Strategy Research Project

A Case for Policy and International Cooperation on Small Satellites

by

Lieutenant Colonel Ralph E. Bordner III
United States Air Force

Under the Direction of:
Dr. Andrew Lippert

United States Army War College
Class of 2017

DISTRIBUTION STATEMENT: A
Approved for Public Release
Distribution is Unlimited

REPORT DOCUMENTATION PAGE

Form Approved--OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
01-04-2017	STRATEGY RESEARCH PROJECT	

4. TITLE AND SUBTITLE
A Case for Policy and International Cooperation on Small Satellites

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Lieutenant Colonel Ralph E. Bordner III
United States Air Force

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Dr. Andrew Lippert

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army War College, 122 Forbes Avenue, Carlisle, PA 17013

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT Distribution A: Approved for Public Release. Distribution is Unlimited.
To the best of my knowledge this SRP accurately depicts USG and/or DoD policy & contains no classified information or aggregation of information that poses an operations security risk. **Author:** ☒ **PA:** ☒

13. SUPPLEMENTARY NOTES
Word Count: 5,991

14. ABSTRACT
The increased use of small satellites, or smallsats, by both nation-state and non-nation-state actors violates the assumptions that current, internationally accepted space debris mitigation guidelines are based upon. Consequently, smallsats change the character and level of risk of on-orbit collisions. In an effort to preserve critical orbital regimes, this paper posits that the U.S. should define near-term, smallsat design and operational best practices to be used as a basis for U.S. policy, leadership and international cooperation. To establish an initial set of best practices, the U.S. should leverage the histories of naval, air and space international norm and law development, as well as current and near-term technical capabilities. U.S. policy and international involvement is the best way to steer space community practices and eventual international law, and the strongest evidence for this idea is history and precedent.

15. SUBJECT TERMS
Smallsats, Norms, Laws, Space Debris

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**		30	**19b. TELEPHONE NUMBER** *(w/ area code)*
UU	UU	UU	UU		

Standard Form 298 (Rev. 8/98), Prescribed by ANSI Std. Z39.18

A Case for Policy and International Cooperation on Small Satellites

(5,991 words)

Abstract

The increased use of small satellites, or smallsats, by both nation-state and non-nation-state actors violates the assumptions that current, internationally accepted space debris mitigation guidelines are based upon. Consequently, smallsats change the character and level of risk of on-orbit collisions. In an effort to preserve critical orbital regimes, this paper posits that the U.S. should define near-term, smallsat design and operational best practices to be used as a basis for U.S. policy, leadership and international cooperation. To establish an initial set of best practices, the U.S. should leverage the histories of naval, air and space international norm and law development, as well as current and near-term technical capabilities. U.S. policy and international involvement is the best way to steer space community practices and eventual international law, and the strongest evidence for this idea is history and precedent.

A Case for Policy and International Cooperation on Small Satellites

On-orbit collision is not a new concern to the international space community. However, with the growing trend to miniaturize satellites and the increase of non-nation-state actors (from high school students to mega-corporations) operating in space, the character and level of risk have changed. Only considering "cubesats" (satellites on the order of a ten-centimeter cube and approximately 1.5 kilogram or less), 2014 and 2015 saw 158 and 131 cubesats, respectively, achieve low-earth orbit. The predictions for 2016 and beyond are larger.[1] Add in other proposed and existing "smallsats" (satellites under 500 kilograms), to include hundred-plus-satellite constellations proposed by telecommunication companies, and the orbital regime immediately surrounding the earth gets significantly more crowded. If left unchecked, this author assesses these satellites and their associated support pieces could increase risk on orbit in three ways:

- Immediate co-orbital collision threat (short/long-term risk)
- Key orbital regime crowding (short/long-term anti-access risk)
- On-orbit collision risk during end-of-life orbital decay (long-term risk)

While space is large and satellites are small, smallsats increase on-orbit collision risk due to their increasing numbers and size, which in many cases challenges the limits of today's tracking technology (about ten centimeters).[2] So, while mitigating debris and on-orbit collisions are nothing new to the international community, smallsats change the assumptions upon which current mitigation strategies were built. Consequently, the space community should change on-orbit practices accordingly.

This paper posits that the United States (U.S.) should define near-term, smallsat design and operational best practices to be used as a basis for U.S. policy, leadership and international cooperation in an effort to preserve critical orbital regimes, the low earth orbit in particular. To establish an initial set of best practices, the U.S. should leverage the histories of naval, air and space international norm and law development, as well as current and near-term technical capabilities. United States policy and international involvement is the best way to steer space community practices and eventual international law, and the strongest evidence for this idea is history and precedent.

Since World War II, the U.S. international relations philosophy has been that of international cooperation. This is currently reflected in the U.S. National Security Strategy which calls for a "rules-based international order advanced by U.S. leadership that promotes peace, security, and opportunity through stronger cooperation to meet global challenges."[3] In the absence of a world-wide, authoritative governing body, cooperation and the establishment of space-based rules and cultural norms are the best options for success. Without them, the resulting anarchy would reduce outer space to a domain where it is every actor for itself.

Precedence shows that cooperation in space does work. For example, the current internationally accepted ruleset for orbital debris mitigation guidelines was initially created by the Department of Defense and the National Aeronautics and Space Administration in the 1990s, ultimately endorsed by the United Nations (UN) General Assembly in 2007.[4] Further, the U.S. is currently conducting international Space Security Dialogues to pursue transparency and confidence building measures (TCBMs) whose goal is "long-term sustainability of space activities."[5] One such effort is the International Code of Conduct for Space Activities.[6] Similar to this paper, these TCBMs effectively encourage best practices as a first step to greater international cooperation and norm development. Ultimately, all space-related efforts should lead to support a robust Space Traffic Management system, similar to the Air Traffic Management system. Such a system and its supporting technology have already been proposed by the International Academy of Astronautics (IAA) and others.[7]

This paper argues in favor of using the international-norms-based approach through an introduction to key concepts, a review of current technologies and mitigation possibilities, and an analysis of international law and norm development within the air, sea and space domains. Reviewing the development and expansion of these other domains demonstrates how international cooperation and government intervention have underwritten success within these domains and that similar efforts within the space domain may generate progress towards future success.

