Smallsats and Mega-Constellations for U.S. National Security: Some Legal Aspects

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ABSTRACT

The smallsat and mega-constellation industry is poised to place more smallsats (those with a mass less than 600 kg) in space in the next decade than all the satellites launched since the beginning of the space race. As advances in technology have made the use of space more feasible and economical, the number of smallsats in outer space has increased at an exponential rate. Technology miniaturization has also affected satellite technology and has allowed for the space industry to use smallsats with capabilities that only a few years ago would have required much larger satellites. These smallsats make possible the recent launch and proposal for mega-constellations (networks of over 100 satellites operating together) in Low Earth Orbit (LEO). The United States National Security Space Strategy recognizes that space operations are of vital importance to US national security For the United States Department of Defense, and militaries across the globe, these proposed mega-constellations provide both the potential for un-matched advantages over current architecture, but also numerous potential risks to national security.

This thesis examines publicly available, unclassified documents, news articles, journals, publications, governmental reports, international treaties, laws and regulations, and other information to assess the current state of the smallsat and mega-constellation industry, as well as the trends going into the future. Using this information, compared with U.S. space policy and legal documents and the known threats to space systems, this thesis then considers how an increase in smallsats and mega-constellations benefits and threatens the United States National Security and whether current regulations are sufficient to address these changes. Some of the legal aspects discussed relate to space activities that include space situational awareness; cyber-security, intelligence, reconnaissance, and surveillance, on-orbit spying, radio interference, space debris, anti-satellite weapons, and space mines, to name a few.

RESUME

L'industrie des petits satellites et des méga-constellations est sur le point de placer plus de petits satellites (ceux dont la masse est inférieure à 600 kg) en orbite au courant de la prochaine décennie que tous les autres satellites lancés depuis le début de la course à l'espace. Les progrès technologiques ayant rendu l’utilisation de l’espace plus viable et plus rentable, le nombre de petits satellites en orbite a augmenté à un rythme exponentiel. La miniaturisation de la technologie a également profité à la technologie des satellites et a permis à l'industrie spatiale d'utiliser des petits satellites avec des capacités que seuls des satellites beaucoup plus gros avaient il y a seulement quelques années de ça. Ces petits satellites ont rendu possible le lancement récent et le projet de méga-constellations (des réseaux de plus de 100 satellites fonctionnant ensemble) en orbite terrestre basse (OTB). La stratégie spatiale de sécurité nationale des États-Unis reconnaît que les opérations spatiales sont d'une importance vitale pour la sécurité nationale des États-Unis. Pour le département de la Défense des États-Unis et pour les forces militaires partout dans le monde, ces projets de méga-constellations ont le potentiel de donner un avantage inégalé par rapport aux structures actuelles, mais ils posent aussi de nombreux risques potentiels pour la sécurité nationale.

Cette thèse examine les documents non classés, les articles de presse, les revues, les publications, les rapports gouvernementaux et d'autres informations disponibles pour évaluer la situation actuelle de l'industrie des petits satellites et des méga-constellations, ainsi que les tendances à venir. En utilisant ces informations comparativement à la politique spatiale et aux documents juridiques américains, ainsi qu'aux menaces connues pour les systèmes spatiaux, cet article examine ensuite comment une augmentation des petits satellites et des méga-

constellations profite et menace la sécurité nationale des États-Unis. Les questions juridiques abordées comprennent la connaissance de la situation spatiale, la cybersécurité, l'obtention de renseignements, la reconnaissance et la surveillance, l'espionnage en orbite, les interférences radio, les débris spatiaux, les armes antisatellites et les mines spatiales, pour n'en nommer que quelques-uns.

ACRONYMS AND ABBREVIATIONS

ADR – Active Debris Removal
ASAT – Antisatellite Weapon
COMSATCOM – Commercial Satellite Communications
COTS – Commercial Off The Shelf
DARPA – Defense Advanced Research Projects Agency
DoD – Department of Defense
DoS – Department of State
DSS – Defense Space Strategy
FAA – Federal Aviation Administration
FCC – Federal Communications Commission
GEO – Geosynchronous Orbit
GPS – Global Positioning System
GSD – Ground Sampling Distance
HEO – Highly Elliptical Orbit
IADC – Inter-Agency Space Debris Coordination Committee
ICBM – Intercontinental Ballistic Missile
IoT – Internet of Things
ISR – Intelligence, Surveillance, and Reconnaissance
ITU – International Telecommunications Union
LEO – Low Earth Orbit
MEO – Medium Earth Orbit
NASA – National Aeronautics and Space Administration
NATO – North Atlantic Treaty Organization
NDSA – National Defense Space Architecture
NOAA – National Oceanic and Atmospheric Administration
NPRM – Notice of Proposed Rulemaking
NSSS – National Security Space Strategy
ODMSP – Orbital Debris Mitigation Standard Practices
OST – Outer Space Treaty
PNT – Position, Navigation & Timing
RPO – Rendezvous and Proximity Operations
SATCOM – Satellite Communications
SBIR – Space Based Infrared Surveillance
SDA – Space Development Agency
SSA – Space Situational Awareness
SSN – Space Surveillance Network
STM – Space Traffic Management
UNCOPUOS – United Nations Committee on the Peaceful Use of Outer Space
UTC – Universal Coordinated Time
WMD – Weapons of Mass Destruction

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Introduction

We simply cannot afford to defend against all possible threats. We must know accurately where the threat is coming from and concentrate our resources in that direction. – *Edwin (Din) Land, Co-Founder of Polaroid Corporation and Proponent of U.S. Government Satellite Programs*[1]

The mega-constellation boom has begun. Companies and governments are in the process of launching mega-constellations: hundreds to thousands of satellites which network together to provide a service. While we are at the beginning of the mega-constellation movement, we are on the cusp of an exponential growth in the number of satellites in outer space. Current proposals will see the number of satellites around earth grow by half just in the year 2020 and up to 10 fold or more in the coming decade.[2] Between just the main two commercial mega-constellation proposals, more than 90,000 satellites will be added to space in the coming years.[3] These two mega-constellations alone have the potential of launching nearly ten-times the total number of satellites ever launched in the history of man-kind.[4]

These mega-constellations are made possible by significant advances in satellite and space industry technology that are making access to space more feasible and economical. This transformation is apparent across space sectors and is being driven

[1] Albert D Wheelon, "Lifting the Veil on CORONA" (1995) 11:4 Space Policy 249–260, online: <www.sciencedirect.com/science/article/pii/0265964695000247>.

[2] *See* "OneWeb Seeks to Increase Satellite Constellation Up to 48,000 Satellites, Bringing Maximum Flexibility to Meet Future Growth and Demand" (27 May 2020), online: *OneWeb* <www.oneweb.world/media-center/oneweb-seeks-to-increase-satellite-constellation-up-to-48000-satellites-bringing-maximum-flexibility-to-meet-future-growth-and-demand>; Mark Harris, "SpaceX Plans to Put More Than 40,000 Satellites in Space", *New Scientist* (17 October 2019), online: <www.newscientist.com/article/2220346-spacex-plans-to-put-more-than-40000-satellites-in-space/amp/> at 40; Michael Sheetz & Magdalena Petrova, "Why in the Next Decade Companies Will Launch Thousands More Satellites Than in All of History" (15 December 2019), online: *CNBC* <www.cnbc.com/2019/12/14/spacex-oneweb-and-amazon-to-launch-thousands-more-satellites-in-2020s.html>.

[3] *See* Harris, "40,000 Satellites", *supra* note 2; "48,000 for OneWeb", *supra* note 2 at 00.

[4] *See* Sheetz & Petrova, "Next Decade", *supra* note 2.

significantly by commercial entities. This is a significant shift from the early days of space exploration which was managed almost exclusively by governments.[5]

There are currently approximately 2,666 operational satellites circling the earth.[6] Much of the western world is reliant on space-based capabilities that are integrated into power grids, shipping and delivery services, car navigation, banking, and television, to name a few. Even a morning bowl of cereal is connected to space through advanced agricultural techniques informing farmers about crop management for higher yields.[7] Nearly all satellite-based capabilities were originally developed for a national security purpose.

The role of space activities in national security is expanding and also becoming critical.[8] The U.S. military uses space systems for communications, missile warning, weather predication and much more. Additionally, the commercialization of smallsats and constellations are posing new regulatory challenges and risks to national security. While there are economic and political reasons for encouraging and facilitating the private space-sector mega-constellations, the resulting threats to U.S. national security necessitate some mechanisms to protect it. While technical solutions are being sought and adopted, they are not sufficient. Thus, regulatory means are also necessary. The U.S. has started slowly adapting exiting law and adopting new regulatory steps to address the

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[5] *See* Bhavya Lal et al, *Global Trends in Small Satellites* (IDA Science & Technology Policy Institute, 2017), online: <www.ida.org/-/media/feature/publications/g/gl/global-trends-in-small-satellites/p-8638.ashx> at 1–1.
[6] *April 2020 Satellite Database* www.ucsusa.org (Cambridge, Massachusetts: Union of Concerned Scientists, 2020), online: <www.ucsusa.org/resources/satellite-database>.
[7] "Rural Broadband" (18 May 2020), online: *American Farm Bureau Federation* <www.fb.org/issues/infrastructure/broadband/>.
[8] *See 2017 National Security Strategy of the United States* (Washington D.C.: The White House, 2017), online: <www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf>; *2020 Defense Space Strategy Summary* (Washington, D.C.: Office of the Secretary of Defense, 2020), online: <media.defense.gov/2020/Jun/17/2002317391/-1/-1/1/2020_DEFENSE_SPACE_STRATEGY_SUMMARY.PDF>.

mega-constellation movement. Are they sufficient? This thesis attempts to address this question.

To answer this question, it is imperative to fully understand the nature of space activities (systems), national security operations and the relevant technologies so that appropriateness of the regulatory steps can be completely assessed. In other words, the proper diagnosis of the risks to national security requires proper understanding of the space systems and technologies. Therefore, this thesis makes significant effort in this regard. This is an important contribution of this thesis as very little, if any, such understanding is expressed in space law literature. As the issue of risks posed by smallsats and constellations to national security started emerging only recently, the level and extent of regulatory steps in the US are limited. Therefore, the thesis attempts to only discuss those laws and regulations that have direct and immediate relevance to U.S. national security and is not a comprehensive and thorough analysis of all the legal aspects of this subject. That would require a much more complex study than an LL.M. thesis of limited length.

To this end, Part I of this thesis will define smallsats and mega-constellations, as well as the new capabilities and trends they support, along with a synopsis of several of the major mega-constellation proposals. Part II addresses the importance of space to U.S. national security, to include the effects of mega-constellations and identification of potential legal issues. In Part III, specific legal effects of mega-constellations will be delineated and reviewed.

METHODOLOGY: This thesis examines publicly available, unclassified documents, news articles, journals, publications, governmental reports, international treaties, laws and regulations and other information to assess the current state of the smallsat and mega-constellation industry, as well as the trends going into the future. Using this information, compared with U.S. space policy and legal documents and the known threats to space systems, this thesis then considers how an increase in smallsats and mega-constellations benefits and threatens the United States National Security.

As this thesis addressed many effects of mega-constellations as applied to national security, there are many works that I reference throughout that are deeper examinations of single aspects covered in this thesis. For example, there are many works currently available that focus on the impacts of mega-constellations on space debris mitigation, space situational awareness, and space traffic management.[9] These works generally address the main issue but do not go so far as to analyze the impacts of these issues on U.S. national security. Other sub-issues, however, are already specifically addressed by other authors. These include the application of the law of armed conflict to outer space and anti-satellite weapon operations.

At the beginning of my research, the existing literature on the full breadth of this topic was scarce. In March of 2020, an article in the journal Joint Force Quarterly published "*Proliferated Commercial Satellite Constellations: Implications for National Security.*"[10] While this work discussed many of the capabilities and implications of mega-constellations on national security discussed in this thesis, this work considers more capabilities of smallsats, more effects on national security, and more legal aspects

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[9] *See e.g. Mitigation of Orbital Space Debris in the New Space Age Report and Order and Further Notice of Proposed Rulemaking* (Washington, D.C.: Federal Communications Commission, 2020), online: <docs.fcc.gov/public/attachments/FCC-20-54A1.pdf>.
[10] Matthew A Hallex & Travis S Cottom, "Proliferated Commercial Satellite Constellations: Implications for National Security" (2020) 97:2nd Quarter 2020 Joint Force Quarterly 20–29, online: <ndupress.ndu.edu/Media/News/News-Article-View/Article/2106495/proliferated-commercial-satellite-constellations-implications-for-national-secu/>.

than this other work. Similarly, a chapter on “Small Satellite Constellations: National Security Implications” is included in the *Handbook of Small Satellites*.[11] Once again, that work is not as thorough as the current thesis which brings specific considerations of relevant U.S. laws and implications for U.S. National Security. This thesis seeks to add a specific contribution to this field of research through a thorough capture and analysis of the legal issues caused by mega-constellations on U.S. national security.

