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Spaceways: Airspace in Outer Space

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Abstract

Forecasted future demand in space travel is driving the need for the development of space traffic management. Currently, orbital space traffic is mostly unregulated with internationally agreed upon best practices and self-interest driving space operators to avoid collisions with other spacecraft. This paper explores the future of space travel by presenting a concept of creating “airspace in space” or spaceways to manage the ever growing volumes of space traffic.

Spaceways are analogous to airspace for aircraft with the goal of increasing levels of safety and reducing probabilities of collision. These goals can be achieved by creating traffic rules, defining valuable orbits and minimum capabilities for spacecraft to be flying in the defined valuable orbits.

The paper will discuss the creation and evolution of airspace for aircraft, provide an explanation for the need of spaceways and discuss a specific concept for defined spaceways in outer space, including some of the disadvantages for creating spaceways. Additionally, airspace is more than managing the flow of air traffic but also a means of nation-states defining the boundaries of their sovereignty. The current legal framework regarding sovereignty in space, arguments for and against a delimitation line between airspace and outer space and the need for international cooperation to define the spaceways will also be discussed. Lastly, further inquiry into liability implications due to the definition of spaceways and potential organizations to create and control the spaceways will be discussed.

Keywords: *Space Traffic Management, STM, Spaceways, Airspace, Orbital, Debris, Space Law, Liability*

Introductions

The development of new forms of transportation follows the trend of slow adoption, steady proliferation and accessibility to the masses. Traffic control as it is understood today likely started in 1722 when the Lord Mayor in London ordered three men to begin coordinating and controlling traffic on the London Bridge (Dockray, Rowell & Whitton, 2005). The need for this traffic management arose due to the volume of traffic trying to cross the bridge with accessibility of owning carts and carriages reaching critical mass. As each new form of transportation has been developed and the volume of this new mode reaches its critical mass, new forms of traffic management had to be created. Although space travel was not invented in the 21st century, it is the era in which critical mass in volumes of space traffic will require managing space movements.

Space traffic management (STM) is not a new concept and the issues surrounding STM are well understood. One of the earliest publications related to STM originated in the United States Air Force (USAF) with a collection of studies conducted in 1993-1994 called SpaceCast 2020. Several white papers were created within the USAF's Center for Strategy and Technology with one relevant paper titled *Space Traffic Control: The Culmination of Improved Space Operations* (USAF, 2014). Even in 1993 and 1994, it was apparent to space industry professionals, particularly with the launch of the Iridium constellation, that greater numbers of spacecraft would be competing for a limited amount of space and electromagnetic spectrum (USAF, 1994). This white paper recommended a creation of a space traffic control system (SPATRACS) to monitor space traffic, provide collision avoidance information to users and to deconflict flight planning (USAF, 1994).

One key issue with operating in space is the risk associated with debris and mitigation

efforts to reduce the amount of debris generated by getting to and operating in space. Collisions are one way debris is rapidly increased and as the volume of debris increases, the risk and probability of collision between objects in space also increases (Schrogl, 2010). Debris mitigation is therefore vital in creating a sustainable environment in which to operate spacecraft.

Debris collisions cannot be controlled, but collisions between active spacecraft or between active spacecraft with other debris can be avoided, assuming that an accurate and timely monitoring and notification system is in place and spacecraft are capable of maneuvering away from debris. A collision between an inactive Russian Cosmos spacecraft with one of the active satellites from the Iridium constellation emphasized the gap in capabilities related to monitoring potential collisions (Orndorff, Boone, Kaplan, Harmon & Lindberg, 2009). Since then, the US Strategic Command (SSSTRATCOM) now provides daily conjunction reports for the entire Iridium constellation (Schrogl, 2010). Monitoring and communicating positions of objects in their domain are the foundations of any traffic management system. For STM, monitoring and communicating (or notifying) are the first two of four elements described by Schrogl (2008) that define the STM regime. Elements three and four are, “concrete traffic rules and mechanisms for implementation and control” (Schrogl, 2008, p.274). This paper focuses on part of element three by introducing and discussing the concept of airspace in space, called *spaceways*, to help coordinate traffic with concrete traffic rules.

