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JETTISONED JUNK, THE UNSEEN U.S. SECURITY RISK DEVELOPING IN SPACE

by

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Disclaimer

Table of Contents

ABSTRACT

The purpose of this research is to propose solutions to the current and future threats space debris poses on U.S. security, military operations, and civilian reliance on space operations. Assessing the utility of space, failure to address the increasing amount of space trash, and reliance on the space domain, this research can address the current threat posed by unmitigated space debris formation and implications to the security of the United States by answering the question "What inadequacies exist in the approach of United States and space-faring nations to address the impact of space debris?"

The study finds that space debris accumulation is increasing despite U.S. policy, military doctrine, and international agreements developed to address this issue. In response to qualitative and quantitative analysis, it has been determined that the international community of space-faring nations is aware of the increasing amount of space debris. However, the increasing reliance on space does not allow for the reduction of space utilization that contributes to trash accumulation in Earth orbits.

By determining and assessing historical treaties, international agreements, commonalities of bilateral space use agreements, and the reliance on space for civilian and military use, recommendations have been developed for addressing further space debris accumulation. Among the key recommendations of the study are:

- The development of an international policy that incorporates the collective ideas of bilateral space agreements.
- A demonstration of monetary commitment to a centralized space debris reduction fund based on the State's historical and current use of space.

- Leveraging trusted international cooperation of space data sharing to increase awareness of space debris.

List of Figures

INTRODUCTION

Seventy-five years after the first successful launch of a U.S. satellite, the government is awaiting the approval of the ORBITS Act[1] introduced to address debris dumped in space that is flying at approximately 18,000 miles per hour in Low Earth orbit (LEO).[2] Human-generated space objects, such as pieces of spacecraft, tiny flecks of paint from a spacecraft, parts of rockets, satellites that are no longer functioning, or explosions of space objects known as "orbital debris," "space debris," "space garbage" or "space junk" threatens military operations and an estimated $120.3 billion of current U.S. dollar GDP produced from the use of space.[3] This research answers the question "What inadequacies exist in the approach of United States and space-faring nations to address the impact of space debris?" The lack of collective government and military action to remediate space debris not only endangers the space systems currently in place but leaves little room for the preservation of space utilization in the future. The purpose of this research is to develop strategies for U.S. and international cooperation that address the current collection of space debris in Earth's orbits.

Space capabilities influence civilian life every day. Satellites monitor weather patterns, provide television entertainment, and direct navigation via Global Positioning System. Operationally, the military requires space capability for targeting, communication, Position, Navigation and Timing (PNT), and Intelligence Surveillance and Reconnaissance (ISR). The Commander of USSPACECOM quotes, "Never a Day without Space"[4] due to the critical role of space for civilian use and military operations. The increased *use* of the space domain has essentially increased the *abuse* of the space domain. The Department of Defense is currently required to identify, catalog, and track space objects. As of January 2022, more than 25,000 objects of at least 10 centimeters in size were tracked and cataloged in Earth's orbit.[5]

Space trash may not concern the average citizen due to the indistinctness of its existence and the lack of personal responsibility for the development of this space trash. Space debris is not falling dramatically from the sky, citizens are not throwing garbage directly into the atmosphere, and space environmentalists are not protesting the launch of satellites by binding themselves to launch vehicles. The advocacy for space pollution is conveyed through printed and electronic media, but little direct impact of space debris has befallen the average citizen; however, preserving the navigation of space vehicles on orbit remains critical.

This research demonstrates the criticality of the space domain and determines how future space use is impacted if the international community does not address the space trash issue. The problem in space can be analogous to the environmental threats present on Earth's surface, with enhanced and cascading effects that ultimately affect the information security of the United States. The space domain is filled with discarded, man-made objects that are not easily removed or disposed of. This garbage threatens the freedom of maneuver and ability to utilize essential, technological civilian and military capability.

This research is focused on the discovery of the space domain, historical and current agreements about the use of space, the necessity of space for military and civilian use globally, and how all these factors have contributed to the current on orbit space trash environment. Furthermore, this research demonstrates commonalities in current space agreements, current efforts and development of space debris clean-up, the deficiency of acting upon the space debris issue, and recommendations for the U.S., military, and international space-faring community to address the current space debris accumulation.

BACKGROUND

"This is an inspiring moment in the history of the human race. We are taking the first firm step toward keeping outer space free forever from the implements of war. It means that astronaut and cosmonaut will meet someday on the surface of the moon as brothers and not as warriors for competing nationalities or ideologies."

LYNDON B. JOHNSON
Remarks at the Signing of the
Treaty on Outer Space
January 27, 1967[6]

Development and Governance of Space Utilization

The increased use, pollution, and reliance of space capability have rapidly developed since 1960. However, like many technological and scientific developments, the use of space was advanced in response to international scientific competition and the growing tensions of war. The scientific space rivalry began in 1952 when scientists named the International Geophysical Year (IGY) due to the increased solar activity cycles.[7] The Soviet Union successfully responded to the solar activity with the first orbital satellite, Sputnik. The United States and the Soviet Union scientific rivalry in space continued with spaceflight superiority. The Cold War of the 1960s enhanced the scientific space contest and added the threat of nuclear war through the utilization of space capability. The Cold War between the Soviet Union and the United States heightened competition in space for the ability to observe the development of weapons, the ability to detect a deployed weapon, improve the capability to track the path and detonation zone of a weapon, and ultimately destroy the weapon before mass destruction could take place.

