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Investigation of national policy shifts to impact orbital debris environments

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ABSTRACT

Low earth orbit has become increasingly congested as the satellite population has grown over the past few decades, making orbital debris a major concern for the operational stability of space assets. This congestion was highlighted by the collision of the Iridium 33 and Cosmos 2251 satellites in 2009. This paper addresses the current state of orbital debris regulation in the United States and asks what might be done through policy change to mitigate risks in the orbital debris environment. A brief discussion of the nature of orbital debris addresses the major contributing factors including size classes, locations of population concentrations, projected satellite populations, and current challenges presented in using post-mission active debris removal to mitigate orbital debris. An overview of the current orbital debris regulatory structure of the United States reveals the fragmented nature of having six regulating bodies providing varying levels of oversight to their markets. A closer look into the regulatory policy of these agencies shows that, while they all take direction from The U.S. Government Orbital Debris Mitigation Standard Practices, this policy is a guideline with no real penalty for non-compliance. Various policy solutions to the orbital debris problem are presented, ranging from a business as usual approach to a consolidated regulation system which would encourage spacecraft operator compliance. The positive aspects of these options are presented as themes that would comprise an effective policy shift towards successful LEO conservation. Potential economic and physical limitations to this policy approach are also addressed.

1. LEO: a natural resource worth conserving

Low Earth Orbit (LEO), the region of space between 200 km and 2000 km altitude, is a global natural resource that must be conserved. Over the past 55 years, humanity has become increasingly dependent on LEO as a home for satellites that perform a myriad of functions affecting the daily lives of people across the globe. LEO satellites provide weather information and support natural resource monitoring. Communications satellites facilitate a global communications network. Scientists use specialized satellites to learn about the ever-changing climate of the Earth, the nature of gravity and relativity, and about our planet's place in space and time. National security interests operate spacecraft to gather intelligence and provide warfighters with critical battlefield information. Furthermore, all signs point to an increase in LEO operations with the emergence of the small satellite market and the initiation of serious efforts to mount human expeditions beyond LEO.

As many within the community know, our use of this resource has been clouded by our lack of forethought and understanding of just how the current uses of LEO impact our future ability to make use of this resource. Already, debris from exploding rocket bodies and fragmented spacecraft pose an increased threat to operational spacecraft throughout LEO. While technical measures such as the passivation of rocket bodies and conservation measures such as the 25-year rule have reduced the debris production over the past few decades, compliance with these guidelines has yet to be fully realized [1]. As a result, many studies have shown that a *business as usual* approach to orbital debris mitigation will allow the debris population in LEO to continue to increase. A theory known as the Kessler Syndrome, first introduced by Don Kessler in the late 1970's, suggests that the LEO satellite population will reach a tipping point where collisions will breed more collisions thereby increasing the

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risk to operational satellites. Many of these recent studies show that the LEO population is rapidly approaching this tipping point. Many within the community point to these dangerous trends and conclude that action must be taken to stem the growth of the debris population.

At the forefront of this discussion over the past decade has been the idea of Active Debris Removal (ADR). The justification for this practice is that, by specifically targeting large objects in LEO for removal, the production of debris through collisions will be reduced and the threat will diminish. However, ADR carries with it many technical and policy challenges that will make it difficult to enact. On the international policy front, advocates of ADR are faced with the questions of ownership of and responsibility for the offending space objects. To further complicate matters, there are those within the national security community that see the same technologies that would enable ADR (specifically automated rendezvous and capture) as tools of war and point to ADR as a potential weaponization of space. The challenge of making ADR a technical reality has spawned advances in deorbit technologies such as tethers, advanced drag augmentation devices, and other advanced propulsion technologies. However, the technologies to support the rendezvous and capture of a passive, uncooperative, tumbling space object have yet to be fully realized.

This paper sets out to cast the problem of LEO environmental conservation in a slightly different light. First, we must view LEO not as a single environment unto itself but rather as a collection of environments delineated by orbital altitude. This idea of using orbital Shells of Interest (SOI) to frame the debris discussion was a cornerstone of the work completed by Bradley and Wien in 2008 [2]. By viewing LEO in this manner, it becomes apparent that there are SOIs where risk to operational assets is significantly higher than in others. Taking this a step further, one could suggest that while some regions of LEO may be declared high risk and potentially require ADR to clean up, other regions may be suitable for higher volume operations now. If this is true, then there is an opportunity to learn from our previous mistakes and implement regulations for these low risk regions to ensure that they remain low risk, providing spacecraft operators safer environments in which to continue to provide their invaluable services.