Aviation, Air Traffic Management and Airspace

Orville and Wilbur Wright’s famous flight on December 17, 1903 was the beginning of the aviation industry (Curley, 2012). Innovators in the US were quickly dominated by the counterparts in Europe who began perfecting the designs of aircraft including the “stick-and-rudder” control design that is still used in aircraft today (Curley, 2012). The years leading up to

World War I saw particularly quick development of aviation technology which gave countries such as Germany an advantage over the US during the war (Curely, 2012).

Towards the end of World War I, the US Postal Service (USPS) began using trainer aircraft and eventually the remaining military surplus aircraft to start an airmail service (Curley, 2012). In conjunction with the US Army, the goal was to create an intercontinental message delivery service (Kern, 2012). In 1920, the USPS created the first version of flight services, named Airmail Radio Station (ARMS) with their first radio station in Bellefonte, PA (Kern, 2012). Radio operators had the responsibility of sending information regarding weather and aircraft departure and arrivals to other stations via the telegraph with Morse code (Kern, 2012). By February of 1921, the first transcontinental airway (shown in the top left image in Figure 1) was created from New York City to San Francisco with radio support intermittently along the entire route (Kern, 2012). First, oil soaked logs were used to create bonfires to direct pilots in the dark or in bad weather but eventually acetylene beacons were developed and lit along the route to allow navigation at night (Norman, 2012). Radio navigation eventually emerged in the US in 1930 to assist pilots in navigating en-route and also during landing (Orndorff et al., 2009).

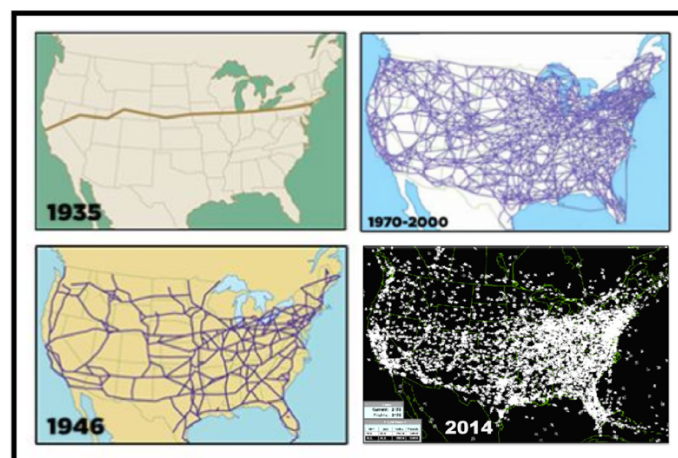


Figure 1. Growth in the aviation network. Adapted from Hunter, S. (2014). How to reach an International Civil Aviation Organization role in Space Traffic Management. ERAU Scholarly Commons

The use of bonfires and primitive radios were the beginnings of the effective, reliable and safe air traffic control (ATC) system that still exists today. The development of today's system was not without its setbacks. Slowly the volumes of traffic increased and eventually, on April 7th, 1922 the first midair collisions took place in France killing six people (New York Times, 1922). At the time, the route between Paris and London was flown by early airline companies with an average of six flights per day with 20 passengers (New York Times, 1922). At that time, aviation was still operating under the "big sky" theory where the volume of the space was large enough and the amount of traffic small enough that the probability of collision seemed impossibly low (Hunter, 2014). The New York Times article (1922, p.1) describes people as shocked to hear the news and that "two airplanes flying in opposite directions on the regular route between the two cities should be a series of tragic coincidences collide in the air seemed hardly credible to most." By World War II, the quantity of active aircraft made it clear to military planners that airspace, as a resource, required careful management (Griffith, 2006).

Another important aspect of early aviation history was the signing of the The Paris Convention, also known officially as *The Convention Relating to the Regulation of Aerial Navigation* (Abeyratne, 2014). This agreement was signed by 26 states on October 13, 1919 and established that the contracting parties (nation-states) had complete and exclusive sovereignty over the airspace above their territory (Abeyratne, 2014). Decades later in 1944, this agreement was expanded in Chicago at the Chicago Convention, formally known as the *Convention on International Civil Aviation*. The Chicago Convention reaffirmed the principles of The Paris Convention and created the rules-of-the-road for the aviation and airline industries, creating the regulatory stability to allow the aviation industry to take off and become as successful as it has today.