The rapid development of space capability required the international community's attention to focus and address space competition, legal challenges, and increased ambitions in space exploration. To contend with enhanced space use, the international community developed several treaties that are currently being exercised. The 1967 Treaty on Principles Governing the

Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies[8] provides provisions to the signatories for a peaceful and cooperative agreement for the utilization of space. The seventeen articles of the 1967 treaty address legal use, scientific exploration, militarization, international cooperation, and State Parties' responsibility in space exploration. Treaties governing the use of space include the Space Rescue and Return Agreement of 1968, requiring rendering assistance to astronauts; the Liability Convention of 1972, which renders the launching State liable for compensation for damage caused by its object on earth or on orbit; the Registration Convention of 1976, where State Parties agreed to register objects launched into space with the United Nations; and the Moon Agreement of 1979 which is not regarded as significant space treaty because it has only 18 signatories, none of them space-faring states except for France.[9] The foundational principles in the 1967 Space Agreement provide important governance for the space debris issue that exists today. The original law of space provides Articles for the governance of space but does not clearly define "space." Defining space, specifically where space begins, was still an issue 43 years after development of the space law. The United Nations Committee on the Peaceful Uses of Outer Space Legal Subcommittee Forty-ninth session 22 March-1 April 2010 posed the question:

> (a) Does your Government consider it necessary to define outer space and/or to delimit airspace and outer space, given the current level of space and aviation activities and technological development in space and aviation technologies? Please provide a justification for the answer; or
>
> (b) Does your Government consider another approach to solving this issue? Please provide a justification for the answer (A/AC.105/871, annex II, para. 7 (f)).[10]

Answers to the United Nations Committee on the Peaceful Uses of Outer Space Legal Subcommittee questions ranged from an immediate need to define space to those nations that saw no need for immediate action. Nations also added that the problem needs to be codified to avoid disparity in decisions on such disputes by national and international courts.[11] Defining where space legally "begins" is still an unsolved issue today.

Article One of the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon, and Other Celestial Bodies (referred to as the1967 Treaty) states, "The exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries."[12] Article One assures the use of space, while Article Seven and the Liability Convention of 1972 address the requirement of signatories and international responsibility for State space activity and the activity of the commercial entities of that State. Article Eight of the 1967 Treaty provides State ownership of space objects by stating "whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object," and Article Seven defines the international liability for damage caused by those space objects.[13] Article Eight demonstrates that space debris should be the responsibility of the State owning the jettisoned rocket, defunct satellite, or the destroyed vessel and Article Seven could be invoked for liability of damage caused by space debris owned by another space-faring nation.

Article Six of the 1967 Treaty provides all commercial and space activity is national activity, and the State is ultimately responsible for space use. In response to Article Six, space-faring countries have developed organizations to internally monitor space activity. The United States utilizes several organizations to cooperatively enforce and develop space policy. Organizations monitoring and enforcing space policy include the Federal Aviation Administration (FAA)

Office of Commercial Space Transportation and the Federal Communications Commission. Similar organizations exist within other nations such as: China National Space Administration, European Space Agency, Indian Space Research Organization, and Russia's State Space Organization, ROSCOSMUS. These organizations are internal to each State and have diverse laws for regulating space use and space debris.

Article Six positions the State as the responsible party for all state activity in space to include the commercial activity of that state. For example, the United States is responsible for all military, commercial, and civil space activity that is commissioned by the United States, even if the spacecraft is launched in another country. Article Six denotes ultimate State responsibly but does not define irresponsible space activity or how to enforce what may be deemed as irresponsible activity within space, to include the State development of space debris. The development of various State space organizations implies that states also have internal laws and policy governing space use that are enforced by the State organizations. The United States, like many other states, has implemented internal regulations and requirements that are specific to addressing space debris.

The National Orbital Debris Implementation Plan directs organizations within the United States government to cooperatively address the unpredictable space debris traveling at tremendous speed threatening space-based capability.[14] *The National Orbital Debris Implementation Plan* addresses international cooperation in regards to the Outer Space Treaty, web-based information sharing, orbital debris remediation, and provides strategic direction to the Department of Commerce, Department of Defense, Federal Aviation Administration, Federal Communication Commission, and NASA to engage the international space community.[15] To support this larger government effort, the Department of Defense has implemented Department of Defense Directive 3100.01, and the Secretary of Defense has published responsible space behaviors.

The Department of Defense Space Policy Directive emphasizes responsible, professional use of space and limiting the creation of long-lived space debris. Emphasis is placed on cooperation with the international space community for information sharing, defense relationships, policy deliberations, and space-related agreements including arms control.[16] The Department of Defense has an extremely important role in space domain awareness by providing information on the tracked data related to 25,000-30,000 pieces of space debris. The debris data collection and sharing of the Department of Defense provides the ability to identify threats of collision, ensure safe launch timing, and identify tracked anomalies in space. Space awareness is shared across the globe and is used internally by United States agencies to enforce space debris regulations.

As part of enforcement of article six of *The National Orbital Debris Implementation Plan*, the United States Federal Communications Commission recently levied its first fine for failing to remove a satellite from orbit and causing concern for the irresponsible development of commercial space debris. Dish Network admitted liability for leaving a satellite in an unplanned orbit at mission end due to a lack of sufficient propellant to move the satellite to the planned orbit. The FCC determined that Dish Network would pay a $150,000 fine and implement safety measures to mitigate future issues with satellite de-orbit missions.[17] This is the first indication of punitive action for the U.S. enforcement of the 1967 Treaty by holding commercial space use accountable by a government organization. Space accountability is an individual State’s responsibility, but agreements between nations provides oversight with the added emphasis of maintaining diplomatic relations.