This paper will focus on the orbital debris regulatory system of the United States and hypothesize different policy avenues available for future regulation of orbital debris mitigation. A brief discussion of the current state of the LEO orbital debris environment and the predicted future states is provided for context. The current technical, economic, and political facets of orbital debris mitigation in the United States are addressed. Several potential policy options are presented and weighed against each other and common themes that reflect the positive aspects of these policy options are highlighted to frame future discussions of what characteristics make effective LEO conservation policy.

2. Current state of orbital debris in low earth orbit

2.1. Sizing up the problem

The population of LEO objects is divided between operational spacecraft and debris objects. Debris is typically categorized as small (<1 cm), medium (1–10 cm), or large (>10 cm). This classification captures both the observability and potential threat of the debris object. Very small debris (<1 mm) can typically be shielded against and, although estimates put the population of objects this size greater than 150,000,000, this debris presents very little threat to operational spacecraft. Large debris, including spent rocket bodies and non-operational spacecraft, can be tracked and cataloged and currently makes up approximately 76% of the over 11,000 unclassified objects tracked in LEO by the Joint Space Operations Center (JSpOC). A collision with a large debris object is typically catastrophic, destroying both objects as was the case in the 2009 collision between the Iridium 33 and Cosmos 2251 satellites. Medium sized debris is not readily tracked by ground assets but poses a lethal threat to operational satellites. Estimates for medium debris populations in LEO range from 500,000 to 800,000 unique particles however, much of this data results from simulations due to very limited observational data sets.

Throughout the life of a spacecraft there are several opportunities to create debris of all shapes and sizes. Large debris is typically created at major events in a spacecraft's life. An upper stage can remain in orbit after it has delivered a satellite. Satellites only operate for a finite period of time and once their mission is complete, they also become space debris. Both of these categories of space debris are subject to guidelines for disposal. In LEO, the overarching guideline is the 25-year rule which states that, after their mission is complete, objects should be placed in orbits that will allow for them to naturally re-enter the Earth's atmosphere within 25 years of the end of their life.

By far, the largest source of space debris is fragmentation, or the break-up of satellites and rocket bodies in orbit. To date, there have been 203 known breakups of orbiting objects. The majority of these have occurred due to explosions. The fragmentation of a five to ten ton satellite can produce 3000–5000 debris objects bigger than 10 cm and 150,000–250,000 debris objects between one and 10 cm [3]. There are several reasons for orbiting objects to explode. Propellant tanks and batteries can be heated by the sun in orbit. The remaining contents of these tanks will evaporate, increasing the pressure until they explode. These pressure vessels can also explode if struck by a small micrometeoroid or piece of debris. It is estimated that as much as 70% of all fragmentations are caused by explosions. Fragmentation can also be intentional, like the Chinese anti-satellite weapon (ASAT) test that destroyed the Fengyun-1C spacecraft in 2007. It is estimated that 28% of the fragmentation events in orbit were deliberate. The remaining 2% of fragmentation events were collisions between orbiting objects [4].

While collisions make up a small percentage of fragmentation events today, several factors lead experts to predict that collision fragments will make up 50% of all objects in LEO within 50 years [5]. First, many spacecraft and rocket bodies now undergo a process known as passivation as part of their end-of-life operations. This includes depressurizing all storage tanks to avoid explosions. Second, the space community expects a general decline in the number of intentional fragmentation events due to increased pressure to avoid the creation of orbital debris. Finally, it is expected that as the population of orbiting assets increases, so too will the probability of on-orbit collisions.

2.2. It's crowded up there

There are currently 22,000 objects being tracked in Earth orbit by JSpOC. 16,000 of these are publicly acknowledged; the remaining 6000 are classified. In addition there are an estimated 500,000 untracked objects larger than 1 cm in Earth orbit, according to NASA. These objects tend to be grouped into three orbit categories; Low Earth Orbit (LEO) extending from 200 km to 2000 km altitude, Geo-Synchronous Orbit (GEO) at approximately 35,800 km altitude and Medium Earth Orbit (MEO) which lies between LEO and GEO. Roughly 73% of all tracked objects in Earth orbit are located in LEO. While GEO is home to many communications satellites that have a high value, only about 5% of the tracked objects reside there. For this reason, the primary focus for orbital debris is LEO.

Fig. 1 shows that within LEO there are distinct regions of higher population. The number of active satellites is overlaid with the