[11] Mark Roberts, Christoph Beischl & Sa’id Mosteshar, “Small Satellite Constellations: National Security Implications” in *Handbook of Small Satellites* (Cham: Springer, 2020) 1, online: <link.springer.com/referenceworkentry/10.1007/978-3-030-20707-6_52-1>.

Part I: Small-Satellites and Mega-Constellations Background

> The same advances in electronics and communications technologies that enabled smartphones and put significant computing power in the palm of everyone's hand are allowing scientists and engineers to design smallsats and coordinated networks of multiple smallsats (known as "smallsat constellations") that deliver novel and diverse capabilities from orbit . . . bringing "Moore's Law" to space.
> - P*resident Obama White House Press Release on* Harnessing the Small Satellite Revolution.[12]

"One of the key trends over the past half a century has been that technology is getting smaller, faster, cheaper, and more powerful every day."[13] The early computers that used to fill entire rooms and warehouses had the same computing power of modern-day musical greeting cards.[14] This miniaturization of computing power has been commonly known as "Moore's Law" based upon the 1965 observation of Gordon Moore, the co-founder of Intel, that the number of transistors in a dense integrated circuit will double approximately every two years.[15] While "Moore's Law" is not a scientific certainty, the observation has set the pace for innovation and development of technology for over 50 years.[16] The same miniaturization of computing power which has allowed us to all carry cellphones with more computing power than desktop computers of decades past, has allowed the satellite industry to replace a single satellite the size of a school bus with a group of satellites the size of shoe boxes to provide the same or improved capabilities at reduce cost: in other words, mega-constellations of smallsats.[17]

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[12] "Harnessing the Small Satellite Revolution to Promote Innovation and Entrepreneurship in Space" (21 October 2016), online: *whitehouse.gov* <https://obamawhitehouse.archives.gov/the-press-office/2016/10/21/harnessing-small-satellite-revolution-promote-innovation-and>.

[13] Dushantha Nalin K Jayakody et al, *Wireless Information and Power Transfer: A New Paradigm for Green Communications* (Springer, 2017) at 156, Google-Books-ID: gb0tDwAAQBAJ.

[14] *See* i*bid*. For the 1995 celebration of the 50th anniversary of the ENIAC computer, the room-sized computer was reimplemented using modern integrated circuit technology into a single chip that could fit in the palm of your hand. Computer History Museum, "ENIAC on a chip - CHM Revolution", online: *Computer History Museum* <www.computerhistory.org/revolution/birth-of-the-computer/4/78/327>.

[15] *See* Intel Corporation, "Over 50 Years of Moore's Law", online: *Intel* <www.intel.com/content/www/ca/en/silicon-innovations/moores-law-technology.html>.

[16] *See ibid*.

[17] *See* Alyssa K King, *Small Satellite Boom Poses Challenges for Regulators* In Focus (Washington D.C.: Congressional Research Service, 2020), online: <https://fas.org/sgp/crs/space/IF11382.pdf>.

This chapter will discuss the definitions, capabilities, and trends relating to small satellites and mega-constellations. Understanding the technological advances and future capabilities and uses of small satellites and mega-constellations allows us to understand how this technology will impact national security in the future and identify the related legal issues.

a. DEFINITIONS

1) Smallsats

Small satellites, frequently referred to as "smallsats," are currently experiencing a renaissance. Currently, there is no internationally agreed-upon definition of what constitutes a smallsat and experts in the field still debate what qualities are the most important in making the classification. Some argue that speed of production and cost should be used to define small satellite projects, while others rely on mass of the satellite.[18] From a U.S. Regulatory perspective, NASA defines smallsats based upon size and mass using a categorization approach. [19] They set a limit of 180 kg or less; "about the size of a large kitchen fridge."[20] The FAA also uses mass to identify smallsats but uses a much broader categorization method with the upper limit of their small satellite mass class at 1,200 kg.[21] Many researchers use the mass of 500kg or 600kg.[22] For the purpose of this thesis, smallsats are defined as those satellites with a mass below 600kg.

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18 *See* Lal et al, "Global Trends", *supra* note 5 at 1–5.

19 *See* Elizabeth Mabrouk, "What are SmallSats and CubeSats?" (13 March 2015), online: *NASA* <www.nasa.gov/content/what-are-smallsats-and-cubesats>. Within NASA's definition of Smallsat, they break smallsats into the following subcategories: Minisatellite 100-180 kg; Microsatellite 10-100 kg; Nanosatellite 1-10 kg; Picosatellite 0.01-1 kg; and Femtosatellite 0.001-0.01 kg. *Ibid*.

20 Mabrouk, "SmallSats and CubeSats", *supra* note 19.

21 *See The Annual Compendium of Commercial Space Transportation: 2018* (Federal Aviation Administration, 2018), online: <www.faa.gov/about/office_org/headquarters_offices/ast/media/2018_AST_Compendium.pdf> at 94. The FAA uses the following subcategories of small satellites: Small 601-1200 kg; Mini 201-600 kg; Micro 11-200 kg; Nano 1.1-10 kg; Pico 0.09-1 kg; and Femto 0.01-0.1 kg. *Ibid*.

22 *See e.g.* Bryce Space Technology uses 600 kg as the upper mass limit for their research into smallsats. *Smallsats by the Numbers 2020* (Bryce Space Technology, 2020), online: <brycetech.com/reports/report-documents/Bryce_Smallsats_2020.pdf>. The Aerospace Corporation and the Asia-Pacific Satellite Communications Council define Smallsats as those satellites having a mass of less than 500 kg. Carrie O'Quinn,

2) Earth Orbits

The laws of physics as related to gravity dictate that in order for a spacecraft to remain near the earth, it must travel at a certain velocity around it. If the velocity is too low, the spacecraft will be pulled back to earth and if it is too high it will stray away from the Earth. The proper velocity depends on the distance away from the Earth's surface which dictates the distance of travel for each orbit and the pull of Earth's gravity. These principles of astrodynamics define the possible orbits that spacecraft can use to remain in orbit around the Earth.[23] The most common orbits are geosynchronous Earth orbit (GEO), medium Earth orbit (MEO), highly elliptical orbit (HEO), and low Earth orbit (LEO).[24]

Satellites in GEO take advantage of the physics principles above to synchronize the necessary velocity to remain in orbit with the same rotational speed as the earth, allowing them to remain over the same longitudinal part of the earth at all times. This orbit requires the satellite to be at 35,786 km above the Earth's surface, traveling at 3 km per second.[25] If the satellite is directly over the equator it is in a special orbit called geostationary orbit (GSO) that will appear to remain in a fixed point in the sky from the ground. Other satellites at that altitude but traveling a path inclined as to the equator will trace a figure eight on the ground due to the orbital path.

Providing Maximum Launchability – A Guide to Defined SmallSat Classification (The Aerospace Corporation, 2018), online: <aerospace.org/sites/default/files/2018-08/DefinedSmallSat_STE052218.pdf>; Sami Ben Amor, "The Rise of Small Satellites" (2019) 2019:2 Asia-Pacific Satellite Communications Council Newsletter, online: <apscc.or.kr/2019-2/> at 10.

[23] *See* "Catalog of Earth Satellite Orbits" (4 September 2009), online: *NASA* <earthobservatory.nasa.gov/features/OrbitsCatalog>.

[24] *See Joint Publication 3-14: Space Operations* (Washington D.C.: Chairman of the Joint Chiefs of Staff, 2018), online: <www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_14.pdf> at I–10.

[25] *See* "Types of Orbits" (30 March 2020), online: *European Space Agency* <www.esa.int/Enabling_Support/Space_Transportation/Types_of_orbits>.

Two of the largest benefits using GEO provides are large coverage area and constant line of sight observation. Because GEO is so far away, a satellite in that orbit can see slightly more than one-third of the earth at all times. Additionally, due to the matched rotational speed, they can provide a consistent observation angle of the earth. These two benefits combined make GEO ideal for certain weather and communication satellites.[26]

MEO is closer to Earth and requires a higher velocity to remain in orbit. This orbit covers all area between GEO and LEO orbits, and includes a semi-synchronous orbit that circles the Earth every 12 hours. This is the orbit used for the Global Positioning System (GPS) constellation because it is consistent and highly predictable.[27]

Highly elliptical orbits (HEO), as their name implies, are distinctly different from most other orbits which track close to circular paths around the earth. HEOs travel an elliptical path that passes close to the earth at perigee and then spends a significant portion of its orbital time passing its apogee (furthest orbital point from the earth) before returning.[28] One of the most common HEO planes is the Molniya orbit invented by Russia for providing service to the high latitude portions of their country that are not served by GEO satellites sitting above or near the equator. This orbit has a high inclination (63.4 degrees above the equator) and high eccentricity (0.722) which provides satellites in this orbit a long viewing time over high-latitude locations (nearly two thirds of the orbit).[29]

The majority of smallsats occupy LEO; which is roughly defined as the area up to approximately 1,200 miles (2000 km) above the Earth's surface.[30] Satellites in this orbit must

[26] *See* "NASA Orbit Catalog", *supra* note 23; "JP 3-14", *supra* note 24 at I–10.
[27] *See* ibid.
[28] *See* "JP 3-14", *supra* note 24 at I–10.
[29] *See* "NASA Orbit Catalog", *supra* note 23.
[30] *See* "JP 3-14", *supra* note 24.

travel much quicker than orbits in MEO or GEO to remain in orbit. It is also much closer to the Earth's surface. These characteristics bring both benefits and detriments. Because satellites in LEO are significantly closer than those in GEO or MEO, they can use much less powerful transmitters to communicate (requiring less power and less weight), communication times are much quicker because the signal has less distance to travel, and they can achieve higher resolution imagery from equivalent equipment.[31] The detriments to LEO are that satellites must move at such a high velocity that they are only visible to ground stations and users for a short period of time before passing them by. Additionally, LEO satellites are so close to the Earth that their coverage area is much smaller as compared with GEO (which can see one third of the planet).[32] Thus, in order to provide any form of consistent coverage from LEO, the space system must use a large number of satellites with the same capabilities spread evenly over several orbital planes that have the ability to work together; also known as a satellite constellation.[33]

3) Mega-Constellations

Currently, there is no international or agreed upon definition of 'mega-constellations.' Constellations of satellites have been used for decades for navigation, communication, and earth observation/remote sensing purposes, to include some well-known systems such as GPS, Galileo, Iridium, and more. All of these systems have less than 100 satellites with the majority of these constellations having fewer than 40 satellites, with a few outliers: namely Planet Labs 140+ earth observation satellites.

This paradigm is currently being turned on its head, however, by a new wave of multi-hundred and multi-thousand satellite constellations being proposed and launched by governments

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[31] *See Ibid* at I–10.
[32] *See Ibid*; "NASA Orbit Catalog", *supra* note 23.
[33] *See* "JP 3-14", *supra* note 24 at I–10; "NASA Orbit Catalog", *supra* note 23; "Types of Orbits", *supra* note 25.

and private companies. While there is not an agreed upon definition of 'mega-constellation,' the NASA promulgated *U.S. Government Orbital Debris Mitigation Standard Practices* updated in 2019 recognize constellations with more than 100 satellites as "Large Constellations."[34] For purposes of this thesis, a mega-constellation is one utilizing more than 100 satellites.

b. CAPABILITIES AND TRENDS

While there is no international agreement on the definition of 'smallsat' or 'mega-constellation', one thing that is agreed upon is that smallsats and mega-constellations have begun to be used for many different purposes that were previously all accomplished by fewer, much larger satellites. As discussed above, technological breakthroughs and electronic miniaturization has been a major driver in the recent trend toward launching more smallsats. For example, Thales Alenia Space claims that their onboard processing capabilities have increased 1000 times since 2006.[35] Further, miniaturization of sensors, integration of processing electronics with sensors, improved solar cells and batteries, and microelectromechanical systems (MEMS) have made it possible for satellite producers to manufacture smallsats that can provide the same or better capabilities than larger satellites of the past.[36]

In the past decade, the smallsat market has exploded, growing on average 23% annually between 2009 and 2018.[37] Understanding the current and projected capabilities of smallsats and mega-constellations, as well as the trends in the market, are critical in analyzing their effects on national security.

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[34] *U.S. Government Orbital Debris Mitigation Standard Practices 2019 Update* (NASA, 2019) at 7.
[35] *See* Sami Ben Amor, "The Rise of Small Satellites" *Asia-Pacific Satellite Communications Council*, online: <https://apscc.or.kr/2019-2/> at 11.
[36] Jeff Foust, "A Quarter Century of Smallsat Progress" *The Space Review* (6 September 2011), online: <www.thespacereview.com/article/1921/1>; Amor, *The Rise of Small Satellites*, *supra* note 35 at 11.
[37] *See* Maxime Puteaux & Alexandre Najjar, "Analysis | Are smallsats entering the maturity stage?" *SpaceNews* (6 August 2019), online: <spacenews.com/analysis-are-smallsats-entering-the-maturity-stage/>. These statistics are based upon compound annual growth rate calculations of Smallsats with a launch mass below 500 kg.