Through decades of continual expansion of the aviation industry, the network of airline routes and radio stations (flight services) expanded as depicted in Figure 1. Additionally, management of airspace increased, including the definition of airspace classifications depicted in Figure 2. Part of the definition of each class of airspace includes the minimum requirements for operating within that airspace. For example, Class B airspace is the airspace around major airports and it has the strictest requirements for operating aircraft, described in Table 1. To enter this airspace, ATC has to give clearance, the pilot must have proper certifications, the aircraft must have two-way radio communications and it requires a minimum separation of three statute miles during visual flight rules (VFR). Class B airspace is shaped like an upside-down tiered wedding cake and connects Class A airspace to the airport on the ground. Class G airspace is the least restricted including not requiring two-way radio communication except under certain circumstances (Mumm, 2015). This concept of varying classes of airspace and requiring different authorities, certifications and capabilities can be extrapolated, augmented and expanded into the space industry.

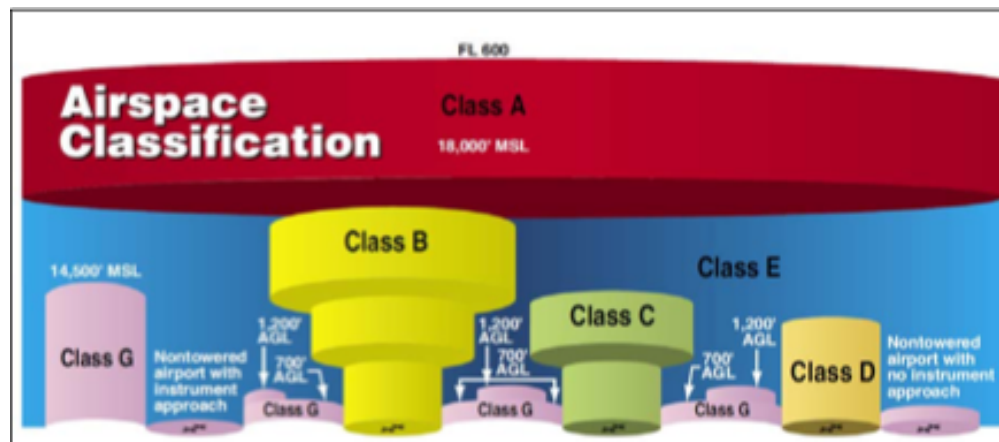


Figure 2. US Airspace Example. Adapted from Hunter, S. (2015). *Safe Operations Above FL600*. ERAU Scholarly Commons

Table 1

US Airspace Classification and Requirements

Airspace	Class A	Class B	Class C	Class D	Class E	Class G
Entry Requirements	ATC clearance	ATC clearance	Prior two-way communications	Prior two-way communications	Prior two-way communications*	Prior two-way communications*
Minimum Pilot Qualifications	Instrument Rating	Private or Student certification. Local restrictions apply	Student certificate	Student certificate	Student certificate	Student certificate
Two-Way Radio Communications	Yes	Yes	Yes	Yes	Yes, under IFR flight plan*	Yes*
Special VFR Allowed	No	Yes	Yes	Yes	Yes	N/A
VFR Visibility Minimum	N/A	3 statute miles	3 statute miles	3 statute miles	3 statute miles**	1 statute mile†
VFR Minimum Distance from Clouds	N/A	Clear of clouds	500' below, 1,000' above, 2,000' horizontal	500' below, 1,000' above, 2,000' horizontal	500' below,** 1,000' above, 2,000' horizontal	Clear of clouds†
VFR Aircraft Separation	N/A	All	IFR aircraft	Runway Operations	None	None
Traffic Advisories	Yes	Yes	Yes	Workload permitting	Workload permitting	Workload permitting
Airport Application	N/A	<ul style="list-style-type: none"> • Radar • Instrument Approaches • Weather • Control Tower • High Density 	<ul style="list-style-type: none"> • Radar • Instrument Approaches • Weather • Control Tower 	<ul style="list-style-type: none"> • Instrument Approaches • Weather • Control Tower 	<ul style="list-style-type: none"> • Instrument Approaches • Weather 	<ul style="list-style-type: none"> • Control Tower

Adapted from Mumm, H. (2015). *Managing the integration and harmonization of national airspace for unmanned and manned systems*