Space-faring nations have bilateral agreements that address issues from the treaties developed in and before 1972, and focus on data sharing, cooperation, surveillance, human space flight, space debris, and lunar exploration. These agreements do not have the number of signatories as the 1967 Treaty; however, the agreements demonstrate the requirement for international partnerships and the cooperation required by space-faring nations. The United States currently has agreements with several countries such as Japan, the United Kingdom, Canada, Australia, and Brazil. Most of United States space agreements are coordinated bilaterally by NASA but other government organizations work to develop a shared understanding of space capability cooperation and specific space armament agreements.

Space-faring nations understand the importance of the freedom of navigation and utilization of space and have developed agreements, committees, and principles that function to ensure safe space operations. The European Union Space Surveillance and Tracking Framework Agreement 2014, is an operational capability focused on the free data sharing from a network of space sensors.[18] A shared platform is used by contributing members to track over 210 satellites with lasers, radars, and telescopes. This data platform demonstrates the coordination and cooperation necessary for space domain situational awareness and the ability to safe-guard space infrastructure within the limited membership of the agreement. Participating European Union member states include France, Germany, Italy, Spain, Poland, Portugal, and Romania.[19]

Principles such as the articles in the Artemis Accords are agreed upon by the 36 nations that have signed the framework as of February 15, 2024. "Orbital Debris" is a principal in the Artemis Accords that addresses the mitigation of space debris and addresses the timely disposal of spacecraft at end-of-life missions. Article 12, Orbital Debris, places emphasis on identifying the Signatory responsible for planning and implementing disposal in cooperative lunar exploration missions.[20] The principles and guidelines in the Artemis Accords may read like the articles in the Space Treaty of 1967, but the Signatories are all voluntary and there is no legal binding to the Artemis Accords.

The United Nations Committee on the Peaceful Uses of Outer Space developed in 1959 continues to govern the exploration and use of space, and address the legal concerns associated with space exploration. The "Space2030" was developed by the United Nations Committee on the Peaceful Uses of Outer Space and was adopted in 2021. This document focuses on space State capacity building and cooperation, with access to space capabilities to improve quality of life.[21]

The United States is a member of the Interagency Space Debris Coordination Committee (IADC) which has thirteen international members.[22] IADC provides recommendations for space debris mitigation guidelines and emphasis is placed on the mitigation of space debris. The design and launch vehicles used by the space-faring nations minimize the generation of debris during and after missions, based on collaborative efforts and inputs to the IADC.[23] International cooperation in IADC focuses on the mitigation of space debris and the preservation of the space environment.

The Necessity of Space of Today's Space Environment

Civilian Dependency

The secure, reliable, redundant, and global capability of satellite networks provides the ability to transmit large amounts of data at high speeds to even the most remote locations on Earth. Satellite capability is unconsciously consumed by billions each day. Customers using Google Maps may need to acknowledge the satellite network used to provide accurate and timely directions. Users of automated teller machines may not recognize the satellite network remotely connecting to give access to the financial transaction. Civilian electrical grids are also affected by the space environment and the space implications are relatively unnoticed by citizens. Space capability supports critical services for civilian life that many consumers may be unaware of.

The advancement in technology and the subsequent reduction in launch costs have provided the ability to support GPS-dependent technology, satellite communications, environmental monitoring, and satellite imagery. Space environmental monitoring offers timely and accurate warnings of developing life-threatening weather. Satellite sensors capture the development of hurricanes and report the real-time impact of terrestrial firestorms. Satellites collect epoch information on long-term ice mapping and provide data about population growth by monitoring city lights. Economic dependency on space capability begins with precise atomic time stamps on global financial transactions. A doomsday situation for space capability impacting civilian life would be the loss of GPS, imaging, and environmental satellite sensors that are damaged simultaneously. The debris in space today is not predicted to impact civilian life in such a significant manner such as a doomsday scenario in which all communications are lost and global chaos ensues, however, a more noticeable impact on civilian reliance on space capability would more likely be attributed to latency in replacing aging environmental monitoring satellites and the loss of future data collection.

Military Dependency

Increased reliance on space technology integrates space and counter-space activity in today's warfighting strategies. The military has developed and depends on space-based capability since the initial developments emerged from the Cold War. Transit, the first global satellite system, was developed in the 1960s. Transit provided navigation data to military and commercial vessels. The United States Naval ballistic missile submarine forces received the initial all-weather navigation information from the project. Transit was handed over to the United States Department of Defense in 1996 and was replaced by today's Global Positioning System (GPS).[24] Continuous technological advances have impacted the military's use of GPS resulting in the United States Government Accountability Office (GAO) developing a study on alternative Positioning Navigation and Timing (PNT) options. The GAO study states, "Given the ubiquity of GPS, the failure, malfunction, or jamming of its signals or equipment could disrupt military activities involving aircraft, ships, munitions, land vehicles, and ground troops. This possibility has led DOD to explore alternatives to GPS."[25] Countless civilian and military systems rely on GPS capability but the military reliance on space capability extends much further than GPS.