1) Reduced Manufacturing Costs

Smallsats are much cheaper to manufacture than the traditional satellites of previous generations. In decades past, satellite manufacturing would regularly take multiple years and cost millions of dollars per satellite.[38] With the rise of smallsats and mega-constellations, these costs are being greatly reduced. This reduction in build-out cost is due to a multitude of factors. First, the use of commercial-off-the-shelf (COTS) technology rather than custom components decreases the cost of production.[39] Further, using standardized form factors also allows for economies in manufacturing related to mounting and attachment. Less radiation hardening and system redundancy is required on smallsats since most smallsats use LEO orbits below 1000km that do not intersect with the Van Allen radiation belts and there is less need to protect against highly charged particle interference with electronics.[40] Further manufacturing cost savings occurs from using components that do not need to be as robust or durable given their shorter planned operating life.

When considering mega-constellations, there are additional cost saving found in mass-production of smaller satellites rather than one-off specialty satellite design and construction.[41]

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[38] *See* Tom Segert & Sanjay Attara, "Mass Manufacturing of Small Satellites, Gearing up for the Henry Ford Moment" (Paper delivered at the 2019 Small Satellite Conference, Utah State University, Logan, Utah, 5 August 2019) [unpublished], online: <digitalcommons.usu.edu/smallsat/2019/all2019/265>.

[39] John J Klein, *Understanding Space Strategy: The Art of War in Space*, first edition ed, Space power and politics (Milton Park, Abingdon, Oxon ; New York, NY: Routledge, 2019) at 191.

[40] *See* Lal et al, "Global Trends", *supra* note 5 at 2–11; Yael Kovo, "Passive Deorbit Systems" (30 March 2020), online: *NASA* <www.nasa.gov/smallsat-institute/sst-soa/passive-deorbit-systems>. The Van Allen Radiation Belts are two (sometimes three) donut shaped rings of highly charged particles that encircle the earth. When the charged particles in the Van Allen Belts impact electronics, the particles can affect how the electronics operate, stop them from working, or even cause an electronic overload. As such, spacecraft that will travel through the Van Allen belts require additional shielding against high-energy particle radiation and, often, redundant systems to allow for continued operations if one is damaged by the radiation. Elizabeth Howell, "Van Allen Radiation Belts: Facts & Findings" (11 May 2018), online: *Space.com* <www.space.com/33948-van-allen-radiation-belts.html>.

[41] *See* Segert & Attara, "Mass Manufacturing", *supra* note 38.

These factors will continue to reduce the cost of production of many satellites to the point where average cost will be 1/10th of prior satellites.[42]

2) Quicker Production Timeline

Similar to the reduction in cost, smallsats have a reduction in production timeline due to many factors. Some of which include the use of standardized COTS components and consistent formfactor requiring less customization per satellite. As a result of these factors, it is estimated that the production time of satellites can be reduced from a number of years to a number of weeks.[43]

3) Reduced Launch Costs

One of the most important factors spurring the renaissance of small satellites is reduced launch cost and increased launch availability.[44] In the history of space exploration, launch costs have always accounted for a significant portion of the expense.[45] Cost of launch is generally determined by mass and orbital plane, as an increase in mass and/or height of orbit necessitates an increase in fuel required. The entry into the market of the Falcon 9 and Falcon Heavy rockets by SpaceX beginning in 2010 reduced the cost of launch to LEO by a factor of 7 and 13, respectively, as compared with the average launch costs between 1970 and 2000.[46] The combination of the closer orbit and reduced weight and size makes smallsat launches less

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[42] *See Ibid*.
[43] *See Ibid*.
[44] *See* Amor, *The Rise of Small Satellites*, *supra* note 35 at 11.
[45] *See* Harry W Jones, "The Recent Large Reduction in Space Launch Cost" (Paper delivered at the 48th International Conference on Environmental Systems, Albuquerque, New Mexico, 8 July 2018) [unpublished], online: <ttu-ir.tdl.org/bitstream/handle/2346/74082/ICES_2018_81.pdf?sequence=1&isAllowed=y>.
[46] *Ibid* at 7–13.

expensive than traditional satellites.[47] As a result of these size and orbit efficiencies, hundreds of smallsats can potentially be launched at a time using smaller, cheaper launch vehicles.[48]

Further, new concepts of how to accommodate smallsats has reduced the barriers to market entry, making smallsat launch even more affordable. These include rideshare opportunities and specialty smallsat launch vehicles.[49] The increase in launch availability and reduction in launch cost, particularly for LEO satellites, is a trend that is likely to continue as more commercial launchers compete for business in the growing smallsat and mega-constellation market.

4) Communication Latency

One of the biggest capabilities that smallsats in LEO offer over traditional MEO and GEO satellites is an increase in communication speed. Since the altitude of LEO satellites is less than 5% of that of GEO satellites, the time it takes for communication signals to reach the satellite and be returned to earth is significantly reduced. Generally, this time is referred to as latency and it is measured in milliseconds (ms). Traditional GEO communications satellites have a latency of around 500ms.[50] Thus, as satellites in LEO are much closer to earth and the signal has much less distance to cover, they can have latency nearly 20 times quicker than traditional GEO communications satellites.

While the reduced latency for LEO satellites has been known and used for some time (Iridium has been operating LEO communication satellites for over 20 years), new technology in the past decade allows for current smallsats to be launched with smaller, more powerful

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[47] *See* Steiner Lag, "Mega-Constellation Satellites on the Horizon" (31 January 2020), online: *DNV GL* <www.dnvgl.com/to2030/technology/mega-constellation-satellites-on-the-horizon.html>.
[48] *See* Klein, *Understanding Space Strategy*, *supra* note 39 at 191.
[49] *See* O'Quinn, "Maximum Launchability", *supra* note 22 at 4. "Rideshare" is when a scheduled launch has excess payload capacity which it sells to smallsat operators who can 'piggyback' their satellite on the main scheduled launch. O'Quinn, "Maximum Launchability", *supra* note 22.
[50] *See* Lag, "On the Horizon", *supra* note 47.

processors and better antennae which allow for increased bandwidth through the systems to serve more customers at greater speeds from LEO at lower operating costs. Several mega-constellation proposals currently pending are expecting latency as low as 25ms.[51] This latency is comparable to terrestrial 5G services and some broadband services.[52]

5) Communication Speed and Ground System Benefits

Smallsat mega-constellations have the ability to increase the volume and speed of communication traffic through space. These increases will benefit multiple current modes of connectivity and also provide benefits to the ground-systems supporting the constellations allowing for new capabilities from space.

BROADBAND: The term broadband generally refers to high speed internet with wide bandwidth data transmission capability. Broadband can be delivered through a variety of technologies including telephone lines, cable coaxial lines, fiber optics, and wirelessly.[53] Satellite provided broadband falls within the wireless category. Not all broadband is equal, however. Traditionally, satellite broadband has had the slowest speed and some of the highest cost for consumers.[54] The proposed broadband mega-constellations currently in development and fielding are trying to take satellite broadband to the next level; bringing the speed of connectivity up while also lowering the cost to connect through the use of LEO smallsat mega-constellations. [55] SpaceX, for example, expects its Starlink system to provide gigabit internet

[51] *Ibid*.
[52] *Ibid*.
[53] *See* "Types of Broadband Connections" (23 June 2014), online: *Federal Communications Commission* <www.fcc.gov/general/types-broadband-connections>.
[54] *See Ibid*; Sheetz & Petrova, "Next Decade", *supra* note 2.
[55] *See* Jon Brodkin, "SpaceX Says 12,000 Satellites Isn't Enough, so it Might Launch Another 30,000" *ars TECHNICA* (16 October 2019), online: <arstechnica.com/information-technology/2019/10/spacex-might-launch-another-30000-broadband-satellites-for-42000-total/>.

speeds[56]; speeds comparable to those provided by cable broadband across the United States and 40 times faster than current satellite broadband providers.[57]

INTERNET OF THINGS: As discussed above, technological advancements in computing technology allowing for reduction in size of components has been a key factor supporting this growth. These same advancements in computing power and miniaturization have led to more and more terrestrial items being modified to have the ability to connect to the internet.[58] This includes smart home devices like smart locks, smart lights, and appliances. It also includes commercial and agricultural equipment. This phenomenon is currently known as the internet of things or IoT.[59] It is estimated that the number of IoT devices will increase to 75.44 billion worldwide by 2025.[60] A new wave of IoT-supporting satellite mega-constellations will be able to cover 100% of the globe without the traditional limitations of terrain and infrastructure, and, because they are in LEO, only require low powered transmission by the ground sensors allowing the sensors to be smaller with longer battery life.[61]

5G TECHNOLOGY: 5G is the next generation of mobile networking and internet connectivity with significantly increased connection speeds, increased bandwidth, and reduced latency.[62] Much of the infrastructure for 5G mobile connectivity will remain terrestrial, as with current 4G LTE coverage, however, the speed of 5G, along with the low latency of LEO, has

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[56] *See* "Starlink", online: *SpaceX* <www.starlink.com>.
[57] *See Measuring Fixed Broadband Report - 2016* (Federal Communications Commission, 2016), online: <www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-report-2016>.
[58] *See* "IoT: Number of Connected Devices Worldwide 2012-2025" (27 November 2016), online: *Statista Research Department* <www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/>.
[59] *See ibid*.
[60] *See ibid*.
[61] *See* Micki Seibel, "Agriculture's Digital Revolution from Space" (20 May 2019), online: *Medium* <medium.com/swarm-technologies/agricultures-digital-revolution-from-space-8b4a0d46b643>.
[62] *See* Christian de Looper, "What Is 5G? The Next-Generation Network Fully Explained" *Digital Trends* (22 May 2020), online: <www.digitaltrends.com/mobile/what-is-5g/>.

created the opportunity to provide 5G coverage by mega-constellations.[63] The satellite portion of 5G will have the ability to supplement terrestrial 5G networks at times of natural disaster and network saturation, but will also have the ability to bring coverage to mobile platforms, remote/rural areas and parts of the globe that are currently underserved by mobile telephone and internet providers.[64]

6) Image Resolution

Similar to the benefits in communication speed by the comparative closeness of LEO as compared with MEO and GEO, remote sensing satellite resolution is also improved by the proximity of smallsats in LEO to earth objects being sensed. Resolution, or the ability to resolve/differentiate small details, is typically broken down into sub-categories; two of which are improved by smallsats.

Spatial resolution is the description of the smallest object size that can be differentiated within the area sensed by a sensor. This resolution is generally expressed in terms of meters of Ground Sampling Distance (GSD) for remote sensing satellites. Early remote sensing satellites generally had low resolution of approximately 30 meters GSD, or the ability to represent a 30 meter by 30-meter square by a single pixel, which allowed the differentiation of city areas from surrounding rural areas. Modern "high resolution' can be as low as .25 meters GSD, allowing the ability to see the lines painted on the pavement of a street. While this high resolution is capable of being captured from space, such detailed imagery is generally restricted to government uses only. Commercially, spatial resolution is currently regularly available in the 1-2 meter GSD range. Remote sensing mega-constellations can provide improvements in spatial

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[63] *See* Andy Baryer, "5G From Space: The Role of Satellites in 5G" (10 March 2020), online (blog): *Futurithmic* <www.futurithmic.com/2020/03/10/5g-from-space-role-of-satellites/>.
[64] *See Ibid*.

resolution based upon their location close to earth. Further, compilation of information gathered from multiple satellites can improve image quality. Last, mega-constellations can provide for imagery taken from different angles at the same time which can provide even further differentiation of sensed objects.[65]

Temporal resolution is the frequency at which sensing occurs over a given area, or how often you can take a measurement of a given area in order to see changes over time. This resolution is generally controlled by the orbit of the satellite system. Some satellites only pass a given area once every two weeks, while others may pass an area every day. Mega-constellations can improve temporal resolution to nearly persistent sensing of the entire globe through increased revisit time (discussed further below).[66]

7) Rapid Revisit Time

Smallsats in LEO have to travel much faster than GEO satellites in order to remain in orbit so close to the earth. The lower the orbit, the higher the velocity required to maintain orbit. For example, Iridium LEO satellites travel at around 17,000 mph while most GEO satellites travel at closer to 7,000 mph.[67] In this way, many satellites in LEO can complete an orbit of earth in around 100 minutes.[68] With LEO inclinations that are close to polar (crossing the north and south poles rather than circling near the equator), a LEO satellite can pass over nearly the entire earth twice each day: one pass in sunlight and another pass at night. [69] This allows a single

[65] *See* Wenxue Fu et al, "Remote Sensing Satellites for Digital Earth" in Huadong Guo, Michael F Goodchild & Alessandro Annoni, eds, *Manual of Digital Earth* (Singapore: Springer, 2020) 55, online: <doi.org/10.1007/978-981-32-9915-3_3>.

[66] *See Ibid* at 78–79.

[67] *See* "Satellites 101: LEO vs. GEO" (11 September 2018), online: *Iridium Satellite Communications* <www.iridium.com/blog/2018/09/11/satellites-101-leo-vs-geo/>.

[68] *See* "NASA Orbit Catalog", *supra* note 23.