First, the space domain must be defined. The most important region of space for this discussion is immediately about the earth, from about 100 kilometers to approximately 36,000 kilometers. This spherical domain can be further sectioned into orbital zones: low earth orbit or LEO (100 km to 2,000 km), medium earth orbit or MEO (2,000 km to 36,000 km) and geosynchronous orbit or GEO (for this discussion, this will be defined as a band of space approximately thirty degrees wide, centered on the equator, at an altitude of approximately 36,000 kilometers). However, since the majority of satellites reside in LEO and GEO, we will exclude the MEO zone from this discussion. This leaves two orbital regions for analysis, and they are depicted in Figure 1.[8] In this model, Z represents orbital altitude. While a simplistic model, it facilitates discussion by reducing space to the relevant portions of outer space central to the subject of this paper.

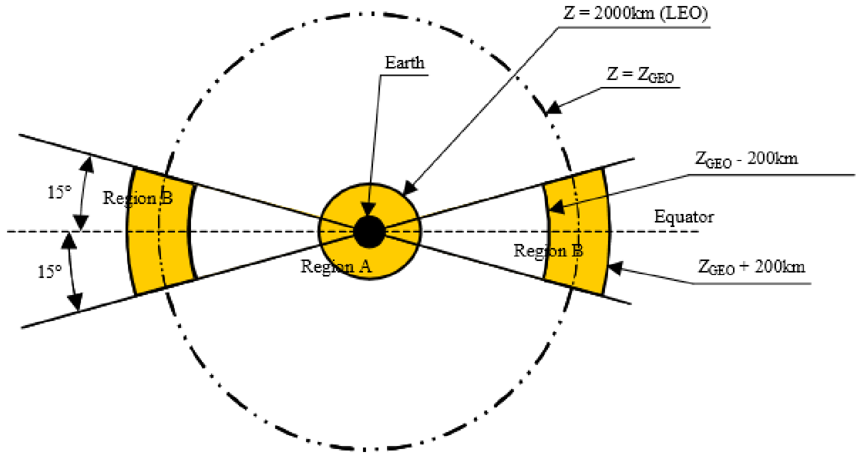

Figure 1. Key Orbital Regions[9]

Satellites exist in these zones by riding on an invisible track in the approximate shape of a circle or an ellipse. Orbital mechanicians call these tracks orbits. Satellites maintain these orbits only if they maintain the velocity required to repeat their prescribed orbital path. To get into orbit, satellites require the assistance of launch vehicles, some of which leave pieces of themselves behind in orbit. All of the parts that do not re-enter the earth's atmosphere become orbital debris. In fact, so do the satellites themselves after their useful life is over. While some of this debris will deorbit, the higher up and more circular the orbit, the longer it will take to naturally occur. Today, more than 21,000 pieces of orbital debris larger than ten centimeters are tracked. Unfortunately, there are approximately 500,000 pieces between one and ten centimeters in diameter, and an estimated 100 million for those smaller than one centimeter.[10] This debris poses a significant risk to spacecraft, and it is getting worse. In fact, some believe that we have already passed the "tipping point," where the "amount of orbital debris will continue to grow, in spite of debris mitigation measures, because collisions will generate new debris faster than it is removed by natural forces."[11]

Clearly, this is why the Inter-agency Space Debris Coordination Committee (IADC) published an international set of non-binding guidelines to minimize the creation of additional orbital debris. The set is very small, and it is composed of four guidelines:

- Limiting debris released during normal operations
- Minimizing the potential for on-orbit break-ups
- Satellite disposal post mission
- Prevention of on-orbit collisions[12]

These guidelines are built on the three principles: preventing on-orbit break-ups, removing spacecraft and orbital stages that have reached the end of their mission operations from the useful densely populated orbit regions, and limiting the objects released during normal operations.[13] These guidelines are mimicked by the U.S. Government Orbital Mitigation Standard Practices.[14] However, there are two issues with these guidelines. First, they are voluntary and are written by and for the target audience of sovereign states instead of private industry. It is true that the term "voluntary" in international agreements has more compliance power over private industry than the term at face value implies, and, as lawyers such as Michael Listener have argued, "even non-binding measures can affect commercial space actives."[15] For example, non-binding commitments to international partners may manifest as domestic regulations. However, commercial space companies can choose to push the boundaries of these guidelines, and considering the second issue with the guidelines, the lack of specificity and loose restrictions, these companies have considerable opportunity to exploit the situation while still complying with international norms.

Simply stated, established space-based regulations and norms have been outpaced by technology. It may be time to codify previous norms and best practices in policy or domestic regulation as well as introduce more restrictive measures, either through best practices or enforceable domestic rule sets.

Small satellites represent a technological jump that has and will continue to change how actors operate in space. Traditionally, access to space was limited to wealthy and technologically advanced nation states due to the cost to achieve orbit. Launch costs vary with launch vehicle, payload size and orbital altitude, but for U.S. systems launching to LEO, those costs have traditionally followed the heuristic of $10,000 to $20,000 per kilogram.[16] Considering satellites can be as massive as 20,000 kilograms, launch costs are usually substantial. However, with miniaturization efforts and advances in commercial launch capabilities, achieving orbit is much more economical. In fact, the cost per kilogram to LEO for a SpaceX launch is about $1,700 to $3,000 (at max payload).[17] However, that is not the only reason why small satellite numbers will continue to grow. The main reason is arguably profit.