Military satellite imaging was developed in the Cold War to identify missile launch sites and USSR production facilities. "Adm. William O. Studeman, acting director of the Central Intelligence Agency, observed in 1995, "CORONA was conceived in … an era when facts were scarce and fears were rampant." "Corona debunked the "missile gap" argument. [And,] it allowed us to base our national security strategy - and spending -- on facts rather than fear, on information rather than imagination."[26] The Cold War provided the catalyst for the CORONA project and the continued development has resulted in the satellite technology used today. Vice president Al Gore noted that satellites, "Recorded much more than the landscape of the Cold War. In the process of acquiring this priceless data, we recorded for future generations the environmental history of the Earth at least a decade before any country on this Earth launched any Earth resource satellites."[27] Many aspects of commercial, civil, and military space capabilities overlap and several programs are interdependent.

Military dependency on space capability has an effect that is known immediately. Disrupting Command and Control (C2) with interruption of data flow and signals has an elevated effect compared to the disruption of Dish Network's television broadcasts. Within national security, lack of military satellite communications obviously outweighs commercial satellite television outages, however, the military reliance on satellite capability may not become apparent to the civilian population until a war requirement emerges and news of loss of satellite support is broadcast globally.

The Russian invasion of Ukraine in February of 2022 immediately highlighted a technological and digital reliance on space. The initial military incursion began with an attack on the ground-based infrastructure of ViaSat's KA-SAT satellite network causing outages to civilian, military, and government users.[28] The cyber-attack on terrestrial satellite capability was pre-emptive to the initial Russian invasion. The nature of reversable attacks such as the ViaSat KA-SAT provides a desired outcome without severe damage or destruction to infrastructure. However, after further review, it was discovered that the secondary and tertiary effects of the attack were far-reaching to include denial of off tens of thousands of Europeans' access to internet and the shut off 5,800 German wind turbines for several months. By weaponizing space, the Russian incursion into Ukraine has demonstrated the intended and unintended consequences of focused space attacks and the far-reaching impacts.

To aid Ukraine in the aftermath of the Russian invasion, the United States provided security assistance that included numerous space-dependent capabilities.[29] The weapons may use precision guided, space enabled capabilities that are pursued by Russian activities to disrupt the effective employment. As demonstrated by a test performed by Professor David Last, some of these capabilities given to Ukraine could be rendered ineffective if space capability was disrupted or denied.[30] In 2010, Professor Last ran a GPS jamming test on the THV Galatea in the North Sea. Professor Last used a low powered GPS noise jammer in the experiment. The noise jammer disrupted the signal to the Galatea's GPS and integrated communications system. The noise jammer was not designed to entirely deny a GPS signal to the vessel, it was simply used to disrupt the signal. In response to the noise jamming, the Galatea reported its position location was land-based and that it was traveling at 846 knots (Mach 1.3) during the test.[31] The space capabilities provided to Ukraine from the United States are much more difficult to disrupt than the 2010 GPS noise jamming test that Professor Last performed on the Galatea, but the outcomes are still very real in a wartime situation. The hardened space capability of 2024 is not susceptible to the same disruption of Professor Last's test, but the dependency and vulnerability of United States space assets in war endures today. The Ukraine terrain remains a battlefield for innovation and technological advantage in both the cyber and space domain with the added enhancement of artificial intelligence.

The space security threat to the United States increases with technological advancements, adversarial capability, and motivation to develop and use reversible effects from space capability. The experiment by Professor Last had unexpected outcomes for the consumer of space enabled GPS and the misunderstood effects of jamming space signals. The Russia and Ukraine war has increased the technological advancements and low-cost threat of implementing space capability in war. These illustrations demonstrate the past illusion of space security and the present development of space dependency. Both examples provide historical and present-day threat examples to the security of space assets, and the need to address the growing reliance on the freedom to use and maneuver in space.

Space Debris

Current Debris by the Numbers

Irresponsible space behavior has been the largest contributor to the current accumulation of space debris. Three major events have occurred in the past two decades and account for almost one-half of the catalogued space debris fragments. The United States and the Soviet Union had been testing anti-satellite capability since the successful launch of Sputnik in 1957, but the first notable event causing a mass deposit of space debris was performed by China in 2007. China destroyed one of its own defunct weather satellites with anti-satellite capability to demonstrate the ability to rapidly remove space capability, presumably sending a message to adversarial States.[32] In November of 2021, Russia catastrophically destroyed its Cosmos 1408 with a direct-ascent anti-satellite launch. This destruction event created more than 1500 pieces of trackable debris. Over 1604 pieces of debris have been added to the U.S. Satellite Catalog from this single event.[33] The demonstrations of space capability of China and Russia reveal a relative level of disregard for the resulting formation of space debris and future impacts to space exploration.