[69] A polar orbit is highly inclined to the equator resulting in the satellite passing from pole to pole as the earth turns beneath it. A special highly inclined LEO orbit is the sun-synchronous orbit. In this orbit, a satellite travels from pole to pole so that its passing of the equator occurs at the same local time each day. One main benefit to a sun-synchronous orbit for earth observation is that it allows observations with a consistent sun/earth angle creating consistency in imagery that assists in comparative analysis. *Ibid*.

satellite to provide a regular revisit rate to a specific part of the earth on a daily basis, if not a shorter time period. In the context of mega-constellations, the rapid revisit time benefit can be even more significant. Mega-constellations in LEO can have nearly continuous, persistent coverage of the earth as each of the distributed satellites in the constellation orbit the earth and take turns passing over a the same given area. [70]

8) Real Time Video

As satellite earth observation resolutions, revisit time, and communication speeds have improved, the real-time video from space has become a foreseeable possibility. Real-time video is defined as transmission of live video with little to no delay from capture to reception.[71] Some real-time video has been streamed from space by the International Space Station as part of the High Definition Earth Viewing System (HDEV) program.[72] While there have not been any commercial real-time video satellite services yet, similar video technology is used in remote sensing Carbonite satellites by Surrey Satellite Technology Ltd (SSTL).[73] These satellites employ a "Forward Motion Compensation (FMC)" mode which processes the captured data to make their 120 second, 1m GSD video appear as if it is being taken from directly overhead despite the satellite moving at nearly 27,000 mph. In videos of Buenos Aires, cars can be seen driving on highways and airplanes taxing around airports.[74] China has also launched the Jilin satellite group; which includes two satellites for 4k HD video imaging at 1.3m GSD.[75] While much of this video capture currently requires timely processing before it is possible to view, the

[70] *See* Klein, *Understanding Space Strategy*, *supra* note 39 at 192.
[71] *See* "Definition of Real-Time Video" (22 July 2020), online: *PCMAG* <www.pcmag.com/encyclopedia/term/real-time-video>.
[72] *See* Susan Runco, Carlos Fontanot & Chris Getteau, *High Definition Earth Viewing (HDEV) Final Report June 2020* (NASA, 2020), online: <eol.jsc.nasa.gov/ESRS/HDEV/files/HDEV-Final-Report_20200715.pdf>.
[73] *See* "Mission Configured Satellites from SSTL" (22 July 2020), online: *SSTL* <www.sstl.co.uk/what-we-do/mission-configured-spacecraft>.
[74] *See Ibid*.
[75] *See* Fu et al, *Remote Sensing Satellites for Digital Earth*, *supra* note 65 at 79.

advent of mega-constellations and improvements in communication technology, video compression, and communication speed, make persistent real-time video is a definite possibility in the near future.

9) Global Coverage

The use of LEO can provide greater coverage of the entirety of the globe as compared with many MEO and GEO satellites, at reduced cost. While satellites in GEO have the benefit of maintaining a relatively constant position as compared to the ground by circling directly over the equator, that benefit comes with a lack of coverage of the far northern and southern parts of the Earth. By contract, launch to LEO polar orbits can provide cost-effective global satellite coverage by using satellites that pass from pole to pole around 12 times per day as the earth rotates beneath.[76] Through the use of distributed satellites in a mega-constellation, complete global coverage is possible.

10) Many Satellites/Redundancy

Mega-constellations use a large number of satellites distributed in orbits with the ability to pass work between themselves to provide consistent coverage of the Earth's surface from LEO.[77] These large constellations provide built-in redundancy. When one constellation satellite becomes inoperable, either temporarily or permanently, there is another satellite following close behind to pick up lost capabilities. This distribution and proliferation of service away from a single point of failure provides new levels of assurance of continued service to customers of mega-constellations.

[76] *See* Lag, "On the Horizon", *supra* note 47.
[77] *See ibid*.

11) Propulsion

Earth, lunar, and solar gravity, radiation, atmospheric drag in LEO, and other forces constantly affect the ability of a satellite to maintain its orbit. On-board propulsion systems can be used to maintain orbit, change orbit, maintain orientation, and de-orbit at the end of mission. These propulsion systems generally rely entirely on fuel that is loaded on the satellite at the time of launch and, when the fuel is depleted, the satellite can no longer maneuver. In 1994, NASA scientists recognized that "for many commercial, scientific, and DoD near-Earth missions, on-board propulsion is the predominant spacecraft mass" and, as discussed above, mass of a spacecraft is directly linked to launch expense.[78] This has always led to a requirement in design and manufacturing of satellites to balance added capability of propulsion systems with the added mass required to operate the system.[79]

Until recently, on-board propulsion systems were deemed almost unnecessary for smallsat missions in LEO because the cost of adding a propulsion system and the related mass cost increase for launch overwhelmed the cost of the mission itself and was unduly prohibitive given that natural decay would occur within 25 years.[80] This led to the launch of many smallsats with no propulsion system to help maintain orbit, nor an ability to actively deorbit at end of mission.

In recent years, however, there has been further emphasis on technological research and development in the satellite propulsion industry specifically targeted at the smallsat, LEO industry. Part of this emphasis is due to a movement for responsible and sustainable space usage

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[78] M Myers et al, "Small Satellite Propulsion Options" (Paper delivered at the 30th Joint Propulsion Conference, Indianapolis, Indiana, 27 July 1994) [unpublished], online: <ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19950005075.pdf> at 1.
[79] *See ibid*.
[80] *See* Kovo, "Passive Deorbit Systems", *supra* note 40.

to avoid leaving non-functioning satellites in orbit for longer than necessary and risking collisions.[81] Additionally, adding propulsion to smallsats can increase their mission life and increase capabilities. There are several different types of propulsion systems available or in development for use with smallsats: electric, chemical, plasma, and passive de-orbit systems.[82] Each of these systems have benefits and drawbacks that are too complex to be discussed here, however, it is important to note that there have been significant developments in the propulsion for smallsats sector in the past decade and the trend is likely to continue as a result of the growing focus on efficient LEO smallsat constellation operations.

c. CURRENT MEGA-CONSTELLATION PROPOSALS

Taking advantage of the trends and capabilities discussed above, there are already several mega-constellation proposals in the works globally. The majority of these proposals are by commercial companies. These constellations range from hundreds to thousands of satellites performing all kinds of services. A few of the most notable proposals are those of SpaceX and OneWeb. SpaceX is developing and has already launched 538 of its Starlink LEO mega-constellation of broadband connectivity satellites.[83] The total Starlink mega-constellation could consist of as many as 42,000 satellites.[84] Similarly, OneWeb has proposed a constellation of

[81] *See* "Responsible Space" (3 March 2020), online: *OneWeb* <www.oneweb.world/responsible-space>; "Long-Term Sustainability of Outer Space Activities" (23 September 2019), online: *United Nations Office for Outer Space Affairs* <www.unoosa.org/oosa/en/ourwork/topics/long-term-sustainability-of-outer-space-activities.html>.
[82] *See* Khary I Parker, "State-of-the-Art for Small Satellite Propulsion Systems" (Paper delivered at the 2016 Biennial Aerospace Systems Conference of the National Society of Black Engineers (NSBE), Arlington, Virginia, 24 August 2016)8 [unpublished], online: <ntrs.nasa.gov/citations/20160010571>; Myers et al, "Propulsion Options", *supra* note 78; Kovo, "Passive Deorbit Systems", *supra* note 40.
[83] *See* Darrell Etherington, "SpaceX Launches 58 More Starlink Satellites and 3 Planet Skysats for First Rideshare Launch" (13 June 2020), online (blog): *TechCrunch* <social.techcrunch.com/2020/06/13/spacex-launches-58-more-starlink-satellites-and-3-planet-skysats-for-first-rideshare-launch/>.
[84] *See* Harris, "40,000 Satellites", *supra* note 2.

48,000 satellites as part of its broadband mega-constellation and has 74 satellites already in orbit.[85]

Other proposals for LEO mega-constellations include Amazon's Kuiper project (3,000+ broadband satellites),[86] Canadian company TELESAT (300 communications satellites),[87] Kepler Communication (140 IoT satellites),[88] two Chinese State-owned corporation's broadband, voice and data constellations Hongyan (320 satellites) [89] and Hongyun (864 satellites)[90], and ROSCOSMOS Sphere project (640 satellites)[91].

The Department of Defense is also planning its own mega-constellation. The Space Development Agency, established in March 2019, is developing the National Defense Space Architecture (NDSA).[92] The vision for the NDSA is "a resilient military sensing and data transport capability via a proliferated space architecture primarily in Low Earth Orbit (LEO)."[93] This system is intended to be engineered for "simplified growth, ease of integration and test, and

[85] *See* Jon Brodkin, "Bankrupt OneWeb Seeks License for 48,000 Satellites, Even More than SpaceX" *Ars Technica* (27 May 2020), online: <arstechnica.com/tech-policy/2020/05/spacex-and-oneweb-seek-licenses-to-launch-78000-broadband-satellites/>; Sheetz & Petrova, "Next Decade", *supra* note 2.
[86] *See* Alan Boyle, "Amazon's Project Kuiper and OneWeb Lift Curtain Higher on Satellite Plans", *GeekWire* (1 October 2019), online: <www.geekwire.com/2019/amazons-project-kuiper-oneweb-raise-curtain-higher-satellite-plans/amp/>; Caleb Henry, "Amazon's Kuiper constellation gets FCC approval" *SpaceNews* (30 July 2020), online: <spacenews.com/amazons-kuiper-constellation-gets-fcc-approval/>.
[87] *See* "The Next Wave: Low Earth Orbit Constellations | Satellite Markets & Research", online: <http://satellitemarkets.com/news-analysis/next-wave-low-earth-orbit-constellations>; Sheetz & Petrova, "Next Decade", *supra* note 2.
[88] *See Next Wave, supra note* 87.
[89] *See* Rui C Barbosa, "Long March 2D Concludes 2018 Campaign with Hongyan-1 Launch" (29 December 2018), online (blog): *NASASpaceFlight.com* <www.nasaspaceflight.com/2018/12/long-march-2d-20-hongyan-1-launch/>.
[90] *See* Larry Press, "Hongyun Project – China's Low-Earth Orbit Broadband Internet Project" (4 June 2019), online (blog): *CircleID* <www.circleid.com/posts/20190604_hongyun_project_chinas_low_earth_orbit_broadband_internet_project/>.
[91] *See* John Sheldon, "ROSCOSMOS Announces Marathon IoT Constellation Amidst Brewing Financial Scandal And Security Row" *SpaceWatch Global* (28 November 2018), online: <spacewatch.global/2018/11/roscosmos-announces-marathon-iot-constellation-amidst-brewing-financial-scandal-and-security-row/>.
[92] *See* "ABOUT US – Space Development Agency" (3 August 2020), online: *Space Development Agency* <www.sda.mil/home/about-us/>.
[93] *See ibid*.

continuous modernization."[94] While the NDSA is still in the research and development stages, its broadband "transport layer" is currently envisioned as a constellation of 300 to 500 satellites in LEO. Based upon initial designs, 95% of the Earth would have two NDSA satellites in view at all times, and 99% would have at least one in view.[95] The SDA is also developing a battle management layer, hyperspace weapon tracking layer, custody layer for targeting, navigation layer for PNT in areas with denied GPS, and more.[96] Additionally, the Defense Advanced Research Projects Agency (DARPA) Small Satellite Sensors program is focused on how a "[d]ense constellation of low-earth-orbit (LEO) micro-satellites can provide new intelligence, surveillance and reconnaissance (ISR) capabilities, which are persistent, survivable and available on-demand for tactical warfighting applications."[97]

d. CONCLUSION

Smallsats and mega-constellations are poised for a boom in launch and implementation that will take advantage of new technology as well as the natural benefits of LEO. In the coming years, satellites under 600kg and in constellations numbering hundreds to thousands will bring new capabilities never before possible. While the majority of these systems are designed to benefit consumers, the fielding of these systems will have major effects on national security. These improved capabilities have caught the attention of National and commercial space actors as seen by the many proposals for mega-constellations.

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[94] *See Final Report on Organizational and Management Structure for the National Security Space Components of the Department of Defense* (Washington, D.C.: Department of Defense, 2018), online: <media.defense.gov/2018/Aug/09/2001952764/-1/-1/1/ORGANIZATIONAL-MANAGEMENT-STRUCTURE-DOD-NATIONAL-SECURITY-SPACE-COMPONENTS.PDF> at 9.

[95] *See* "Transport – Space Development Agency" (3 August 2020), online: *Space Development Agency* <www.sda.mil/transport/>.

[96] *See* "About SDA", *supra* note 92.

[97] "Small Satellite Sensors" (25 July 2020), online: *DARPA* <www.darpa.mil/program/small-satellite-sensors>.