Spaceways

The concept of spaceways as envisioned in this paper is not prevalent in existing literature, although the term does appear in several articles and books. There are two leading ways with which this term is used in relation to STM. The most commonly found usage is described by Pelton & Jakhu (2010, p.112) as serving “the purpose of routing traffic transitioning to and from space.” The spaceways would likely be utilized in conjunction with space transition corridors (STC) which are dynamic volumes of airspace to allow spacecraft to fly through the National Airspace System (NAS) (Pelton & Jakhu, 2010). This view of spaceways promulgated into a variety of other published literature but maintains its focus on spaceways as means of traversing through the NAS. Pelton and Jakhu (2010, p.112) do describe spaceways as “similar

to today's airways and jet routes" which is comparable to the second most commonly used concept for spaceways. The USAF (1994, p. D-16) as part of their SpaceCast 2020 study describes spaceways similarly as, "like today's airways and jet routes" but with the concept being traffic de-confliction and sequencing in orbit.

STCs are novel approaches to managing and reserving airspace for sub-orbital and orbital spacecraft leaving the surface of the Earth. The trivial differentiation in definitions between 'STC' and 'spaceways' argues for a single term (STC) to describe the route from the surface of the Earth, through airspace, in its transition to space. This paper argues that the term 'spaceway' should be used as described by the USAF (1994, p. D-16) as a means of managing "travel through the region of near-Earth space," similar to how airspace is used as means to manage air traffic near the surface of the Earth.

Orbits

Physics makes defining spaceways more difficult than it does describing different classes of airspace. Solar system gravitational forces dictate current space routes (Elder and Hughes, 2005). Aside from a geostationary equatorial orbit (GEO) (an area of space directly over the equator that allows a satellite to remain in a fixed position over the surface of the Earth at an altitude of approximately 35,786 km), orbiting objects are not able to maintain positioning in a tightly defined volume of space (Finch, 1986). Instead, orbits, by their very nature, create halos of volume on a revolution basis and volumes similar to toroids or hollow spheres encompassing the entire earth on larger time scales, as shown in Figure 3. A set of six fundamental parameters define orbits: inclination, right ascension of the ascending node, argument of perigee, eccentricity, mean motion and mean anomaly (Kaiser, 2015). The orbital element set specifies the exact orbit but is not an ideal solution for bounding spaceways. Orbits with different orbital

parameters may still have conjunctions. For example, two spacecraft may be in orbits with different inclinations but similar altitudes, and their spaceways would cross at two different points as show in Figure 4.

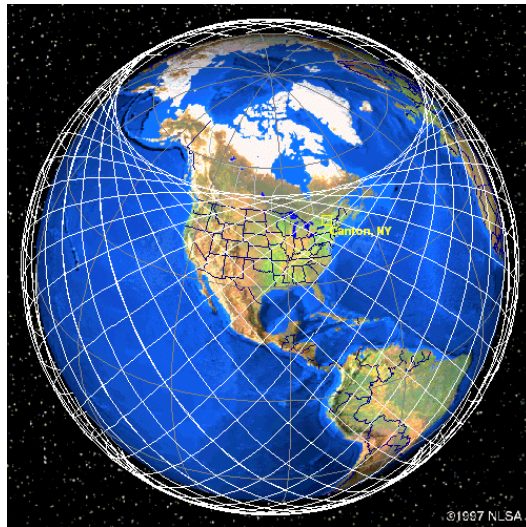


Figure 3. example of toroid-like volume swept out by an inclined orbit. Adapted from:

https://qph.ec.quoracdn.net/main-qimg-4f10dbba1695b821142a45632e109e4a?convert_to_webp=true

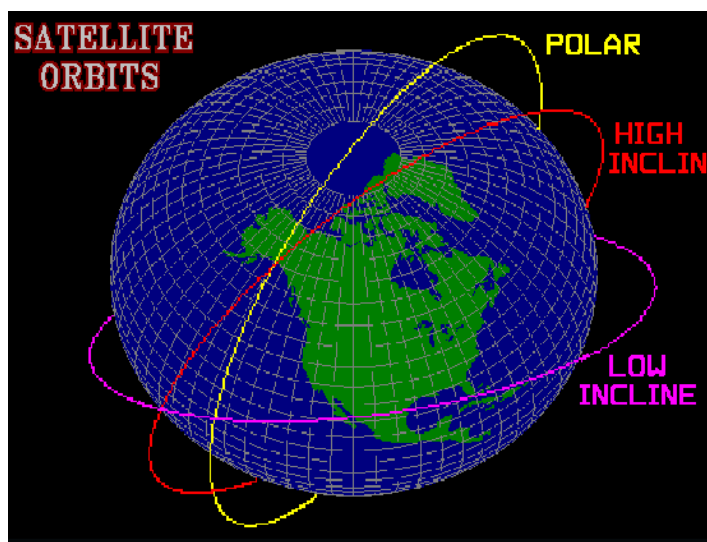


Figure 4. Examples of orbits at different inclinations. Adapted from Orbits. (n.d.).

