Incidents at Sea Agreement*. DIPLOMACY IN ACTION. https://2009-2017.state.gov/t/isn/4791.htm

United States Government Accountability Office. (2016, July 27). *Defense Space Acquisitions: Too Early to Determine If Recent Changes Will Resolve Persistent Fragmentation in Management and Oversight*. https://www.gao.gov/products/gao-16-592r

United States Space Force. (n.d.). *Geosynchronous Space Situational Awareness Program*. United States Space Force. Retrieved March 31, 2024, from https://www.spaceforce.mil/About-Us/Fact-Sheets/Article/2197772/geosynchronous-space-situational-awareness-program/

United States Senate. (2021). *Space Situational Awareness, Space Traffic Management, and Orbital Debris: Examining Solutions for Emerging Threats: Hearing before the Committee on Commerce, Science & Transportation Subcommittee on Space and Science*, https://www.commerce.senate.gov/2021/7/space-situational-awareness-space-traffic-management-and-orbital-debris-examining-solutions-for-emerging-threats/819ef822-3e6d-4ab1-9a56-31c6d60969c9

Vlasic, I. A. (1995). Space law and the military applications of space technology. *Perspectives on International Law. A Publication on the Occasion of the Fiftieth Anniversary of the United Nations and a Contribution to the Decade of International Law / Edited by Nandasiri Jasentuliyana; Foreword by Boutros Boutros-Ghali.*

Zenko, M. (2011, November 30). *A Code of Conduct for Outer Space*. Council on Foreign Relations. https://www.cfr.org/report/code-conduct-outer-space