<u>Part II: Mega-Constellations and National Security</u>

An army prefers high ground [and] when the enemy occupies high ground,

do not confront him . . . – *Sun Tzu, The Art of War*[98]

More than a decade before the launch of the first satellite into orbit around the Earth, governments and militaries were exploring the possibilities of accessing space. In the early 1940's, the United States began considering a national security space program. By 1946, Major General Curtis E. LeMay, then Deputy Chief of the Army Air Staff for Research and Development, asked Douglas Aircraft Company's engineering division to begin project RAND (Research and Development) and produce a report on the feasibility of the U.S. launching satellites in just three weeks' time.[99]

The resulting report, *Preliminary Design of an Experimental World-Circling Spaceship*, published 2 May 1946, mainly focused on the engineering feasibility of satellites but included a section on the military importance of satellites; namely, precise observation by a craft that cannot be brought down by an enemy that hasn't also mastered the technical challenges of accessing space, and that such a craft would be "virtually undetectable from the ground" by the current radar technology.[100] The study went on to identify communication relays, weather prediction, and scientific investigation as further benefits of satellites, while recognizing that "there are doubtless many important possibilities which will be revealed only as work on the project proceeds."[101]

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[98] Sun Tzu, *The Art of War*, translated by Samuel B. Griffith (New York, Oxford University Press, 1963), online: <http://archive.org/details/artofwargriff00sunz>.
[99] *See Preliminary Design of an Experimental World-Circling Spaceship:* (Santa Monica, California: RAND Corporation, 1946), online: <www.rand.org/pubs/special_memoranda/SM11827.html>.
[100] *Ibid* at 10.
[101] *Ibid* at 11–15.

The report compared the situation regarding space exploration in 1946 to that of consideration of airplanes prior to the first flight of the Wright brothers.

> We can see no more clearly all of the utility and implications of spaceships than the Wright brothers could see fleets of B-29's bombing Japan and air transports circling the globe. Though the crystal ball is cloudy, two things seem clear: 1. A satellite vehicle with appropriate instrumentation can be expected to be one of the most potent scientific tools of the Twentieth Century. 2. The achievement of a satellite craft by the United States would inflame the imagination of mankind, and would probably produce repercussions in the world comparable to the explosion of the atomic bomb.[102]

This statement shows how, even before the space race had begun, space was recognized as playing an important role in national security as the ultimate high ground, or the place with the most natural advantages over adversaries as described by Sun Tzu. [103]

Today, satellites and their space-based capabilities, are essential to day-to-day life of the developed world. These capabilities are of even more critical importance to militaries, providing intelligence gathering, communications, navigation, timing, weather, early warning, and many more capabilities.[104] In October 2019, NATO announced that space is essential to NATO's defense and security and "recognized that space is part of our daily lives, and while it can be used for peaceful purposes, it can also be used for aggression."[105] In response, NATO developed its first ever Space Policy and declared that space is a war-fighting domain, just like air, land, sea, and cyberspace.[106]

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[102] *Ibid* at 1–2.
[103] *See* Klein, *Understanding Space Strategy*, *supra* note 39 at 40.
[104] *See* Joseph Trevithick, "Space Force Looks Go for Launch but Questions Remain About How It Will 'Dogfight in Space'" *The Drive, The Warzone* (10 December 2019), online: <www.thedrive.com/the-war-zone/31420/space-force-looks-go-for-launch-but-questions-remain-about-how-it-will-dogfight-in-space>.
[105] *See* "Space is Essential to NATO's Defense and Deterrence" (14 October 2019), online: *NATO* <www.nato.int/cps/en/natohq/news_169643.htm>.
[106] *See ibid*; "NATO's Approach to Space" (27 April 2020), online: *NATO* <www.nato.int/cps/en/natohq/topics_175419.htm>.

The Chairman of the Joint Chiefs of Staff Joint Publication 3-14 on Space Operations doctrine, published in 2018, further delineates the National Security benefits provided by operations in space.[107] This publication notes that the natural characteristics of space provide some unique advantages applicable to all space operations. First, though diminishing with time, space provided freedom of action to those few actors capable of accessing it.[108] Second, overflight restrictions that apply to aircraft under international law do not extend to overflight in outer space. Thus, space provides the benefit of unrestricted overflight, to include collection of information from denied areas that are otherwise inaccessible from the ground, maritime, or airborne systems.[109] Third, users of space enjoy a global perspective, elsewise unmatched. From rapidly orbiting LEO satellites that circle the earth in 90 minutes to GEO satellites that can see approximately 1/3 of the earth's surface, satellites provide a truly global view of the planet and the actions occurring thereon. This perspective also provides a greater level of responsiveness to change than terrestrial or airborne systems. Many satellites can support multiple users in multiple locations at the same time and rapidly reallocate service to areas with greater need.[110] The fourth and final benefit listed in the Joint Publication is speed, reach, and persistence referring to how orbital mechanics allows satellites to cover vast areas in short periods while also allowing for continuous and persistent operations not achievable through terrestrial methods.[111]

The current National Security Strategy published in 2017 by President Donald Trump notes that maintaining U.S. "leadership and freedom of action in space" is a vital national interest.[112] This strategy recognizes that, as our dependence on space based capabilities has

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[107] *See* "JP 3-14", *supra* note 24 at I–4.
[108] *See ibid*.
[109] *See ibid* at ix, I–4.
[110] *See ibid* at I-4-I–5.
[111] *See ibid* at I–5.
[112] "2017 NSS", *supra* note 8 at 31.

increased, so too have the number of actors who now have access to space capabilities.[113] While this thesis focuses on U.S. National Security impacts, indeed, the risks and benefits derived from space exploration and the growth of mega-constellations are inherently international as they apply equally to all nations who access space capabilities. As such, many of the principles below will apply equally to other Nations and may require international cooperation to fully address.

a. NATIONAL SECURITY USES OF SPACE

Just as the 1946 RAND study predicted, the uses of outer space for the benefits of humanity, as well as militaries, have been ever increasing since the first satellite was placed in orbit. Today, the United States uses many satellites for various capabilities in ensuring the national security. These uses fall into a few categories: Communications; Intelligence, Surveillance, and Reconnaissance (ISR); Weather/Environmental Monitoring; Navigation; and Missile Warning. While these are the main military/traditional national security uses that will be discussed below; it is acknowledged that many other systems integral to national security are also supported by space systems, as well. Indeed, space systems are integral to banking systems, national power grids, public utilities, and much more. While this thesis will not develop these additional national security uses, it is acknowledged that the national security benefits and potential problems are larger than it first appears.

1) Communications (SATCOM)

In 1958, the first prototype military communications satellite was launched into orbit, known as Project SCORE (Signal Communications by Orbiting Relay Equipment), which transmitted a recorded Christmas message from President Eisenhower to the world.[114] Today,

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[113] *See ibid*.
[114] *See* Air University & Air Command and Staff College, and Space Research Electives Seminars, *AU-18 Space Primer*, third edition ed (Maxwell Air Force Base, Alabama: Air University Press, 2009), online: <www.jstor.org/stable/resrep13939> at 10, 183.

militaries have become nearly dependent on SATCOM (satellite communications) capabilities to allow for transfer of information and command and control of forces.[115]

The main benefit of SATCOM is overcoming the terrestrial obstructions and limitations posed by terrain, distance, and the earths curvature by allowing a direct link overhead that is forwarded to the recipient anywhere on earth. The disadvantages associated with SATCOM relate to the vast distance the communication has to travel to reach the satellite in space and then be communicated back to the recipient. This distance creates signal attenuation (loss of some signal due to the distance) which is remedied by increasing the transmission power and the receiver sensitivity.[116] In early SATCOM systems, this meant that the ground terminals had to be larger with more power in order to maintain effective communications. Modern technology, however, has significantly reduced this system disadvantage making satellite ground terminals much smaller and easier to operate.[117]

Another disadvantage related to the signal travel distance is latency when using GEO and MEO communication satellites. As discussed in Chapter 1 above, signals traveling to GEO or MEO orbits can take 240ms or longer one way, not to mention switching or processing time and the return trip to earth.[118] This delay is most noticeable in voice communications.

The United States military uses a variety of different SATCOM satellites to meet its communication needs, to include commercial SATCOM contracts for bandwidth on commercial communications satellites. Military SATCOM satellites are generally expensive to produce as they are designed to provide continuous service, despite jamming or other disruption attempts.[119]

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[115] *See ibid* at 183.
[116] *See ibid* at 184.
[117] *See ibid*.
[118] *See ibid*.
[119] *See ibid* at 183.

These satellites generally are used for the most critical and sensitive communications. The majority of operational SATCOM is provided by commercial SATCOM providers through contracts with the Department of Defense through a DoD combined COMSATCOM office.[120]

Just as communication latency and bandwidth has been the driving force for the current SpaceX, OneWeb, and other broadband mega-constellations, these communication capabilities will provide a direct impact on national security. For example, the U.S. Army currently uses a mix of government and commercial communications satellites in GEO orbit for their bandwidth requirements.[121] According to Maj. Gen. Peter Gallagher, director of the Army Futures Command's Network Cross Functional Team, the current GEO systems have insufficient bandwidth, high latency, and are unlikely to meet the Army's needs in the future.[122] Maj. Gen. Gallagher made those remarks at the 2019 Army's annual conference where he explained that the army was interested in a LEO alternative which can provide "significantly more throughput, more bandwidth, more capacity of your transport pipe with lower latency, so the data will flow much faster from end to end."[123]

This is the same goal the SDA NDSA intends to meet with its proliferated LEO mega-constellation.[124] The increase in rapid data and communication exchange between forward operators, analysts, command teams, and support services through the use of LEO mega-constellations has the potential to greatly improve the efficiency of operations.[125] Additionally, such constellations have the ability to increase connectivity speeds for areas currently

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[120] *See ibid*.
[121] *See* "Army eyes commercial megaconstellations to support its future battlefield network" (15 October 2019), online: *SpaceNews.com* <https://spacenews.com/army-eyes-commercial-megaconstellations-to-support-its-future-battlefield-network/>.
[122] *Ibid*.
[123] *Ibid*.
[124] *See* "SDA Transport Layer", *supra* note 95.
[125] *See* Hallex & Cottom, "Proliferated Constellation Implications", *supra* note 10 at 25–26.

underserved by satellite communications such as the arctic and Pacific ocean.[126] Of course, through the commercial and other nation's mega-constellations, U.S. adversaries will also have increased communication potential to support global operations. For example, China will be able to more directly support its operations in Africa or naval operations in the Pacific.[127]

2) Intelligence, Surveillance, and Reconnaissance (ISR)

ISR is defined by the Department of Defense as "an integrated operations and intelligence activity that synchronizes and integrates the planning and operation of sensors, assets, and processing, exploitation, and dissemination systems in direct support of current and future operations."[128] For space purposes, ISR consists of the observation and detection of information about people and places of interest using a space-based system and the processing of that information for the benefit of military operations.[129] Space systems have the ability to collect a diverse set of information all across the globe that can be invaluable to situational awareness and military planning during conflict or peacetime.[130] This can include humanitarian assistance, disaster management, adversary capability assessment, target analysis, battle damage assessment, and much more.[131] One of the main reasons that space-based ISR is such a valuable tool is that the general rules of airspace sovereignty do not extend to outer space under the Outer Space Treaty that guarantees freedom of exploration and use of outer space by all states.[132]

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[126] *See ibid*.
[127] *See ibid* at 26.
[128] *DOD Terminology Program* (Washington D.C.: Joint Chiefs of Staff, 2020), online: <www.jcs.mil/Doctrine/DOD-Terminology-Program/>.
[129] *See* Air University & Air Command and Staff College, and Space Research Electives Seminars, *Space Primer*, *supra* note 114 at 167.
[130] *See ibid*.
[131] *See ibid*.
[132] *See Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies*, U.N.T.S. 1967 at Art II.

While aircraft can be prohibited by a nation from passing through the airspace above it as that airspace is its sovereign territory, a satellite is under no such restrictions.

One of the most common forms of space-based ISR is imagery collection which consists of imagery gathered via photography, electro-optics, infrared sensors, lasers, or radar sensors which create images of objects.[133] Today there are numerous satellite systems, both governmental and commercial, operated by several different nations that collect space-based remote-sensing or earth observation imagery.[134] Within the United States government, there are several agencies that are responsible for managing space imagery; namely, the National Reconnaissance Office, the National Geospatial-Intelligence Agency, and the Defense Intelligence Agency.[135] These agencies collect, catalog, process, distribute, and maintain databases of imagery collected by national imaging satellites, as well as purchase and collect imagery from commercial satellite operators.