Global constellations on the order of hundreds of satellites whose purpose is to provide services to the entire earth are now economically feasible. Unlike the Global Positioning System constellation (which is projected to cost over $22 billion to completely modernize), a smallsat constellation may only cost a few million, depending on the size and scope.[18] A larger example of a smallsat constellation is OneWeb's internet-providing system that consists of 648 satellites.[19] The cost of this constellation is in excess of $2 billion, which is amazing considering traditional government costs.[20] And OneWeb is not alone in its small satellite efforts in space.

In the past decade, over $2.5 billion has been invested in small satellites with a bulk of that in the last couple of years.[21] With this increase, comes increased risk. Due to conservative international deorbit guidelines, it may take as long as twenty-five years to deorbit. With timelines such as those, LEO will become increasingly crowded as the annual total of new on-orbit systems increase from current levels to several hundred or more annually.

The good news is companies appear to be sensitive to this scenario and how the public will respond. OneWeb in particular promises to exceed international standards, deorbiting no more than five years after disposal.[22] But even if this is the case, can the rudimentary pieces of our space traffic management system keep up with the demand of OneWeb and others? And what if these large corporations decide to relax their debris management goals to current international guidelines to meet company goals? Clearly, current debris guidelines have a flaw when put in context to increased smallsat use, especially if swarms of smallsat constellations prove to be a lucrative business model. The “big space” theory no longer applies and access to the LEO belt starts to become a more dangerous proposition. But what can be done to prevent collisions?

Mitigation strategies consist of active and passive techniques. Passive approaches might include orbital zone restrictions based on satellite capabilities and design standards (to mitigate issues from on-orbit collision or during re-entry). The value of the passive strategies are that they can establish characteristics for a particular orbital regime, which aids in the formation of right-sized active mitigation strategies as well as set baseline expectations for post-collision and re-entry scenarios. They also potentially segregate lesser advanced satellites from their more expensive orbital neighbors.

On the other hand, active mitigation strategies could include on-orbit propulsion capability, satellite tracking, and a robust space traffic management system. Active mitigation strategies cost more to employ, but they potentially enable longer and more complex missions. From the three provided active strategies, the enabling assumption is that the satellite's position can be found, either by ground-based systems or the satellite itself. The expectation of a LEO satellite to determine its own orbital position information, called an ephemeris, with suitable accuracy to aid in collision avoidance is reasonable. For GEO, this assumption is not as easy to make, however suitable ephemerides can be found.[23] Regardless, the literature is replete with Global Navigation Satellite System (GNSS) algorithms to achieve meter-level or better LEO positional accuracy, and as such, it is a trending, on-orbit technology.[24] In fact, the previously discussed OneWeb constellation touts a GNSS system as well as an electric thruster system to mitigate collisions.[25] These types of thrusters have been successfully used on orbit, to include for LEO collision avoidance.[26] However, satellite-based orbit determination systems and maneuvering capabilities add expense. If on the other hand a satellite is built such that it cannot identify its own position, its orbit must be actively determined from the ground. While normal telemetry and commanding provides suitable location accuracy for operations, collision avoidance requires higher accuracy. This can be achieved through advanced radar tracking or laser ranging. While actual capabilities are classified, open sources state that the future U.S. Air Force's Space Fence will be able to track five centimeter objects in space, and under the most favorable conditions, objects as small as one centimeter.[27] Laser ranging is even better, providing accuracy to the millimeter level; however, this network has limited availability.[28] Regardless, should an operator's space asset risk collision with orbital debris or another active satellite, it must be able to respond appropriately, either through on-board propulsion or some type of pre-collision safing action. Presumably, the need for such an action would be cued by a Space Traffic Management system. Of course, no official worldwide system is currently in place, so the satellite operator is left to provide this capability for themselves. While it is true that the U.S. Joint Space Operations Center provides collision avoidance services to the space community for free upon request, it is a resource intensive service and cannot be depended on by commercial systems. Normally, manned missions and government assets have priority. It is only a matter of time before the space community creates a Space Traffic Management system though. Similar to evolution of the Air Traffic Management system, pieces of a space version are slowly appearing, to include launch notification, the aforementioned collision warning services, and rudimentary national legislation and international agreements. The U.S. government should make efforts to influence the development of this system now since small efforts early on in any developing system generally yield large effects at maturity.

While Space Traffic Management may have been discussed informally over the years, it did not pick up much traction until 2006, after the IAA published a study on it entitled, *Cosmic Study on Space Traffic Management.*[29] They established a need for a system and concluded with a notional framework that covers all phases of space activities. Since their original study, many authors have further explored this concept.

Additionally, Gregory Orndorff, Bradley Boone and Marshall Kaplan of the Johns Hopkins University's Applied Physics Laboratory (JHU-APL) Space Department, along with Gary Harmon and Robert Lindberg (supporting contributors from Booz Allen Hamilton and the National Institute of Aerospace, respectively), coined the term Space Traffic Control, which they describe as the technical aspects of on-orbit traffic management system.[30] While both the IAA and JHU-APL papers are excellent and serve as a starting point for discussion, their concepts cannot be quickly applied.

This study advocates for smaller actions to secure short-term gains that will enable the larger Space Traffic Management System, which resonates with current change management thinking.[31] These perceived near-term gains would stem from heuristics that should appeal to most space stakeholders. For example, rather than try to implement a fully integrated warning and traffic management system, the key orbital regimes could be assigned restrictions based on on-board capability to meet more aggressive decay requirements. This would minimize clutter from decaying systems after their useful life. Further, the space community could implement a mix of voluntary best practices or mandatory requirements regarding community-wide notification prior to any orbital maneuver. This notification could require an associated pre- and post-ephemeris to some community-determined quality. The key point being the initiatives would fit within a crawl-walk-run model instead of a straight-to-system approach. The benefits of this method are gradual learning, incorporation of new technology as it emerges, and co-opting support of stakeholders as the genre matures.

Before making further recommendations, it is useful to survey the development of norms and international law within the air, sea, and space domains. Insights from these domains can inform the development of the nascent space domain. The ensuing examination is not to glean particular practices, but to identify previous trends that may inform the establishment of rules and norms in the space domain.