Retrieved November 11, 2016, from <http://www.astronomycafe.net/qadir/orbits.gif>

A more complex example, the semi-major axis, eccentricity and inclination could all be different and still there could be instances where the spaceways would intersect and conjunctions are possible. Herein lies the complexity in defining spaceways using orbital elements. It is more appropriate to define spaceways using 3-dimensional volumes.

Using the aviation industry as a model, airspace and the requirements for operating within volumes were created to protect and maintain high levels of safety in areas of varying levels of use. Recall from Figure 1 and 2 the placement of Class B airspace around major airports and the requirements for operating within this volume. A similar concept could be utilized in space by defining the highest density orbits and orbits with the most applications (Rathgeber, Schrogl & Williamson, 2011). Low Earth orbits (LEO) from approximately 400-1000 km, including lower inclination orbits, polar orbits and sun synchronous orbits are often utilized for Earth observation satellites, while geosynchronous orbits (GSO) are often used for telecommunications (Rathgeber, Schrogl & Williamson, 2011). These volumes could be reserved by defining toroids or hollow spheres as spaceways with required minimum capabilities to operate within these regions. A static, vast volume may be too exclusionary and simplified if certain capabilities are mandatory. The intent of this paper is not to recommend a specific method of defining spaceways but to influence the conversation on possible regulations. The method that is selected to define the spaceways, static or dynamic, will need to protect these valuable orbits that provide utility in space. The next section describes some potential capabilities that could be required for operating within reserved regions.

Capabilities

Maneuver

The primary discriminator in satellite capabilities is the ability for the spacecraft to maneuver. The ability to maneuver requires advanced attitude control and propulsion systems. Additionally, the spacecraft must be designed with the capability of carrying the large propellant mass. Adding the ability to maneuver to a satellite greatly increases its cost, but provides the ability to move when a collision is imminent. Spacecraft with these advanced capabilities should clearly be allowed to operate in restricted regions of space. Requiring this capability could be very limiting. Cubesats are launched as secondary payloads on many launches and the orbit that they are released into is at the mercy of the primary payload. Unless the primary payload does an orbit transfer, the cubesats will end up in the same orbit as the larger, more expensive and more capable spacecraft. Requiring maneuver capability would essentially eliminate these shared rides of cubesats with larger spacecraft. One option for that could be to require a second upper stage maneuver after the primary payload has been released to release the cubesats in a different orbit. This could also impose a higher cost on the cubesats for the additional propellant required, thus negatively impacting that market.

Tracking

Recall the first of four elements of STM is monitoring. One capability that could be required in orbit would be to place technologies on all spacecraft launched into restricted orbits to make them easier to track. This could be equivalent to an ADS-B transmitter that will be required on aircraft as part of the FAA's NextGen System (Strohmeier, Schäfer, Lenders & Martinovic, 2014). Advanced or cooperative versions of this system could provide orbit determination data (state vectors) and identification information (Elder and Hughes, 2005). Basic versions would simply provide identification information and not be able to communicate exact position to space traffic control on the ground (Elder and Hughes, 2005). The differentiation

between basic and advanced is made because cubesats, even if equipped with an attitude control system, likely do not have adequate sensors (such as star trackers) to accurately perform an orbit determination. Requiring the advanced version of broadcasted orbit position may be exclusionary of cubesats, similar to a requirement for maneuver capability.

Another alternative would be requiring on-board technology that helps the existing space situational awareness (SSA) network track spacecraft, without a transmit capability. The concept behind this technology is to place a device on spacecraft than when illuminated by a tracking radar, the signal is bloomed to make the object more easily detected. The returned signal could also be encoded with data to identify the spacecraft. This is analogous to how RFID works for applications such as contactless badge readers.