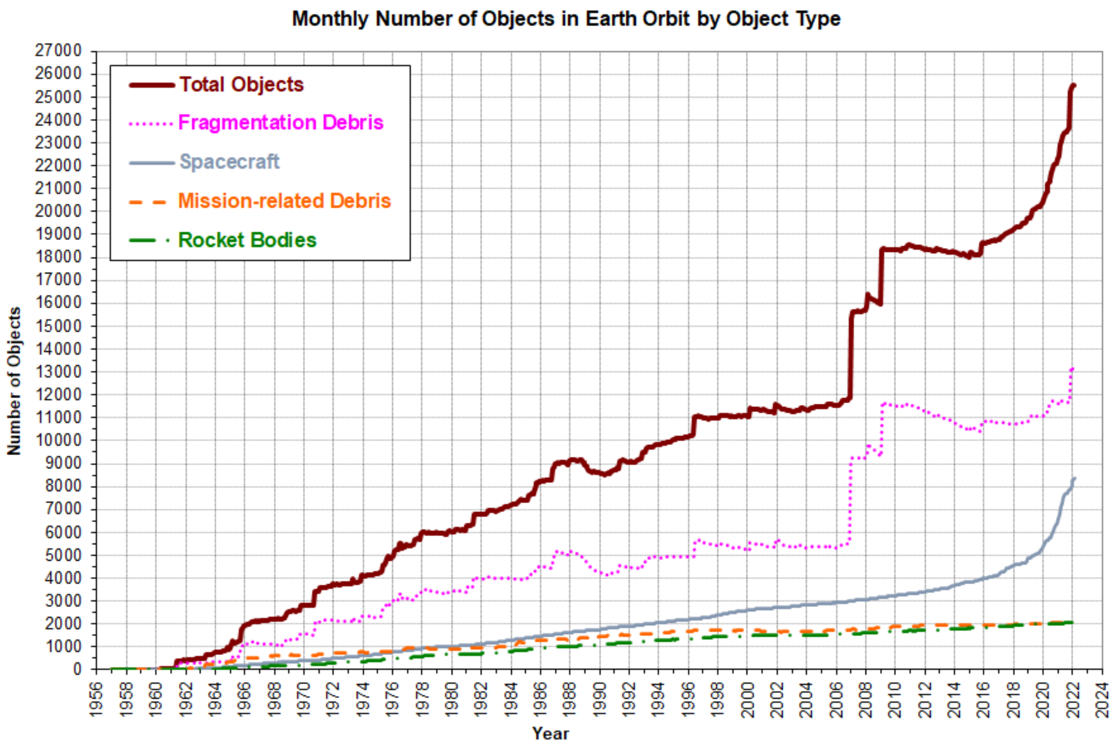

Figure 1. Chart showing number of objects >10 cm in LEO. (Reprinted from NASA Orbital Debris Program Office)

In 2009, a United States communication satellite accidentally collided with a nonoperational Russian satellite. The spike in space debris was not as substantial as the deliberate 2007 China anti-satellite demonstration, as demonstrated in Figure 1, but the accidental nature of the event exhibits the unavoidable environmental conjunctions of the future. Inadvertent conjunctions will continue to escalate the growing amount of trash in space and continually increase the number of debris that endanger the vehicles of space-faring nations. However, the number of mission-related debris and rocket bodies slowly increases in conjunction with space exploration evolution and does not have similar sharp jumps in numbers.

Figure 1 demonstrates the sharp increase in fragmentation and total space objects in the years 2007, 2009, and 2021 from intentional and unintentional events creating large amounts of space debris. This debris was the result of the 2007 and 2021 anti-satellite demonstrations and the 2009 collision of a dead satellite.

As space dependency increases from technology requirements, military necessities, and lower cost investment, more space vehicles will be utilized. The number of space vehicle launches has steadily increased as the number of space-faring nations have developed capability. Figure 2 depicts the increase in orbital launches and the increased number of nations participating in space exploration. The 2022 Challenges to Security in Space report observed, "The combined operational space fleets of China and Russia have grown by approximately 70 percent between 2019 and 2021…. recent and continuing expansion follows a period of growth (2015– 2018) where China and Russia had increased their combined satellite fleets by more than 200 percent."[34] The drive to modernize and increase capabilities for both countries is reflected in nearly all major space categories—satellite communications (SATCOM), remote sensing, navigation-related, and science and technology demonstration.

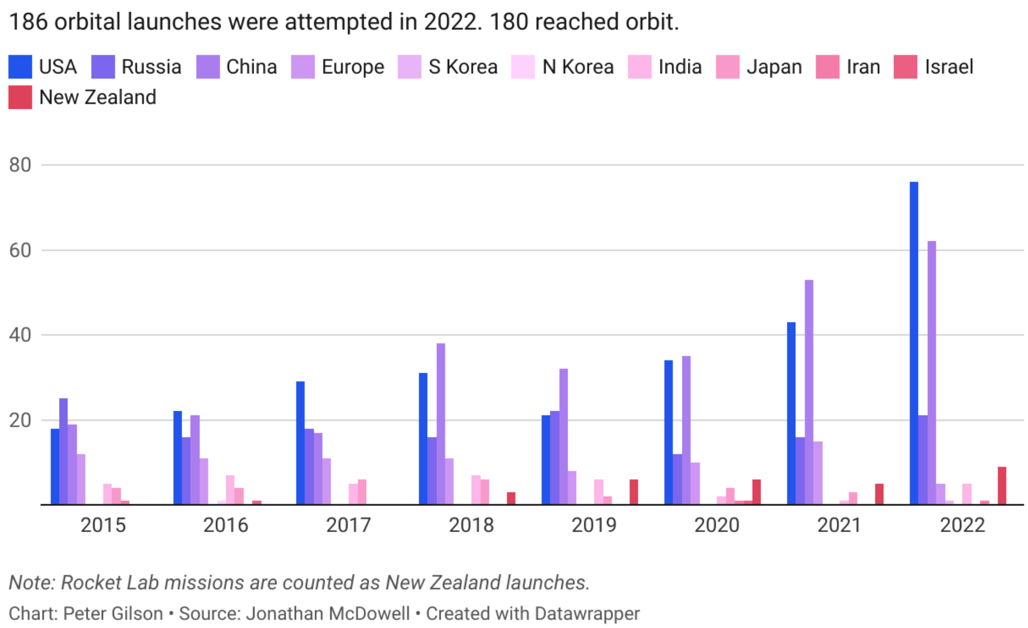

Figure 2. Orbital Launches by Country (Reprinted from report credited to Jonathan McDowell January 10, 2023)