Maritime law emerged from land-based law of various nations and cultures as activity on the sea increased and as the need arose. According to Joseph Story, a former Associate Justice of the Supreme Court of the United States, it developed over time through "slow and cautious steps; by the gradual accumulations of distant times, and the contributions of various nations."[32] The earliest known maritime law focused on the conduct of sailors, rules of business, aspects of the vessels on the seas, and interactions between all of those involved in nautical matters.[33]

A key omission from this code is the claim to the sea itself. Through its absence, one may infer that the sea was assumed to be a domain common to all. This assertion is supported by the historical spread of this early maritime concept. For example, the Greeks and Romans never formally claimed legal ownership rights over the seas (with the exception of limited jurisdiction over immediate coastal areas for fisheries).[34] However, over the centuries, relative claims of sea sovereignty increased according to the power and influence of the maritime powers. After trans-oceanic discoveries in the 1500s, Spain and Portugal used the religious views of Pope Alexander VI on the oceans and trans-oceanic passageways as a basis to block trade to others.[35] Eventually in 1609, this led Hugo Grotius to make his famous argument that the seas were free to all since "it is so limitless that it cannot become a possession of any one, and because it is adapted for the use of all."[36] While countered by Wellwood, Selwood and others, Grotius's opinion became universally accepted by end of the 18th century, leaving only the question of where the high sea ended and where territorial waters began.[37] Opinions varied for decades, but ultimately stability was reached such that codification of international norms began. In that regard, efforts commenced in the 1880s by the Institut de Droit International (Institute of International Law) and continue to this day by the United Nations Convention on the Law of the Sea (UNCLOS).[38]

In parallel with the evolution of thought on sovereignty, maritime laws within territorial waters also evolved. One of the earliest known collections of laws was that of the Consolato del Mare, dating back to somewhere between the 10th and 14th centuries.[39] The topics covered included the ownership, building, and equipment of ships; the authorities and duties of the master and owner; the rights and duties of the mariners; the responsibilities in the shipment of goods; and wages.[40]

Due to this early bifurcation, today's laws pertaining to the sea can be divided into two general categories, Maritime (or Admiralty) Law and the Law of the Sea. Admiralty Law pertains to domestic law regarding navigation and shipping, to include maritime activity, insurance issues, piracy, and some aspects of international maritime laws.[41] On the other hand, the Law of the Sea covers the laws between nations on the sea beyond territorial waters and in sea lanes, much of which is codified in UNCLOS.[42] The Law of the Sea is essentially an amalgamation of international law, and as such, its sources include international treaties, customs and general principles of law.[43]

The laws and norms within the air domain took a similar path to that of the sea domain; it started with local and regional rules and norms, ultimately forging their code through continued, persistent international cooperation. Further, their development leveraged precedents set within the sea domain. Counterintuitively, air law's oldest roots lie in Roman law, dating back almost 2,000 years. The Romans may have been the first to address the sovereignty of the domain with their assertion of "Cuius est solum, eius est usque ad coelum" (who owns the land, owns even to the skies)."[44] This thought continues today, although there was a small departure from this idea in the 19th and early 20th century.

In 1901, Paul Fauchille and Ernest Nys formally claimed that no state had claim to the air except to their right of “droit de conservation” (right of self-preservation), using Grotius’s “freedom of the seas” as an inspiration.[45] And in 1902, they presented their “freedom of the air” concept to the Brussels Session of the Institut de Droit International.[46] They were opposed by John Westlake, a British lawyer, who argued for state sovereignty of the air, but his ideas were discarded in light of Fauchille and Nys.[47]

This was the first time a significant international agreement had been forged. Up to that time, laws and norms developed independently through state decree or regional agreement regarding safety, sovereignty, ruleset, and other aspects, depending on the application. For example, the first air law is commonly agreed to be the Parisian ordinance from 1784 requiring a permit for balloon flight over the city.[48] From an international perspective, the first diplomatic, aviation-related document was Bismark’s assertion to the French government during the Franco-German War that that “aeronauts overflying the territory occupied by the German troops would be treated as persons operating behind the battle lines.”[49]

As technology and use progressed, so did international cooperation. It took its largest step forward after the conclusion World War I. During the war, the Netherlands prohibited flight over its territory as did Switzerland. Also, Denmark, Sweden, Norway, Greece, Spain, Italy, Romania, Bulgaria and China protested any violation of their airspace.[50] By the end of World War I, it was evident that there was a near unanimous state opinion on the sovereignty of the airspace above their lands. Effectively, the idea of free skies had been eclipsed by the necessity of sovereignty, returning once again to the ancient Roman maxim.

At the First International Convention of Air Navigation in 1919, attended by thirty-eight states, this practice was codified within three key articles drafted and signed by the attendees, Articles 1, 2 and 15. Collectively, they stated that “every Power has complete and exclusive sovereignty over the airspace above its territory” (Article 1), where territory included “national territory,” “colonies” and “terrestrial water adjacent thereto” (Article 2). Further, a “state has the right to cross the air space of another” if it follows “the route fixed by the state over which the flight takes place,” effectively restricting the free air space concept to an a priori agreement with the underlying state.[51]

Similar to maritime domain development, divisions arose in the air domain between private and public aspects, as well as among those who saw the air domain as sovereign rather than free to all. In addition to sovereignty, the First International Convention of Air Navigation in 1919 also addressed registration of aircraft, certificates of airworthiness, and licensure of personnel, to name a few.[52] Six years later, the International Conference on Private Air Law established an advisory committee of experts to investigate the issues of damage liability, insurance, finances and registration. The committee’s purpose was to foster a more uniform set of laws and practices within the international domain, and to allow "complete sovereignty in all matters" to the states.[53]