Just as satellite imagery has become a part of daily life through the use of Google Maps and similar navigation and mapping web services, satellite imagery intelligence has become an essential part of the military intelligence program, as evidenced by its role in the 1991 Operation Desert Storm.[136] During Desert Storm, satellite imagery was used to create regularly updated maps of Kuwait and Iraq, to include accessibility of roads, locations of radar sites, as well as identification of Iraqi military command and control locations.[137] The United States military

[133] *See* Air University & Air Command and Staff College, and Space Research Electives Seminars, *Space Primer*, *supra* note 114 at 168.
[134] *See ibid* at 169.
[135] *See ibid*.
[136] *See* Lang, Sharon, *SMDC History: 25 Years Since First 'Space War'* (2016): online: *U.S. Army* <https://www.army.mil/article/161173/SMDC_History__25_years_since_first__Space_War_/?from=RSS>
[137] *See ibid*.

credits the transformative effects of space-based capabilities on how quickly the operation was completed and dubs Operation Desert Storm as the first "space war."[138]

In addition to military use of remote sensing imagery, U.S. federal and local government agencies also use remote-sensing information in support of National Security through natural and manmade disaster response; agricultural productivity monitoring; natural resource management; weather and climate monitoring, urban planning and mapping, transportation infrastructure management; electrical system monitoring; and much more.[139]

As discussed above, DARPA is considering how a remote sensing mega-constellation could fit in the current architecture. Such a constellation could provide imagery to fill gaps between when the current larger high resolution national security satellites can observe an area, allowing for persistent observation from outer space of access-denied areas.[140] These systems could also offer real time global satellite imagery, meaning a view of any point on earth at any time accessible with minimal delay from image capture to reception by analysts on earth.[141]

3) Weather/Environmental Monitoring

Weather information can be critical to military operations.[142] Through a network of GEO and polar orbiting satellites, the U.S. military can create a picture of the weather at any point on earth and monitor environmental changes to provide valuable information for military operations planning.[143] Weather can affect many portions of military operations; from target area specific

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[138] *See ibid.*
[139] *See* "Key Topics – Office of Space and Advanced Technology" (11 February 2019), online: *Department of State* <www.state.gov/key-topics-office-of-space-and-advanced-technology/>; National Research Council, *Using Remote Sensing in State and Local Government: Information for Management and Decision Making* (Washington, D.C.: The National Academies Press, 2003), online: <doi.org/10.17226/10648>.
[140] *See* Lal et al, "Global Trends", *supra* note 5 at 2–4.
[141] *See* Lag, "On The Horizon", *supra* note 47.
[142] *See* Air University & Air Command and Staff College, and Space Research Electives Seminars, *Space Primer*, *supra* note 114 at 201.
[143] *See ibid*.

weather, weapon guidance, safe aviation and naval travel, to mid-air refueling.[144] Satellite weather sensing capabilities also provide monitoring of nuclear, biological and chemical weapon use and effects, worldwide. It can also be used to forecast tides, sea ice conditions, and more for safe surface vessel and submarine operations. The military weather system also collects solar activity and space weather data for safe satellite and space operations.[145] Mega-constellations have the potential to increase the quality and accuracy of weather data through the increased quantity of sensors.

4) Position, Navigation, And Timing (PNT)

Probably the most well-known military satellite capability, the Navstar Global Positioning System (GPS), which was initially procured for military navigation purposes, has now become a publicly available system connected to cell phones, computers, cars, airplanes, banks, ATMs, and more used by millions of people every day.[146] The U.S. GPS system is a constellation of around 29 satellites orbiting the Earth in six orbital planes in MEO.[147] With this setup, a user should be able to receive signals from four GPS satellites at any given time.[148] GPS operates by each satellite broadcasting its location, status, and precise time and a GPS device receiving these signals from four satellites, and using geometry to determine its three-dimensional location on earth.[149] GPS location information is used by aircraft, naval vessels, and troops on the ground for accurate navigation and mapping. It is also used for guiding precision

[144] *See ibid*.
[145] *See ibid* at 201–202.
[146] *See ibid* at 217–218.
[147] *See* "GPS: Frequently Asked Questions" (29 May 2020), online: *GPS.gov* <www.gps.gov/support/faq/#jamming>.
[148] *See* Air University & Air Command and Staff College, and Space Research Electives Seminars, *Space Primer*, *supra* note 114 at 218.
[149] *See* "GPS FAQ", *supra* note 147.

munitions to their intended targets and is more precise than other forms of precision guidance as GPS signals are not obstructed by cloud cover.[150]

The GPS system also provides accurate timing information. The DoD uses Coordinated Universal Time (UTC) for operations world-wide and precision timing is important to many military applications.[151] One such use is coordinated frequency changes for military communication systems. These systems change frequency at precise times to prevent adversaries from intercepting the communications. Using the precision timing information from GPS, these systems can operate seamlessly without user input.[152]

The GPS system has one additional function: detection of nuclear detonations in support of treaty monitoring and nuclear force management.[153] This part of the system uses optical, x-ray, dosimeter, and electromagnetic pulse sensors to detect, pinpoint, and quantify the yield of a nuclear detonation.[154]

5) Missile Warning

In the late 1950s through the 1960s, the Missile Defense Alarm System (MIDAS) operated to detect exhaust gases from ICBMs (intercontinental ballistic missiles) and provide early warning of their launch.[155] Today, the Space Based Infrared Surveillance (SBIRS) satellites in GEO and HEO, as well as Defense Support Program satellites, perform early warning for missile launches. SBIRS and missile defense is considered one of the nation's highest priority space programs.[156] Information concerning a missile launch gathered by the

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[150] *See* Air University & Air Command and Staff College, and Space Research Electives Seminars, *Space Primer*, *supra* note 114 at 217.
[151] *See ibid*.
[152] *See ibid*.
[153] *See ibid* at 218.
[154] *See ibid*.
[155] *See ibid* at 227.
[156] *See* "Space Based Infrared Surveillance SBIRS" (20 March 2018), online: *Lockheed Martin* <www.lockheedmartin.com/en-us/products/sbirs.html>.

sensors is rapidly processed with other available data and provides combatant commanders with details such as identification of type, launch location, in-flight data, and predicted impact point which can then be used by military missile defense assets to respond to an attack.[157]

Proliferated LEO mega-constellations with imaging, radar, and/or ELINT capabilities will be beneficial for missile warning and defense. As the mega-constellations are capable of providing nearly continuous coverage of the entire earth, these capabilities can be put to use to provide continuous coverage of known missile operating areas.[158] Further, the SDA is already planning to use the LEO mega-constellation NDSA for this purpose.[159] Specifically, the tracking layer is being designed to provide global warning, tracking and targeting of missile threats for missile defense, to include advanced hypersonic missile systems.[160] The same reduced latency, global coverage, and redundancy that benefits LEO mega-constellation communications capability will improve missile warning and defense.

6) Nuclear Deterrent Operations

While not an entirely separate use from those previously discussed, the United States uses a combination of ISR, communications, missile warning, and the other space-based capabilities to deter strategic attacks on the United States and its allies. This system relies on space based and terrestrial sensors and intelligence to remain aware of military actions by adversaries, globally. Early warning systems are critical to ensuring a retaliatory strike is possible before an enemy makes a successful first strike.[161] The system also uses secure communications satellites

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[157] *See* Air University & Air Command and Staff College, and Space Research Electives Seminars, *Space Primer*, *supra* note 114 at 227.
[158] *See* Hallex & Cottom, "Proliferated Constellation Implications", *supra* note 10 at 26.
[159] *See* Theresa Hitchens, "Thompson: AFSPC Will Use Mega Constellations" *Breaking Defense* (30 April 2019), online: <breakingdefense.com/2019/04/thompson-afspc-will-use-mega-constellations/>.
[160] *See* "Tracking – Space Development Agency", online: <https://www.sda.mil/tracking/>.
[161] *See* Herbert F York, "Nuclear Deterrence and the Military Uses of Space" (1985) 114:2 Daedalus 17–32, online: <www.jstor.org/stable/20024976> at 19–21.

to ensure 24/7, 365 unjammable, redundant communication between the country's senior leadership and the nuclear triad of bombers, submarines and missile silos that are ever on alert.[162] Navigation and timing support is essential to secure communications, military planning, and precision munitions delivery. This system of nuclear operations and deterrence would not be possible without space-based capabilities.[163]

b. INCREASING THREATS IN SPACE

As summarized by the 2020 United States Defense Space Strategy (DSS) Summary, released in June 2020, "Space is vital to our Nation's security, prosperity, and scientific achievement. Space-based capabilities are integral to modern life in the United States and around the world and are an indispensable component of U.S. military power."[164] The DSS further notes that the United States, more than any other nation, relies on space-based capabilities to protect national security and project power across the globe.[165] The DSS goes on to note that access to and freedom to operate in space are not guaranteed; and notes how potential adversary actions, as well as commercial developments, have made the space environment more complex and the threats more numerous.[166]

While the U.S. appears to be the most space dependent country in the world currently, the use of space-enabled capabilities is increasing world-wide and is leading to space being an essential element of most nations' national security. As discussed above, technological advancements are making access to space more affordable and, thus, more accessible to users

[162] *See* Jim Garamone, "Nuclear Triad Will Continue to Deter, STRATCOM Commander Says", *DOD News* (17 March 2020), online: <www.defense.gov/Explore/News/Article/Article/2114855/nuclear-triad-will-continue-to-deter-stratcom-commander-says/>.
[163] *See* York, "Space Nuclear Deterrence", *supra* note 161 at 19–22.
[164] "2020 DSSS", *supra* note 8 at 1.
[165] *See ibid* at 3.
[166] *See ibid*.

globally.[167] Since 2013, the number of satellites in operation has increased nearly 50%.[168] Governments, in particular, have the ability to field satellites that support their own military and national security activities.[169] Currently, more than 50 countries have active satellites orbiting the planet.[170] Of those countries, nine have independent launch capability: China, India, Iran, Israel, Japan, Russia, North Korea, South Korea, and the United States.[171] The European Space Agency also provides launch capability collectively to its members and partners: Austria, Belgium, Canada*, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, The Netherlands, Norway, Poland, Portugal, Romania, Slovenia*, Spain, Sweden, Switzerland, and the United Kingdom.[172]

As a result of these advancements, the space environment is getting "increasingly congested, contested, and competitive," according to the U.S. Government.[173] These 3 C's describing the outer space environment were explained in detail in the 2011 National Security Space Strategy (NSSS) summary.[174]

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[167] *See Competing in Space* (Wright Patterson AFB, Ohio: National Air and Space Intelligence Center, 2018), online: <media.defense.gov/2019/Jan/16/2002080386/-1/-1/1/190115-F-NV711-0002.PDF> at 25; *Challenges to Security in Space* (Washington, D.C.: Defense Intelligence Agency, 2019), online: <www.dia.mil/Portals/27/Documents/News/Military%20Power%20Publications/Space_Threat_V14_020119_sm.pdf> at 7.

[168] *See* "DoS Key Topics", note 139.

[169] *See* "Competing in Space", *supra* note 167.

[170] *See* "April 2020 Satellite Database", *supra* note 6; "Challenges to Security", *supra* note 167 at 7.

[171] *See* "Challenges to Security", *supra* note 167 at 7.

[172] *See* "ESA Member States, Canada and Slovenia" (29 July 2020), online: *ESA* <www.esa.int/Education/ESA_Member_States_Canada_and_Slovenia>. States indicated with an asterisk are not ESA member states but have agreements with ESA that qualify them participation in certain ESA activities. Slovenia has notably been heavily involved with Remote Sensing through the University of Maribor and the Faculty of Electrical Engineering and Computer Science hosting ESA training courses. "Slovenia signs Association Agreement" (5 July 2016), online: *ESA* <www.esa.int/About_Us/Corporate_news/Slovenia_signs_Association_Agreement>.

[173] "JP 3-14", *supra* note 24 at viii.

[174] *See 2011 National Security Space Strategy Unclassified Summary* (Department of Defense and Director of National Intelligence, 2011), online: <https://archive.defense.gov/home/features/2011/0111_nsss/docs/NationalSecuritySpaceStrategyUnclassifiedSummary_Jan2011.pdf>.

1) Congested

The first "C", congested, refers to the increase of the number of satellites in orbit and man-made space debris, as well as the congestion of radio frequency spectrum. While outer space is vast, the useful orbital planes in space are relatively few in number and already used by the approximately 2600 operational satellites, and 1400 or so inactive satellites, currently in orbit. Additionally, all spacecraft destined for higher orbits must fly through lower orbits.