Future Debris by the Numbers

Space debris objects range from debris in the size range of 5 millimeters to 10 centimeters to massive objects that are larger than an automobile. Estimations of the nontrackable debris range from 600,000-900,000 objects and the massive trackable objects are estimated to be greater than 1,300 objects.[35] A typical satellite breakup creates approximately 250 pieces of debris that can be catalogued and potentially impact space vehicles, but the dangers posed by massive object conjunctions are exponentially larger. A collision of two massive objects would create 3,500-15,000 catalogued pieces of debris.[36]

The annual probability of collision is based on its orbital altitude. Orbiting debris can remain clustered and at an altitude of 1,500 kilometers with a collision probability of 1 in 5,000.

The probability of collision increases to 1 in 800 as altitude of object orbit is decreased from 1,500 kilometers to 850 kilometers.

Figure 3. Computer Rendering of Tracked Objects (Reprinted from 2022 DIA Report Challenges to Security in Space)

[Computer rendering of tracked objects greater than 10 centimeters in Earth's orbit. Red, yellow, and green objects are representations of active satellites in the GEO orbital belt and in MEO. [Note: The objects are not drawn to scale; the objects are approximately 10,000 times greater than actual size.]

The life of space debris is not only dependent on its orbit, but also the relative size of the debris. Larger objects orbiting closer to earth will gravitationally move toward earth's atmosphere but smaller objects that have clustered in higher orbit will potentially remain in orbit for thousands of years. NASA guidelines for the United States space program state that "spacecraft in LEO must deorbit, or be placed in graveyard orbit within a maximum of 25 years after the completion of their mission."[37] The standardization of spacecraft lifetime provides another mechanism to limit collisions and conjunctions of defunct spacecraft. The future number of tracked space debris can be affected by policies that provide specific guidelines and requirements for design, manufacture, and disposal of satellites.

Risk of Unfettered Space Utilization

A dominant source of new man-made debris results from collisions involving spacecraft and non-maneuverable upper stages of rockets. These jettisoned components lack propulsion and cannot alter their trajectories once the satellites are delivered into orbit.[38] Non-maneuverable objects cause a cascading effect once released into orbit. These uncontrolled objects cause spacecraft to maneuver off their current path to avoid catastrophic collision or conjunction. This propulsion maneuver uses excessive fuel and alters the original calculations for spacecraft life and end-of-life maneuvers. Spacecraft development and launch calculations must account for unknown maneuvers and collision avoidance in orbit. Payloads and fuel supply must increase and calculations for end-of-life and de-orbit procedures must adjust to these unpredictable events. The factor of unpredictability and the estimation of collision avoidance maneuvers is adjusted based on the current space environment and the known space launches. These factors increase the creation of more upper stage non-maneuverable objects. The instances such as the miscalculation of de-orbiting an end-of-life satellite by Dish Network in 2023 will become more frequent, and the miscalculations of lifespan and orbital transfer leads to increased large spacecraft debris abandonment.

The probability of collisions is growing with the increased number of space launches. Currently, the average interval between the catastrophic collisions of objects in the United States Satellite Catalogue that are located in low Earth orbit is approximately five to nine years.[39] The frequency of conjunctions increases as the number of objects presenting in LEO is not addressed and action is not taken to counteract this increasing trend.

Spacecraft breakup will also continue to contribute to the space debris issue. Aging spacecraft is not designed with the same technological advancements and requirements of today's spacecraft; batteries explode, calculations for spacecraft lifetime may be shortened, and space effects may have impacted vessels to a greater extent than originally planned. For example, a Soviet-era communications satellite recently deposited six fragments, including the vehicle, during an unexpected breakup in 2023.

The terrestrial world is becoming more dependent on space and more satellites are being launched in to orbit to supply the required services. Enhanced space warfare capabilities are used in all domain operations and antisatellite capabilities are being deployed in to space. Additionally, space exploration and cislunar research has increased in the last decade adding to the number of space vehicles that will be launched. The expansion into space will create more vehicles in space, more vehicles in space will create more debris, more debris will increase the requirement for shielding, more shielding will increase the weight of vehicles, more vehicle weight will increase launch propulsion requirements, increased launch requirements will increase non-maneuverable and jettisoned upper stages of rockets; therefore, increasing the space debris development cycle. The increased debris will increase the number of collisions and the number of collisions will increase the amount of space debris. The infinite loop of increased space debris deposits will continue unless it is explicitly interrupted.

Addressing Space Debris

Mitigation

Bi-national agreements contain space debris mitigation language and address the need to share research and development practices that impact the new development of space debris. To address space debris mitigation issues with the United States, the Federal Aviation Administration (FAA) has recently proposed new space debris mitigation practices. These practices will likely be shared with countries that have partnered with the United States to include; Australia, Canada, France, Germany, New Zealand, and the United Kingdom.