In addition to international cooperation by states, industry also formed its own guiding bodies in the hopes to standardize operations. The International Air Traffic Association, an association of airline operators, was created in 1919 "with a view to cooperate to mutual advantage in preparing and organizing international aerial traffic."[54] This body grew over time, similar to the other consortiums, and numbered thirty participants by World War II.[55] From 1919 until the advent of World War II, there were three conventions on public air law and four on private air law, and the aviation industry was "organized and fast becoming the most legally regulated industry in the world."[56]

World War II provided a dramatic boost to the aviation industry, both to commerce and the underlying technology, and it drove an overwhelming international response to forge agreements. While territorial sovereignty was still an important contributor to these agreements, economics and transport were the driving forces. The Chicago Conference of 1944 attempted to address many of the concerns of the day, but it ultimately fell short as it pertains to economic considerations. These drove the transformation of the International Air Traffic Association into the International Air Transport Association, as well as the need for bi-lateral and multi-lateral agreements to secure details such as trade routes and carrier rates.[57] Bi-lateral agreements are the norm to this day, and they represent one of the major shortcomings of the Chicago Convention, making air transportation "more expensive and less convenient."[58] The Chicago Convention was very effective because it canonized much of the work done at the 1919 Paris Convention as well as established the concepts and general provisions for rules of the air, aircraft registration, airspace, and other aviation-related standards.[59] Its annexes contained suggested practices, rules and technical standards, but they did not require signature and, as such, were not binding.[60] While it has been amended over the past six decades, the convention is the guiding, international aviation agreement used today. In fact, the International Civil Aviation Organization that oversees international aviation cooperation was created by the Chicago Convention and it was the first organization of the United Nations to be established after World War II.[61]

In the space domain, most international cooperative efforts have centered on protecting access for all, preventing the claim of ownership by none, and keeping it free from weaponization. While bi- and multi-lateral space activity agreements exist, the four United Nations space treaties to which the U.S. is a signatory are the most relevant for this analysis. They are the *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies* (also known as the *Outer Space Treaty* (OST), ratified in 1967), the *Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space* (ratified in 1968), the Convention on International Liability for Damage Caused by Space Objects (ratified in 1972), and the Convention on Registration of Objects Launched into Outer Space (ratified in 1976).[62] Similar to that of the air and sea domain, they split along lines of sovereignty and more pragmatic matters, such as return of astronauts, response to accidents and liability.

The OST addresses the former and embodies the spirit of Grotius, declaring that outer space exploration “shall be carried out for the benefit and in the interests of all countries and shall be the province of all mankind.”[63] Other key highlights include “outer space is not subject to national appropriation by claim of sovereignty," "states shall not place nuclear…or other weapons of mass destruction in orbit or on celestial bodies," and the "moon and other celestial bodies shall be used…for peaceful purposes."[64] Noticeably absent from these treaties, as well as most other agreements, are mentions of best practices for operation or design that were seen in both the air and sea domains. Considering the youthfulness and historical difficulty in becoming a space-faring nation, this is understandable. And over the last couple of decades, this has slowly begun to change; space debris is one such example.

While avoiding "harmful contamination" of outer space was mentioned in Article IX of the OST, the international community did not converge on specifics until acceptance of the United Nations Inter-Agency Space Debris Coordination Committee (IADC) guidelines in 2007.[65] These guidelines were in response to the "increasing risk to space vehicles" due to man-made, orbital debris, and while they addressed all of Earth-orbiting space, they paid particular attention to the preservation of two key orbital regimes, GEO and LEO.[66] They emphasize limiting debris release, minimizing potential for break-up on orbit, planning for disposal and preventing orbital collisions by "introducing space debris mitigation measures into the spacecraft or orbital stage's lifecycle, from the mission requirement analysis and definition phases."[67] This language infers not only implications on the design of the spacecraft, but also on their operation.

Another example of international cooperation is the *Conduct for Outer Space Activities* that the European Union drafted in 2008.[68] While the U.S. never signed the code, it has endorsed the creation of a non-binding *International Code of Conduct for Outer Space Activities*.[69] These recent cooperative efforts indicate that there is an appetite to establish norms for space, similarly seen during the maturation of the air and sea domains. Since advances in technology have made access to space more than a nation state capability, this is excellent timing as nation states may now need to regulate commercial space activity more closely, as was similarly done on the sea and in the air.

If private law works closely with that of international law and norms, the synergy could be beneficial to both commerce as well as the preservation of key orbital regimes. The U.S. should actively be involved, and lead where appropriate, in order to shape the eventual outcomes from these collaborations. Regardless, the key takeaways from re-examination of international law and norms within the maritime, air and space domains are:

- International cooperation in the global commons (air, sea and space) is unavoidable due to the nature of the domains and the inability to persistently occupy it.

- Out of necessity, international cooperation increases over time as technology and use increases.

- International laws and best practices for construction of sea vessels and aircraft are mature, while those for outer space are emerging.

- Nations states covet freedom of operation in all domains. As such, claims of sovereignty are generally limited to the least possible footprint, up to the point of self-preservation by the state. In this regard, air is the most restricted.

- Within each domain, private and international law developed independently due to lack of ability to enforce law at the international level. However, both sets of laws generally complement each other, with international agreements encouraging the commonality between national and international laws.

The previous list provides a good starting point when considering a way forward for both domestic and international laws and norms regarding small satellite operation and development. In order to translate them into specific recommendations, they must be juxtaposed with what is technologically possible. For example, maneuvering in space is costly as satellites are not built to be refueled. However, if maneuvering capability could be increased without significant cost, the international community could leverage that ability for de-orbit guidelines or on-orbit collision avoidance.

The U.S. government should hold a space summit with industry to discuss candidate items for inclusion in domestic policy and a set of best practices for smallsats. An initial policy need not be overly complicated or even comprehensive. Based on this paper's discussion of current technical capabilities and requirements to minimize orbital collisions, a primary target could be the LEO regime. In order to decrease the likelihood of collision, LEO could be broken up into orbital zones based on satellite capability and assigned more conservative timelines to de-orbit than international standards.