In addition to the satellites still in orbit, there is also a large amount of space debris. At time of the 2011 NSSS, the "DoD track[ed] approximately 22,000 man-made objects in orbit, of which 1,100 are active satellites," and was aware of hundreds of thousands of smaller objects that are too small to track.[175] Today, more than 500,000 pieces of debris the size of a marble or larger are tracked orbiting the earth with "many millions of pieces of debris that are so small they can't be tracked."[176] The majority of all space debris is in LEO, through which all spacecraft ascend and many de-orbit at the end of mission.[177] A collision with any one of these pieces can cause major damage to spacecraft. Between the increase in launches and the growth in space debris, the useful parts of space are getting more congested.[178]

As to radiofrequency congestion, each active satellite in space uses multiple frequencies for command, tasking, telemetry, and mission communications. The International Telecommunication Constitution, Convention and regulations together compose the international agreement that governs radiofrequency use as well as assignment of GEO orbital slots. The convention recognized that the electromagnetic frequency spectrum and orbital positions are

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[175] *Ibid* at 1–2.
[176] Mark Garcia, "Space Debris and Human Spacecraft" (13 April 2015), online: *NASA* <www.nasa.gov/mission_pages/station/news/orbital_debris.html>.
[177] *See* Paul B Larsen, "Small Satellite Legal Issues" (2017) 82:2 J Air L & Com 275 at 300.
[178] *See* Steve Skotte, "Space Is Congested" (23 March 2020), online (blog): *DAU News* <www.dau.edu/training/career-development/program-management/blog/Space-Is-Congested>.

finite, rules must be made to prevent conflicts, and some level of equitable distribution must occur to ensure that the entire spectrum is not used solely by developed countries, leaving developing countries without access.[179] The International Telecommunication Union (ITU) is a body of the United Nations that implements the Convention. With the expected growth of the number of satellites in orbit, the risk of harmful radiofrequency interference also increases as more satellites attempt to use this limited resource.[180]

2) Contested

Space is also *contested* in that more countries and non-state actors are developing counterspace capabilities to "deny, degrade, deceive, disrupt, or destroy" satellites in space.[181] In particular, the 2020 DSS notes that U.S. space assets are "potential targets at all levels of conflict" due to their strategic importance to the United States.[182] In fact, the U.S. military's historical advantages gained through the use of space-based capabilities over the past 25 years, as well as our increasing reliance on those systems, makes U.S. satellites attractive targets for counterspace weapons to potential adversaries."[183]

The use of outer space is governed by a series of United Nations treaties, as well as several bilateral and multilateral disarmament agreements. One of the most foundational international agreements, the 1967 Outer Space Treaty, to which 110 countries are party, prohibits placing weapons of mass destruction (WMD) in orbit or on any celestial body in

[179] *See Constitution of the International Telecommunication Union* (Geneva: International Telecommunication Union, 2019).
[180] *See* "2011 NSSS", *supra* note 174 at 2.
[181] *Ibid* at 3.
[182] "2020 DSSS", *supra* note 8 at 1.
[183] Joseph Trevithick, "USAF Secretary Gives Ominous Warning That Show Of Force Needed To Deter Space Attacks" *The Drive, The Warzone* (11 April 2019), online: <www.thedrive.com/the-war-zone/27396/usaf-secretary-gives-ominous-warning-that-show-of-force-needed-to-deter-space-attacks>; "Challenges to Security", *supra* note 167 at 7.

space.[184] Further, the moon and celestial bodies may only be used for peaceful purposes and all activities in outer space must be carried out "in the interest of maintaining international peace and security. . . "[185]

While some nations have attempted to interpret this language as prohibiting militarization of space, none of this language outright prohibits military uses of outer space, WMDs from traveling through space, the placement of non-WMD weapons in space, nor anti-satellite weapons.[186] Additionally, the outright requirement of "exclusively for peaceful purposes" was proposed during preparatory work for the OST, but was rejected by both the US and USSR.[187] In essence, the language has been interpreted to allow all "non-aggressive" uses of outer space; an interpretation that conforms with the general principle of international law that prohibits the threat and use of force contained in Article 2(4) of the UN Charter.[188] This interpretation allows for military uses of space such as arms control, and deterrence, as they have a peaceful intent.[189] It also allows for use that enhances military actions in other domains.

Under the non-aggression doctrine, the development and deployment of counterspace weapons is permissible. This has allowed the development of several different types of counterspace weapons: kinetic, non-kinetic physical, electronic, and cyber weapons.[190] Each of

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[184] *See OST*, *supra* note 132 s IV.
[185] *Ibid* at III, IV.
[186] *See* "Legal Agreements & Space Weapons" (11 February 2004), online: *Union of Concerned Scientists* <ucsusa.org/resources/legal-agreements-space-weapons>.
[187] Colleen Driscoll Sullivan, "The Prevention of an Arms Race in Outer Space: An Emerging Principle of International Law" (1990) 4:2 Temp Intl & Comp LJ 211, at 222-223.
[188] *See* Jinyuan Su, "The "Peaceful Purposes'' Principle in Outer Space and the Russia-China PPWT Proposal" (2010) 26 Space Policy 81–90, online: <reader.elsevier.com/reader/sd/pii/S026596461000024X?token=C35442B5865675A57E8B4AEA3B07036D4D368AE00BD3FB7A470D786804765A99C798CEBA96CF186968A780BE5C18CD94> at 82–83.
[189] *See Ibid* at 222.
[190] *See* Todd Harrison et al, *Space Threat Assessment 2020* (Center for Strategic & International Studies; Aerospace Security Project, 2020), online: <csis-website-prod.s3.amazonaws.com/s3fs-public/publication/200330_SpaceThreatAssessment20_WEB_FINAL1.pdf?6sNra8FsZ1LbdVj3xY867tUVu0RNHw9V>.

these types of counterspace weapons cause different effects, either permanent or temporary, and can come in different forms.[191] Kinetic anti-satellite (ASAT) weapons were some of the first developed. These systems operate by causing damage by making physical impact with the target satellite. Both the USA and USSR developed kinetic ASAT systems as part of ballistic missile defense programs during the 1950s.[192] These early systems were not optimal ASAT systems as the explosion would indiscriminately destroy any nearby satellites and the resultant radiation would continue damaging satellites in low earth orbit.[193]

Today, Kinetic ASAT weapons include direct-ascent and co-orbital ASAT weapons. As recently as 15 July 2020, Russia tested another co-orbital ASAT system, according to U.S. Space Command.[194] In this test, Russian inspector satellite Cosmos 2543 released a smaller object into orbit at high speeds.[195] Curiously, Cosmos 2543 was actually deployed from another Russian inspector satellite, Cosmos 2542, in December 2019. These same satellites shadowed the US KH-11 spy satellite named US 245 in February of this year by matching their orbital period in a manner that allowed the Russian satellites to maintain constant surveillance of the US satellite rather than passing every 11-12 days as on their original orbits.[196] The combination of these two recent actions by these Russian satellites shows the potential danger of "killer satellites" with the ability to maneuver close to another satellite and disrupt its operations or destroy it.[197] This

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[191] *See ibid* at 2.
[192] *See* Laura Grego, *A History of Anti-Satellite Programs* (Cambridge, Massachusetts: Union of Concerned Scientists, 2012), online: <www.ucsusa.org/sites/default/files/2019-09/a-history-of-ASAT-programs_lo-res.pdf> at 2.
[193] *See ibid*.
[194] *See* Tyler Rogoway, "Russia Tests Another Anti-Satellite Weapon as Battleground Space Looms" *The Drive, The Warzone* (21 December 2016), online: <www.thedrive.com/the-war-zone/6631/russia-tests-another-anti-satellite-weapon-as-battleground-space-looms>.
[195] *See* Theresa Hitchens, "Russian Sat Spits Out High-Speed Object In Likely ASAT Test", *Breaking Defense* (23 July 2020), online: <breakingdefense.com/2020/07/russian-sat-spits-out-high-speed-object-in-likely-asat-test/>.
[196] *See* Joseph Trevithick, "A Russian 'Inspector' Spacecraft Now Appears To Be Shadowing An American Spy Satellite" *The Drive, The Warzone* (30 January 2020), online: <www.thedrive.com/the-war-zone/32031/a-russian-inspector-spacecraft-now-appears-to-be-shadowing-an-american-spy-satellite>.
[197] *See ibid*.

destruction or disruption could be accomplished by several means, to include: spraying chemicals, high-power microwaves, blinding lasers, radiofrequency jamming, or using a mechanism to physically capture and attach to the target satellite

Non-kinetic physical weapons are generally directed-energy systems such as lasers or highly focused radiofrequencies which can be used to disable, damage or destroy a satellite or ground station without making physical contact.[198] The effect of these weapon systems generally happen very quickly after implementation as the energy used generally travels at the speed of light, a characteristic that also makes the use of these weapons systems harder to detect and accurately attribute.[199] Laser counterspace systems can be operated from the ground but require high-power and high-quality laser beams as well as sophisticated tracking and control and adaptive optics which can take into account the distortion caused by traveling through the atmosphere. If successful, such attacks can damage or disable sensors and solar arrays on satellites, causing temporary or permanent damage.[200] A high-powered radiofrequency, or microwave, weapon can interfere with a satellites electrical operation, corrupt memory data, and cause permanent damage to electrical circuits and processors.[201] These systems are currently in-development by several nations, to include France's proposed laser-armed mini-satellites for defense purposes.[202]

Electronic counterspace weapons exploit a satellite's essential communications using electromagnetic radio frequencies. These systems generally use jamming or spoofing techniques to interfere with communications between the satellite and ground stations. Jamming is the

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[198] *See* "Competing in Space", *supra* note 167 at 21; Harrison et al, "Space Threat Assessment 2020", *supra* note 190 at 3.
[199] *See* Harrison et al, "Space Threat Assessment 2020", *supra* note 190 at 3.
[200] *See ibid*.
[201] *See ibid* at 3–4.
[202] *See* Trevithick, *Space Force Go for Launch*, *supra* note 104.

prevention of sending signals to (uplink) or receiving signals from (downlink) satellites by creating radio frequency noise in the same frequency band and at a direction that can be picked up by the satellite's or receiver's antennae.[203] This frequency noise prevents that proper reception of the intended communication. Such interference can be difficult to distinguish from unintentional interference between properly operating systems that use close or identical frequencies.[204] Intentional jamming is also completely reversable in that as soon as the jamming system is turned off, the system communications will resume operating as normal.[205] This can make identification and attribution of intentional jamming difficult.[206]

Spoofing is a more sophisticated version of electronic counterspace weaponry that attempts to trick the satellite or ground station into accepting the fake signal being transmitted by the spoofing system as the real signal.[207] Spoofing the downlink or uplink of a satellite can cause injection of faulty data into the system. Spoofing of tracking, telemetry, and control signals by an attacker can possibly give them full control over the satellite.[208] Such spoofing would require cracking the encryption used to protect the signal, which is generally considered a difficult proposition. One type of spoofing that does not require cracking of encryption is "meaconing," which is the rebroadcast of a previously broadcast original signal without altering the signal. This method has been used to spoof GPS signals through time-delayed rebroadcasts.[209] The technology necessary to create a jamming or spoofing counterspace weapon is commercially

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[203] *See* Harrison et al, "Space Threat Assessment 2020", *supra* note 190 at 4.
[204] *See ibid*.
[205] *See ibid*.
[206] *See ibid*.
[207] *See ibid*.
[208] *See ibid*.
[209] *See ibid*. In 2017, Norway's largest regional airport in the northern-most part of the country lost GPS signal due to jamming. Analysis indicates that Russia was responsible for the jamming. It is also possible that Russia performed additional jamming in January 2019 when the norther region of Norway once again lost GPS signal. Todd Harrison et al, "Space Threat Assessment 2019 Summary" (4 April 2019), online: *Aerospace Security* <aerospace.csis.org/space-threat-assessment-2019/>.

available and relatively inexpensive since the technology needed is nearly identical to that needed for legitimate satellite operations.[210]

Cyber counterspace attacks target the data within the signals, rather than the radio signals themselves.[211] Just as personal computers and internet websites can be disrupted by malware, viruses, denial of service attacks, and more, so too can satellite data systems if an attacker can find an entry point.[212] Cyberattacks can be used to monitor or steal data, corrupt data, shut down components, or even take control of the entire system.[213]

The growing interest in ASAT systems currently seen worldwide is particularly concerning for National Security purposes since many space systems play important roles in early warning systems, disaster response, as well as essential communications. These systems are also key to the United States' nuclear deterrent program.[214] Intentional attacks on any one of these numerous systems using counterspace weapons could have grave effects and untold political ramifications.

3) Competitive

Last, space is continually getting more *competitive.* With the rapid growth of commercial space activities in the past few decades, many more countries, companies, and other entities have access to space and space-based capabilities than ever before.[215] Long gone are the days when you had to develop and launch your own satellite to access space-based capabilities such as imagery, location data, weather data, communications, and even human space flight. All of these

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[210] *See* Harrison et al, "Space Threat Assessment 2020", *supra* note 190 at 4; Grego, "ASAT Program History", *supra* note 192 at 15.
[211] *See* Harrison et al, "Space Threat Assessment 2020", *supra* note 190 at 4–5.
[212] *See* "Challenges to Security", *supra* note 167 at 19; Harrison et al, "Space Threat Assessment 2020", *supra* note 190 at 5.
[213] *See* Harrison et al, "Space Threat Assessment 2020", *supra* note 190.
[214] *See* Trevithick, *Space Force Go for Launch*, *supra* note 104.
[215] *See* "Challenges to Security", *supra* note 167 at 7.

capabilities are now, or soon will be, widely available through commercial entities.[216] The Defense Intelligence Agency of the United States recognizes that this commercialization and availability of space-based capabilities "is reducing the ability of all countries to remain undetected while performing sensitive testing and evaluation activities or military exercises and operations."[217] Access to these capabilities may even allow relatively small non-state actors (e.g. terrorist groups) to improve operations or counter U.S. operations.[218] Along with the erosion of the U.S. technological advantage, there are additional international competition effects on the U.S. space industry associated with acquiring and retaining a technical workforce, specialized supplies, and critical technologies in order to maintain a technological edge.[219]

While nearly a decade has passed since the 2011 NSS was published using the 3 C description of the outer space environment, the current U.S. administration continues to use the same terms. In 2018, President Trump published several policy documents specifically related to space. On 23 March 2018, President Donald J. Trump unveiled his "America First National Space Strategy".[220] A major priority of this NSS is public-private partnership and support for the American commercial space industry as the means to maintain America's space technological superiority.[221] This priority is a response to the increased competitiveness of space. In the 18 June 2018 Space Policy Directive-3, which focuses on space traffic management (STM), the Trump administration recognized that "space is becoming increasingly congested and contested,

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[216] *See* "2017 NSS", *supra* note 8 at 31.
[217] *See* "Challenges to Security", *supra* note 167 at 7.
[218] *See* "Competing in Space", *supra* note 167 at 25.
[219] *See* "2011 NSSS", *supra* note 174 at 3.
[220] "President Donald J. Trump is Unveiling an America First National Space Strategy" (23 March 2018), online: *The White House* <www.whitehouse.gov/briefings-statements/president-donald-j-trump-unveiling-america-first-national-space-strategy/>.
[221] *See ibid*. One of the first paragraphs of the 2018 NSS states the priority this way: "The Trump administration's National Space Strategy prioritizes American interests first and foremost, ensuring a strategy that will make America strong, competitive, and great." *Ibid*.

and that trend presents challenges for the safety stability, and sustainability of U.S. space operations."[222] This recognition of the ever increasing threats to safe and sustainable space use has led to a plurality of responses.

c. MEGA-CONSTELLATION EFFECTS ON NATIONAL SECURITY

In addition to the impacts on the space programs listed above, mega-constellations will also lead to more effects on national security, both positive and negative. It is recognized that the majority of the effects discussed below are international in nature. That being said, this thesis will focus on the U.S. view of these effects and the legal implications.