On September 30, 2023, the FAA announced a proposal to implement rules to limit increased space debris accumulation. The new regulation proposal provides commercial launch operators several options requiring disposal of their rocket upper stages within 30 days of launch or mission completion, "By performing a controlled reentry after mission completion, moving to a less congested or graveyard orbit, placing them in an Earth escape trajectory, retrieving them with active debris removal within five years after launch, or performing an uncontrolled atmospheric disposal within 25 years.[40]

Disposal

NASA has identified three small spacecraft disposal methods for the United States – direct retrieval, atmospheric re-entry, and maneuvering into a storage orbit. Atmospheric reentry is deemed the most feasible for the majority of spacecraft missions.[41] A large space object naturally enters the Earth's atmosphere approximately once per week with a majority of the object burning upon reentry.[42] The natural method of scorching space debris is preferred and becoming more feasible due to technology advancements in calculating and controlling the satellite lifetime and disposal.

Direct retrieval and maneuvering into a storage orbit both require additional propellant and capability to avoid orbiting vessels. Development of maneuvering is not limited to self-guided movement into a different orbit. Additional movement techniques are being explored such as “pushing” the vessel with a pointed laser. Moving a vehicle into a storage orbit decreases the likelihood of a conjunction but does not contribute to a decrease in space debris.

CONCLUSIONS

Space debris continues to accumulate with every orbital launch. The civilian and military support required from space capability is not globally decreasing. The need for more mitigation and coordination efforts increases among the space-faring nations as the space debris situation continues to evolve. The purpose of this research was to answer the question, “What inadequacies exist in the approach of United States and space-faring nations to address the impact of space debris?” Highlighting the inadequacies in the approach the United States and space-faring nations have developed to contend with the increased space debris has both historical and current oversights. The implications of the inadequacies have resulted in the increased vulnerability the United States freedom of the use of space and ultimately threaten the security of the United States. Conclusions for combating space debris are found though policy and legal implications, partnerships of adversarial space-faring nations, space situational awareness, and an authoritative, collective governing body to police the use of space.

1. Legality of Space Use

The Space Treaty of 1967 continues to accrue new State signatories from the original 18 members. However, the language has yet to evolve to provide legal definitions for space, specifically where space begins. Legal definitions are essential to enforcing space laws and foundational to agreements and principles. The language that clearly defines where space begins is necessary to ensure that states identify the use of the space domain versus the air domain. To enforce the Space Treaty of 1967, states must definitively understand and acknowledge where the space domain begins. The current language for space is defined by scientific suggestions interpreted differently by space-faring nations. Over 120 nations have signed or are ratifying signatures to a treaty that lacks a legally binding definition of space. The need for more agreement is two-fold. An unclear air and space border could lead to increased violations of sovereign airspace as the use of space vehicles is increased, and objects continuously orbiting the earth in the limit of the air domain may not have space laws to enforce the prohibition of nuclear capability that is clearly defined in the Space Treaty of 1967.

The Space Treaty of 1967 enforcement remains challenging because the governing body has yet to define how to enforce violations uniformly. News of Russia violating the Space Treaty of 1967 in 2024 by developing a satellite with nuclear capability was reported, but the repercussions of the action were not published. This violation could create the most significant instance of space debris creation if it were detonated or collided with another space vehicle, yet the action seemingly went unpunished. The violation of the Space Treaty may become more untenable once the satellite is launched into orbit. However, the response from the space-faring nations remains to be seen.

Articles Seven and Eight of the Space Treaty of 1967 are difficult to enforce due to the large amount of space debris currently created, approximately 25,000 – 30,000 pieces. It is challenging to attribute debris to a specific State, mainly if a State is found liable for damage to another State’s space vehicle in orbit or damage caused by debris on terrestrial structures. Thousands of pieces of debris are impossible to assign to the current space-faring nations. The current registration requirements for space launches may provide a clearer understanding of ownership and liability for future claims, but the littered space environment has thousands of unclaimed fragments.

2. Space Use Security Risks to United States

Bilateral agreements between space-faring nations are encouraged for continued space exploration, space situation awareness, and limiting space debris, but these agreements may pose security implications for the United States. Specifically, the China and Russia Lunar Exploration Agreement of 2020. This agreement combines the collective efforts and capability of two of the most significant space-faring nations. This agreement may decrease the number of debris jettisoned into space when China and Russia utilize the launch for dual-purpose exploration. However, the national security risk may increase when adversaries highlighted in the National Security Strategy merge efforts to explore lunar activities.

China and Russia are responsible for the two most significant space debris creation events. Their ownership of the incidents may prevent future irresponsible space behavior, as the two nations hold each other accountable for freedom of space maneuver. The bilateral agreement can provide a space policing function to preserve collective space exploration and mitigate space debris. However, this agreement could limit space data and information sharing in the United States.

The collective funding and research from both nations under the China and Russia Lunar Exploration Agreement of 2020 may enhance scientific space discovery. Lunar exploration has recently provided a discussion of resources that exist on other planets. China and Russia's cooperative agreement may lead to future identification and mining of resources unavailable to the United States. The competition for resources is not decreasing, and combining efforts of advanced space-faring nations could lead to a dearth for the ostracized United States.

3. Space Situational Awareness

Several nations have bi-lateral agreements and have developed coordinating organizations to share space situational information. Space domain awareness and space debris tracking information can decrease the number of collisions and ensure space vehicles are safe to launch. The space awareness and information sharing will allow conjunctions to decrease and the ability to maneuver safely from the path of currently tracked debris. Agreements to address space situational awareness have included the European Union Space Surveillance and Tracking Framework agreement and the Artemis Accords. These agreements have several signatories but do not have a singular, globally shared network of space domain awareness. The United States Department of Defense uses the Space Force to track and identify space debris and share information with the larger space-faring community; however, there are several state networks that share information outside of the United States agreements.