Also for consideration as part of this summit, the region between 400 to 2,000 kilometers could be reserved for satellites with onboard orbit determination and maneuver capabilities, leaving the lower region for the those satellites without them. Since most satellites below 400 kilometers will naturally de-orbit within a few years, this would allow the lower section of LEO to self-cleanse. The rest of LEO above 400 kilometers could require on-board orbit determination capabilities as well as propulsive capability for maneuver and end of life operations. Additionally, future satellites that are able to maneuver and/or provide positional information could be held to a five year de-orbit rule, which starts after their useful life has ended. If they do not have those capabilities, the five-year clock starts upon achieving orbit. Effectively, this policy would imply that the orbital region used by the satellite must be returned for future use.

Further, the policy could address construction techniques and materials used to encourage complete or nearly complete disintegration upon de-orbiting, if a controlled de-orbit was not possible. Once again, the policy does not have to be overly prescriptive or comprehensive; it can start with guidance on materials that are known to persist after re-entry due to high melting points. While this idea may upset some in industry, this level of regulation it is not much different than the restrictions placed on current sea and air systems. In fact, it is less stringent.

Finally, the community must discuss standardizing operating processes and integrating efforts across the space enterprise. This last initiative would be the start of unifying all stakeholders toward a long-term goal of creating a space traffic management system. An example of this could be pre- and post-maneuver notifications and rudimentary collision avoidance operations.

The U.S. government can lead the international effort to maintain, or improve, the quality of key orbital regimes. By following the precedent already set by the air and sea domains, as well as capitalizing on the momentum already started in the space domain, U.S. policymakers can push for smart regulations and international engagement. Several international treaties are already in place, which can serve as a foundation for future codification through either additional treaties or non-binding, best practices for small satellite design and operation. As these norms solidify and technology advances, nations can pass regulations and forge international agreements to further strengthen them. It is in the U.S. government's best interest to actively participate in setting conditions for any eventual Space Traffic Management architecture though smart domestic policy and international advocacy. The following items may serve as a good starting point:

- Bifurcate the LEO region into at least two regions: 1) a lower region that self-cleanses every few years and is populated by small, non-maneuverable small satellites which cannot self-locate, and 2) an upper region that is home to more advanced satellites that can maneuver and determine their own orbital parameters.

- Mandate that all satellites in the LEO region vacate their orbit either through natural decay or through active measures at the end of their useful life. In either case, they must re-enter the earth's atmosphere within a period of time shorter than current international timelines (for example, five years).

- Mandate that small satellites disintegrate during re-entry, or that the likelihood of any significant issue upon impact is less than a community agreed upon percentage.

- Establish an international group, potentially under the umbrella of the United Nations, to develop a future space traffic management system.

Some may argue that space has historically been lightly regulated and should stay that way, but inspection of the historical record of the air and sea domains show that international agreements and norms are not only inevitable, they are necessary. However, based on current policy initiatives, this is years, if not decades, away, and smallsat constellations are already outpacing current norms and regulations. Despite these exigencies, any further efforts to regulate and foster norms must proceed with caution so the U.S. retains freedom of action in space. In concert with any enumeration of best practices or establishment of domestic policy, the U.S. government should perform a cost benefit analysis to explore the tradeoffs between regulation of space and freedom of action. These ideas are just a few items to explore while building a viable Space Traffic Management architecture.

To aid in this policy development, the space community must investigate best practices for smallsat construction and operations. Additionally, it should discuss what partitions within the LEO belt make sense from a current and near-term technology perspective. The U.S. should engage international partners as well as domestic commercial stakeholders to investigate common ground regarding acceptable LEO orbital lifespan and de-orbit timeline norms as well as rudimentary operational best practices. The time for action is now. While there is no impending crisis, there is arguably not much room for delay as the smallsat industry is setting their own norms in the absence of any guidance. The U.S. government can either let them act, potentially creating a fait accompli in space for generations to come, or lead the way.

Endnotes

[1] Jeff Foust, "Industry Remains Optimistic About Continued Growth of Cubesats," *Spacenews Online*, August 18, 2016, http://spacenews.com/industry-remains-optimistic-about-continued-growth-of-cubesats/ (accessed December 20, 2016).; California Polytechnic State University, *CubeSat Design Specification*, Rev 13 (San Luis Obispo, CA: California Polytechnic State University, April 6, 2015), 1, https://static1.squarespace.com/static/5418c831e4b0fa4ecac1bacd/t/56e9b62337013b6c063a655a/1458157095454/cds_rev13_final2.pdf (accessed January 25, 2017).

[2] Roger C. Thompson, "A Space Debris Primer," *Crosslink Magazine Online*, December 10, 2015, http://www.aerospace.org/crosslinkmag/fall-2015/a-space-debris-primer/ (accessed December 20, 2016); Mike Gruss, "Lockheed Martin Lands $914M Space Fence Contract," *Spacenews Online*, June 2, 2014, http://spacenews.com/40776lockheed-martin-lands-914m-space-fence-contract/ (accessed February 27, 2017); Ben Greene, *Laser Tracking of Space Debris* (Queanbeyan, Australia: Electro Optic Systems Pty Limited, n.d.), 2, http://cddis.nasa.gov/lw13/docs/papers/adv_greene_1m.pdf (accessed November 2, 2016).

[3] Barack H. Obama, *National Security Strategy* (Washington, DC: The White House, February 2015), 2.

[4] Executive Agent for Space Staff, *Smallsat Challenges and Proposed Solutions,* White Paper (Washington, DC: U.S. Department of Defense, n.d.), 9; United Nations Committee on the Peaceful Uses of Outer Space, *Report of the Committee on the Peaceful Uses of Outer Space,* Supplement No. 20 (New York: United Nations, 2007), 47, http://www.oosa.unvienna.org/pdf/gadocs/A_62_20E.pdf (accessed February 27, 2017).