Currently, SSTRATCOM tracks objects 10 cm and larger which means cubesats can be tracked (the size of a standard 1U cubesat is defined as 10 cm x 10 cm x 10 cm) (Rathgeber, Schrogl & Williamson, 2011). The capacity and accuracy are already not adequate and larger volumes of cubesats are predicted to be launched in the coming decades (Contant-Jorgenson, Lála & Schrogl, 2006). Also, primary targets of the SSA network are going to be military and civil spacecraft, constellations and large commercial systems (Rathgeber, Schrogl & Williamson, 2011). Providing technology to increase the tracking capability of the existing SSA system would be advantageous for an effective STM system.

Disposal

Responsible and reasonable use of space calls for appropriate space debris mitigation (Pelton & Jakhu, 2010). This includes disposal at the end of a mission. One requirement for restricted spaceways could be having planned and approved disposal concept of operations. In the case of the satellites that have maneuver capability, this could mean a deorbit burn to either

place the spacecraft in a lower restricted spaceway or to deorbit the vehicle completely. To make accommodations for non-maneuverable spacecraft, the disposal plan could be simply showing that the spacecraft naturally deorbits in a reasonable time frame. Air drag decreases with altitude so ideally small, less capable satellites would be launched in lower orbits that quickly rid themselves of debris. Setting a maximum duration which these less capable spacecraft can operate in spaceways would limit the altitude in that they could be deployed. At GEO, the standard practice of moving old satellites into a graveyard orbit is already in use.

Other considerations

In addition to considerations related to hardware on orbit, there are also operational and ground considerations. How frequent and through what network is telemetry and command available? In the case of maneuverable satellites, if the operator is notified of a potential conjunction, the ground infrastructure will need to support short timelines to quickly divert its course. Temporary restrictions could be placed on cubesat launches if manned space mission are taking place in or around the orbit so as to minimize risks to astronauts. These temporary restrictions could be placed when vital missions require stability in the orbital debris environment.

Sovereignty in Space

Unlike with airspace, the concept of spaceways does not include extending the idea of sovereignty into space. Earlier in this paper, the concept of national sovereignty of airspace above territories was mentioned. Some countries, primarily along the equatorial belt, have tried to claim that satellites in GEO violate their sovereignty guaranteed in the Chicago Convention (Finch, 1986). This is due primarily to the ambiguity of the Chicago Convention not defining 'airspace' (Finch, 1986). For any useful mission, it is impossible to remain in an orbit over a

single country, thus negating support for the concept of sovereignty in orbit.

There have been calls to identify an official, legal boundary between airspace and outer space but to date, no definition exists. In 1962, the Scientific and Technical Sub-Committee and Legal Sub-Committee of the United Nation's Peaceful use of Outer Space (UNCOPUOS) committee became the central group coordinating and working towards international cooperation in peaceful uses of space (Halstead, 2007). The concept of a boundary was a mentioned topic but the committee did not feel the issue was a high priority and the two leading space-baring nations, the US and the USSR, did not believe it to be in their interests to define a boundary (Halstead, 2007). When moving forward with developing a STM system and the use of spaceways as part of that system, the concept of a delimitation line may have impacts on the definitions of spaceways.

Liability

The creation of spaceways will also introduce other legal challenges in space, in particular the concept of liability. The international space treaties define liability, but at a nation-state level. New international agreements or common national laws, at a minimum, will need to be devised and signed expanding liability of space activities to private users. An understanding by all users operating within certain airspace is required so people understand the potential financial burden of operating in restricted spaceways. If required capabilities are leniently defined, but liability for collisions is high, the impact on the cheap, cubesats may effectively block them from operating in those regions. If liability limits are set low, cubesat operators may create havoc in the spaceways, negating the purpose of having the spaceways in the first place. A compromised solution will need to be sought.

Conclusion

The purpose of this paper was to extend the idea of creating defined volumes in space called spaceways, which would be a tool to assist space traffic controllers managing space traffic. Unlike airspace, physics dictates that spaceways are large instead of tightly-bound volumes. Several different capabilities and implications related primarily to cubesats were discussed. A compromised solution will be required to create an environment of responsible space use, while also not stifling pieces of the space industry. Moreover, financial stability will need to be guaranteed so that businesses continue to find utility and profits by operating in space.

The concept for spaceways, or even STM in general, cannot be solved at a national level. Orbits are inherently a global domain. An international agency capable of coordinating global efforts and standardizing systems will be required to make sure all actors in space are following and operating by the same rules. As a leader in space technology, the US is in a position to provide leadership in the development of an efficient and safe STM system.

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