Information sharing between specific states may create issue for the United States should our nation not be incorporated. The lack of information or coordination could result in constrained resources that require the United States to continually invest in technology that could be leveraged from other nations. Additionally, space domain awareness requires the correct classification of information. The United States's government may be able to avoid current classification constraints by using releasable, external space domain information from partner states. Ensuring the United States is included and leading efforts to share space domain information is essential to continued safe and free space exploration.

4. Space Policing

To further address the question “What inadequacies exist in the approach of United States and space-faring nations to address the impact of space debris?”, it is essential to highlight the lack of centralized governing and enforcement body for all space activities. Many agreements have soft language that include recommendations with no stated outcomes or terms for violations. Ensuring space use remains responsible and free is difficult with this type of suggestive language.[43]

RECOMMENDATIONS

Article One of the Space Treaty of 1967 states, "Outer space is free for exploration and use by all states without discrimination and is not subject to national appropriation by any means."[44] For space to remain free for exploration, all space-faring nations must be dedicated to ensuring the space environment is not encumbered with debris that can disrupt space missions and operations. To achieve the ability for space to remain a vital and open asset to civilian and military life, all space-faring nations should agree to enhance or implement space policy, investment, and data-sharing recommendations.

1. Policy

Unified space-faring states must ensure violations of the Space Treaty of 1967 have clear consequences with cataloged ownership of debris, reported ownership of orbital spacecraft, and cost analysis of secondary and tertiary damage impacts. There has yet to be a large-scale uniform enforcement policy of Article Seven or Article Eight of the Space Treaty of 1967. The groundbreaking enforcement policy may have global economic and diplomatic impacts that would provide far-reaching consequences for violations of space utilization.

The policy must legally define where space begins. The adoption of the Kármán line, 100 kilometers above the Earth's surface, is a standard scientific definition of the beginning of space, but space-faring nations have not agreed on the legal "start" of space.[45] The legal definition of the beginning of space should be agreed upon and added to the current Space Policy. This would allow policy, infractions, and consequences for a more open space domain, free from encumbering space trash.

A ratified policy requires significance equivalent to the infraction. Penalties that appraise the short and long-term effects as feeble fines or sanctions could be determined too inconsequential, and infractions would continue with little regard for freedom to maneuver in space. The Space Policy of 1967 requires addendums or additional articles that clearly define infractions concerning the creation of space debris and ensure the State is held responsible for the man-made objects.

Enforcement of the Space Treaty should leverage the United Nations preamble stating, "…establish conditions under which justice and respect for the obligations arising from treaties and other sources of international law."[46] The Space Treaty of 1967, with additional input concerning the definition of where space begins and stated space debris infractions, would then have a more complete and modernized method to address space debris.

2. Investment

Space debris clean-up requires innovation and technological solutions that increase the cost of space exploration. A centralized space debris fund that considers state historical space use, current state space capability, and State efforts to mitigate space debris should be factored in when leveraging a space use "fee." The United Nations should manage the newly developed centralized fund, which could be introduced as a legally binding principle.

Investing in a space debris fund may encourage more responsible space behavior, including research and development measures to create less space debris. The initial investment of state input would combine the collective knowledge and innovation from all space-faring nations to include funding to support space debris research and development techniques. The space use “fee” would be leveraged on space-faring nations before vehicle launch. An initial requirement would be adjusted based on the historical and current use of space. The states that currently rely on space capability would initially fund this investment.

3. Data Sharing

Space situational awareness is vital for understanding and navigating the space environment. Space agreements provide the ability to share space data between countries, and the United States is addressing classification limitations concerning space data sharing. The Assistance Secretary of Defense for Space Policy has undertaken the first stage of data sharing. Dr. John Plumb advocates for space control, cooperation, and classification priorities.[47] The program does not target all space data and the ability to share at an unclassified level but instead addresses space programs at the Special Access Program (SAP) level. SAPs are reviewed to ensure classification can be downgraded to a sharable Top Secret level, thus increasing the ability to provide increased space domain awareness.[48] Developing and progressing programs such as the Combined Space Operations Initiative, with its current ten national members, can provide greater space domain information sharing.

Space-faring nations that pay launch fees and participate in a centralized space debris investment fund could be entitled to a more advanced space domain awareness picture developed from the fund. In support of the larger goal of retaining and maintaining unrestricted access to space, states would ensure a global collaboration of space domain awareness. Not only will a fund encourage the minimalization of space debris, but membership may also require shared space domain capability. Space-faring states would have an incentive to access a globally built space domain capability that could decrease the cost of developing and maintaining bilateral space data-sharing agreements or remove the requirement to develop individual State space domain awareness pictures. A complete data picture will ensure that states can access information that can lead to the avoidance of collisions and data that provides a safer space for vehicle launches. Collision avoidance will undoubtedly impact the creation of more space debris, and collisions cannot be avoided if space objects cannot be seen promptly.

Ultimately, space-faring nations must acknowledge the rising issue of man-made space debris and the risks it poses to the use of space capability. Recommendations for addressing space debris cannot be solved by a singular State with a singular method. The collective efforts of responsible space behavior today will result in the use of space as infinite as the domain itself.

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