[5] Frank A. Rose, "Protecting Space for Future Generations is in the Vital Interests of the Global Community," April 2, 2013, linked from *the Mission of the United States Geneva Home Page*, https://geneva.usmission.gov/2013/04/02/protecting-space-for-future-generations-is-in-the-vital-interests-of-the-global-community/ (accessed November 30, 2016).

[6] Frank A. Rose, “Pursuing Space TCBMs for Long-Term Sustainability and Security,” February 28, 2013, linked from the *U.S. Department of State Home Page* at “Diplomacy in Action,” https://www.hsdl.org/?view&did=735060 (accessed November 30, 2016).

[7] International Academy of Astronautics, *Cosmic Study on Space Traffic Management* (Paris, France: International Academy of Astronautics, 2006), 10-16, http://iaaweb.org/iaa/Studies/spacetraffic.pdf (accessed December 19, 2016); Gregory Orndorff et al., *Space Traffic Control: Technology Thoughts to Catalyze a Future Architecture* (Pasadena, CA: AIAA SPACE 2009 Conference & Exposition, September 14-17, 2009), 6485.

[8] Steering Group and Working Group 4, *IADC Space Debris Mitigation Guidelines* (Houston, TX: Inter-Agency Space Debris Coordination Committee, September 2007), 6, http://www.iadc-online.org/Documents/IADC-2002-01%2C%20IADC%20Space%20Debris%20Guidelines%2C%20Revision%201.pdf (accessed February 27, 2017).

[9] Ibid.

[10] NASA, “Frequently Asked Questions,” linked from the *NASA Home Page* at “Orbital Debris Program Office,” https://www.orbitaldebris.jsc.nasa.gov/faq.html#3 (accessed December 19, 2016).

[11] Steven A. Hildreth and Allison Arnold, *Threats to U.S. National Security Interests in Space: Orbital Debris Mitigation and Removal* (Washington, DC: Congressional Research Service, January 8, 2014), 5; Donald J. Kessler and Burton G. Cour-Palais, "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt," *Journal of Geophysical Research* 83, no. A6 (June 1, 1978): 2637–2646.

[12] Steering Group and Working Group 4, *IADC Space Debris Mitigation Guidelines,* 5.

[13] Ibid., 4.

[14] For background on U.S. Government orbital debris mitigation practices, see NASA Orbital Debris Program Office, *U.S. Government Orbital Debris Mitigation Standard Practices* (Washington, DC: NASA, n.d.), https://www.orbitaldebris.jsc.nasa.gov/library/USG_OD_Standard_Practices.pdf (accessed February 27, 2017).

[15] Michael J. Listener, “International Space Law and Commercial Space Activities: The Rules do Apply,” *The Space Review Online*, June 3, 2013, http://www.thespacereview.com/article/2305/1 (accessed December 19, 2016).

[16] Wiley J. Larson and James R. Wertz, *Space Mission Analysis and Design,* 3rd ed. (Torrance, CA: Microcosm Press, 1999): 802.

[17] *SpaceX Capabilities and Services Home Page*, http://www.spacex.com/about/capabilities (accessed December 19, 2016).

[18] Congressional Budget Office, *The Global Positioning System for Military Users: Current Modernization Plans and Alternatives* (Washington, DC: Congressional Budget Office, October

28, 2012), XI, https://www.cbo.gov/sites/default/files/112th-congress-2011-2012/reports/10-28-GPS.pdf (accessed December 20, 2016).

[19] *OneWeb Home Page*, http://oneweb.world/ (accessed December 19, 2016).

[20] Peter B. de Selding, "Virgin, Qualcomm Invest in OneWeb Satellite Internet," *Spacenews Online*, January 15, 2015, http://spacenews.com/virgin-qualcomm-invest-in-global-satellite-internet-plan/ (accessed December 20, 2016).

[21] Clay Dillow, "Here's why Small Satellites are so big right now," *Fortune Online*, August 4, 2015, http://fortune.com/2015/08/04/small-satellites-newspace/ (accessed December 20, 2016).

[22] Peter B. de Selding, "OneWeb Pledges Vigilance on Orbital Debris Issue," *Spacenews Online,* October 15, 2015, http://spacenews.com/oneweb-pledges-vigilance-on-orbital-debris-issue/ (accessed December 19, 2016).

[23] Li Qiao et al., *A Multiple GNSS-based Orbit Determination Algorithm for Geostationary Satellites* (Queensland, Australia: International Global Navigation Satellite Systems Society Symposium, December 1-3, 2009), 1-2.

[24] Oliver Montenbruck and Pere Ramos-Bosch, "Precision Real-time Navigation of LEO Satellites Using Global Positioning System Measurements," *GPS Solutions* 12, no. 3 (July 2008): 187; Oliver Montenbruck et al., "Reduced Dynamic Orbit Determination Using GPS Code and Carrier Measurements," *Aerospace Science and Technology* 9, no. 3 (April 2005): 261.

[25] *OneWeb Solution Page*, http://oneweb.world/#solution (accessed December 19, 2016); Amy Svitak, "SpaceX, OneWeb Unveil Rival Broadband Constellation Plans," *Aviation Week & Space Technology Online*, January 21, 2015, http://aviationweek.com/space/spacex-oneweb-unveil-rival-broadband-constellation-plans (accessed December 19, 2016).

[26] Annalisa Mazzoleni et al., *Collision Avoidance Operations of DEIMOS-1 and DEIMOS-2 Mission* (Daejeon, Korea: 14th International Conference on Space Operations, May 16-20, 2016), 2-4.

[27] Mike Gruss, "More Satellite Collision Warnings to Come with Space Fence Data," *SpaceNews Online,* September 22, 2016, http://spacenews.com/more-satellite-collision-warnings-to-come-with-space-fence-data/ (accessed December 19, 2016).

[28] *International Laser Ranging Service Page*, https://ilrs.cddis.eosdis.nasa.gov/index.html (accessed December 19, 2016).

[29] International Academy of Astronautics, *Cosmic Study on Space Traffic Management* (Paris, France: International Academy of Astronautics, 2006), 10-16, http://iaaweb.org/iaa/Studies/spacetraffic.pdf (accessed December 19, 2016).

[30] Orndorff, *Space Traffic Control*.

[31] For more information on leading change management theory, see John P. Kotter, *Leading Change* (Boston: Harvard Business Press, 1996).

[32] William W. Story, ed., *Miscellaneous Writings of Joseph Story* (Boston: Charles C. Little and James Brown, 1852), 96.

[33] Percy Thomas Fenn Jr, “Justinian and the Freedom of the Seas,” *American Journal of International Law* 19 (1925): 717.

[34] James Kraska, *Maritime Power and the Law of the Sea* (Oxford: Oxford University Press, Inc, 2011), 34; Fenn, “Justinian and the Freedom of the Seas,” 717-718.

[35] B. P. O’Connell, *The International Law of the Sea*, Volume I (Oxford: Clarendon Press, 1982), 2.

[36] Hugo Grotius, *Mare Liberum* (Seattle, WA: CreateSpace Independent Publisher Platform, 2012), 30, Kindle e-book.

[37] Colin Mackenzie, ed., *An Abridgement of all Sea-Lawes,* Version 1.02 (Scotland: Gray’s Inn, Barrister Advocate, 2012), 61-72, http://maritimelawdigital.com/uploads/PDFs/Welwod-Sea_Laws.pdf (accessed February 28, 2017); John Selden, *Mare Clausum* (London: Excudebat Will. Stanesbeius, 1635); O’Connell, *The International Law of the Sea,* Volume I, 10-13.

[38] O’Connell, *The International Law of the Sea*, 20-28.

[39] Joseph Story, *Miscellaneous Writings of Joseph Story* (Boston: Charles C. Little and James Brown, 1852), 97-98.

[40] Story, *Miscellaneous Writings of Joseph Story*, 98.

[41] *Legal Information Institute Admiralty Law Overview Home Page*, https://www.law.cornell.edu/wex/admiralty (accessed November 15, 2016).

[42] *The Encyclopedia Britannica Law of the Sea Home Page*, https://www.britannica.com/topic/Law-of-the-Sea (accessed on November 15, 2016).

[43] Michael John Garcia, *International Law and Agreements: Their Effect upon US Law* (Washington, DC: Congressional Research Service, February 18, 2015), 1, http://freerepublic.com/focus/f-news/3302662/posts (accessed 15 November 2016).

[44] John Cobb Cooper, “Roman Law and the Maxim "Cuius et solum" in International Air Law,” *McGill Law Journal* 1 (1952): 25; Peter H. Sand, Jorge de Souse Freitas, and Geoffrey N. Pratt, “An Historical Survey of International Air Law Before the Second World War,” *McGill Law Journal Online* 7, no. 1, 24, http://lawjournal.mcgill.ca/userfiles/other/6355045-sand.pdf (accessed November 19, 2016).

[45] Raymond W. Young, *The Aerial Inspection Plan and Air Space Sovereignty* (Washington, DC: United States Government Printing Office, 1959), 108; Sheila F. Macbrayne, “The Right of Innocent Passage,” *McGill Law Journal* 1 (1952): 272.

[46] Sand, Freitas, and Pratt, “An Historical Survey of International Air Law,” 28.

[47] Raymond W. Young, *The Aerial Inspection Plan and Air Space Sovereignty* (Washington, DC: United States Government Printing Office, 1959), 108.

[48] Sand, Freitas, and Pratt, "An Historical Survey of International Air Law," 25.

[49] International Law Association, *28th Conference Report* (London: International Law Association, October 1913), 533. Sand, Freitas, and Pratt, "An Historical Survey of International Air Law," 29.

[50] Sand, Freitas, and Pratt, "An Historical Survey of International Air Law," 32.

[51] Ibid., 33-34.

[52] Ibid., 34.

[53] Ibid., 36.

[54] Ibid., 42.

[55] Ibid.

[56] Ibid., 24-42.

[57] Ibid., 126-139.

[58] Ibid., 139.

[59] International Civil Aviation Organization, *Convention on Civil Aviation* (Chicago: International Civil Aviation Organization, 1944).

[60] Sand, Freitas, and Pratt, "An Historical Survey of International Air Law," 129.

[61] Ibid., 130.

[62] For background on outer-space related treaties, see United Nations, *Treaties and Principles on Outer Space* (New York: United Nations, 2002), http://www.unoosa.org/pdf/publications/STSPACE11E.pdf, (accessed on November 28, 2016)

[63] United Nations, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies* (New York: United Nations, 1967), http://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html (accessed March 1, 2017).

[64] Ibid.

[65] Ibid.; United Nations Committee on the Peaceful Uses of Outer Space, *Report of the Committee.*

[66] Inter-Agency Space Debris Coordination Committee, *Report of the Inter-Agency Space Debris Coordination Committee Activities on IADC Space Debris Mitigation Guidelines & Supporting Document* (Inter-Agency Space Debris Coordination Committee), 2, 10, http://www.iadc-online.org/Documents/42nd_UN_COPUOS_STSC.pdf (accessed November 28, 2016); Steering Group and Working Group 4, *IADC Space Debris Mitigation Guidelines.*

[67] Steering Group and Working Group 4, *IADC Space Debris Mitigation Guidelines*, 5-7.

[68] Micah Zenko, "A Code of Conduct for Outer Space, Policy Innovation Memorandum No. 10," November 2011, linked from the *Council on Foreign Relations Home Page* at "Publications," http://www.cfr.org/space/code-conduct-outer-space/p26556 (accessed on November 30, 2016).

[69] U.S. Department of State, *An International Code of Conduct for Outer Space Activities: Strengthening Long-Term Sustainability, Stability, Safety, and Security in Space* (Washington, DC: U.S. Department of State, n.d.), https://state.gov/documents/organization/181208.pdf (accessed March 1, 2016).