1) Rapid Launch

Space launch is a highly regulated national activity. While not a specific advantage of mega-constellations, the boom of such constellations will have a major impact on the small satellite launch and rapid launch industries and their regulation. With thousands of smallsats set to be launched just for the mega-constellations already announced in the coming decades, further industry concentration on and competition in the small satellite launch sector appears assured.[223] These developments have already started driving down launch costs, a trend that is expected to continue.[224] Further developments in the small launch industry will also likely improve launch

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[222] *See Space Policy Directive-3, National Space Traffic Management Policy* (Washington, D.C.: The White House, 2018), online: <www.whitehouse.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/>.

[223] *See* Mike Safyan, "Rocket Launch Trends Roaring into the 2020s" (30 January 2020), online (blog): <www.planet.com/pulse/rocket-launch-trends-roaring-into-the-2020s/>; Jeff Matthews, "The Decline of Commercial Space Launch Costs" *Deloitte United States* (2020), online: <www2.deloitte.com/us/en/pages/public-sector/articles/commercial-space-launch-cost.html>; But see Jeff Foust, "Out to Launch: The Small Launch Industry's Inflection Point" *SpaceNews* (3 August 2020), online: <spacenewsbusiness.net/SNDE/87e9d8c6558f1b358b413106cc3cddb3849922c5.pdf>. SpaceNews reports that the small launch vehicle industry is at an inflection point due to the global COVID-19 pandemic and a series of small launch vehicle failures which have led investors to shy away from the small launch vehicle industry. This downtrend is exacerbated by the expansion of the affordable ride share programs of SpaceX and other larger launch vehicle companies. *Ibid* at 12.

[224] *See* Matthews, *Decline of Launch Costs*, *supra* note 223; Jones, "Reduction in Space Launch Cost", *supra* note 45.

timeline responsiveness. Short-timeline, or rapid launch, will be a benefit to National Security as, until recently, national security spacecraft launch was a process that took years of planning and coordination and used only a limited number of launch locations that each relied on complex, one-of-a-kind infrastructure.[225] This launch process was expensive and limited the flexibility of development timelines, launch dates, and more. This added to the decision matrix that pushed most national security satellites to be built exquisitely, with redundant systems, designed to last. This design structure is also expensive, thus reducing the number of satellites and launches that could be afforded within the budget. All of this resulted in the current situations where the majority of national security space assets are large, sophisticated satellites hosting multiple capabilities in high orbits that are difficult to disguise or defend making them attractive targets for adversaries.[226]

As discussed above, the entry of commercial companies into the launch market, as well as the development of smallsat focused launch vehicles have made flexible, rapid (short-time line) launch at reduced expense a real possibility.[227] A rapid launch capability specifically benefits the reconstitution ideal of space resiliency by ensuring that vulnerable national security satellites can be quickly replaced. In fact, the United States Air Force Air University, Space Horizons Research Task Force released a study in January 2017 on "Fast Space: Leveraging Ultra Low-Cost Space Access for 21st Century Challenges."[228] This report recognizes that industry developments have the potential to reduce launch costs between 3 and 10 times lower than today and potentially lead to "aviation-like sortie access to space" within "hours rather than

[225] *See* "DARPA Launch Challenge" (25 July 2020), online: *DARPA* <darpalaunchchallenge.org/about.html>.
[226] *See* Jones, "Reduction in Space Launch Cost", *supra* note 45 at 6.
[227] See Air University, *Fast Space: Leveraging Ultra Low-Cost Space Access for 21st Century Challenges* (Maxwell Air Force Base, Alabama: USAF Air University, 2017), online: <www.airuniversity.af.edu/Portals/10/Research/Space-Horizons/documents/Fast%20Space_Public_2017.pdf> at 25.
[228] Air University, "Fast Space", *supra* note 227.

days" through "a rapidly deployable launch-on-demand system."[229] Such capabilities can provide the "ability to immediately deliver additional effects worldwide such as precision navigation and timing, electronic warfare, cyber effects, directed energy, kinetic attack, and rapid global transport of cargo and personnel."[230]

Rapid launch, when paired with rapid manufacturing of smallsats for specific missions, will allow a degree of space-based national security capability responsiveness, heretofore unheard of. Such developments could potentially allow for mission specific satellites to be launched into LEO within a matter of weeks or days of initial planning, as compared to the year plus timeline currently used, at a significantly reduced cost, as well. This rapid launch and refresh time could allow the military to develop "payloads tailored to maximize immediate effect instead of mission duration."[231]

The U.S. military is already taking advantage of the benefits of small launch by "having small and dedicated satellites that can be launched with little advanced warning."[232] Following up on the smallsat architecture are several programs focused on rapid launch of these satellites. Known as the operationally responsive space-lift initiative, the United States Air Force began researching rapid launch options in 2003.[233] This program considered the benefits of space planes, air-launched boosters, and other option to move launch timelines from months down to hours or days.[234]

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[229] *Ibid* at II, 7–8.
[230] *Ibid* at 2.
[231] *Ibid*.
[232] Ram S Jakhu & Joseph N Pelton, *Small Satellites and Their Regulation*, SpringerBriefs in Space Development (New York, NY: Springer New York, 2014), online: <http://link.springer.com/10.1007/978-1-4614-9423-2> at 14.
[233] *See* Air University & Air Command and Staff College, and Space Research Electives Seminars, *Space Primer*, *supra* note 114 at 270.
[234] *See ibid*.

More recently, DARPA ran a prize-based program in 2020 called the "DARPA Launch Challenge" which challenged commercial competitors to "launch payloads on extremely short notice, with no prior knowledge of the payloads, destination orbit or launch site and do it not just once, but twice, in a matter of days."[235] This challenge aimed to find unique solutions for rapid and flexible launch of smallsats to support resilient military space capabilities.[236] While the program closed with no winners (the final competitor, Astra, scrubbed its launch with less than a minute left), it was viewed as a success by DARPA who recognized that the rapid launch industry has matured to the point where a company could be prepared for a launch within a little over two weeks.[237]

Just as commercial improvements in small launch vehicles will benefit the U.S. government, these improvements will make rapid launch more available to adversaries. An adversary's ability to quickly launch satellites with short notice could be used against U.S. national security interests. In his paper, "A 2019 View of the Impending Small Launch Vehicle Boom," Carlos Niederstrasser, a Northrop Grumman master systems engineer, listed 148 small launch vehicle projects that may be available to the United States (meaning that Iranian projects are not included).[238] At that time, only eight of the launch vehicles had flown, but five of them were Chinese.[239]

The rapid launch movement raises a legal issue, however: as the launch of space objects is highly regulated, can current regulations keep pace with industry desire for rapid launch?

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[235] "DARPA Launch Challenge", note 225.
[236] *See ibid*.
[237] *See* "DARPA Launch Challenge Closes with No Winner", *SpaceNewsFeed.com* (3 March 2020), online: <www.spacenewsfeed.com/index.php/news/4428-darpa-launch-challenge-closes-with-no-winner>.
[238] *See* Debra Werner, "How Many Small Launch Vehicles are Being Developed? Too Many to Track!" (24 October 2019), online: *SpaceNews* <spacenews.com/carlos-launch-vehicle-update-iac/>.
[239] *See ibid*.

2) Space Situational Awareness (SSA)

Given the growing number of satellites being launched, as well as the amount of space debris present, accurate tracking and prediction of space object location and operations is become ever more essential to safe space operations.[240] This concept is known as space situational awareness (SSA). The United States considers SSA "fundamental" to all space operations; particularly those concerning national security, as it helps avoid collisions and ensure continued operations.[241]

The United States DoD and NASA work together to track and catalog debris, as well as to characterize the satellite environment.[242] The Department of Defense, through the recently reconstituted United States Space Command (USSPACECOM) operates the Space Surveillance Network (SSN) which uses a system of ground and space based sensors to track space objects and makes basic SSA data available publicly to registered users at www.space-track.org.[243] The information gathered from the SSN system is used to predict collisions between satellites (conjunctions) or space debris and provide warnings (conjunction warnings), when possible, to allow satellites to take evasive maneuvers.[244] It is also used in operational planning to ensure the safety of launches and operations of spacecraft.[245]

The boom in smallsat LEO mega-constellations will likely tax the current SSA infrastructure of ground-based radars and SSA communication. [246] If all of the proposed mega-

[240] *See* "Challenges to Security", *supra* note 167 at 10.
[241] "JP 3-14", *supra* note 24 at II–1.
[242] *See* Garcia, "Space Debris & Human Spacecraft", *supra* note 176.
[243] *See* "Space-Track.org" (2 July 2020), online: *Space-Track.org* <www.space-track.org/documentation#odr>.
[244] *See* Col Mark A Baird, "Maintaining Space Situational Awareness and Taking It to the Next Level" (2013) 27:5 Air & Space Power J, online: <www.airuniversity.af.edu/Portals/10/ASPJ/journals/Volume-27_Issue-5/SLP-Baird.pdf>.
[245] *See ibid* at 51.
[246] *See generally* Klein, *Understanding Space Strategy*, *supra* note 39 at 200. LEOSAT, a California-based company, is developing an SSA system of ground-based, phased-array radars specifically to monitor LEO and provide SSA services commercially noting the planned rise in smallsats and cubesats as a market driver making their business possible. *Ibid.*

constellations are in fact launched, there is the potential to more than quintuple the number of satellites in space within the next decade.[247] Each launch of these satellites has the potential to create even more space debris from rocket bodies, detachable stages, and satellite/launch vehicle interface parts, to name a few.[248]

While adequate SSA coverage allows us to identify, track, and catalog satellites, a lack of this coverage due to current system limitation and over-tasking from mega-constellations may result in misidentification of orbit tracks, failure to identify new objects released from satellites (like that from the recent Russian inspector spacecraft discussed above), or other nefarious changes to a satellite or its orbital parameters.[249] Many of the technological breakthroughs that are making mega-constellations possible also add complexity to acquiring accurate SSA data.

The DoD SSN system's primary sensor network is ground-based and was designed for early warning missile tracking. The capabilities of this system work well at identifying and tracking satellites in simple orbits.[250] The sheer number of new satellites will pose a challenge to the system to accurately catalog and track potential conjunctions.[251] The current SSN system attempts to verify its catalog of orbital information every several hours, yet the addition of many thousand more satellites without increased SSA infrastructure will force longer delays between rechecks of orbits. Formation flying, or multiple smallsats traveling relatively closely together

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[247] *See* Tate Ryan-Mosley, Erin Winick & Konstantin Kakaes, "The Number of Satellites Orbiting Earth Could Quintuple in the Next Decade" *MIT Technology Review* (26 June 2019), online: <www.technologyreview.com/2019/06/26/755/satellite-constellations-orbiting-earth-quintuple/>.

[248] *See* Bill Keeter, "Space Debris" (5 December 2018), online: *NASA* <www.nasa.gov/centers/hq/library/find/bibliographies/space_debris>.

[249] *See* P North et al, "SSA Degradation from Large Constellations: A Starlink-based Case Study" (Paper delivered at the 2020 International Conference on Space Situational Awareness, 15 January 2020) [unpublished], online: <https://celestrak.com/publications/ICSSA/2020/IAA-ICSSA-20-00-20.pdf>.

[250] *See* Bhavya Lal et al, *Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)* (Washington D.C.: Institute for Defense Analyses, 2018), online: <www.ida.org/-/media/feature/publications/g/gl/global-trends-in-space-situational-awareness-ssa-and-space-traffic-management-stm/d-9074.ashx> at 14.

[251] *See ibid*.

and working as a group, will also challenge the current system which has difficultly distinguishing between objects traveling close together.[252]

Further, the addition of propulsion systems and atmospheric drag systems for smallsats can allow these satellites to change their orbits in ways that make orbital prediction and projection difficult to obtain using the current SSN that only reverifies orbits every several hours.[253] This causes issues of misassociation and mistagging of orbits when a satellite maneuvers while it is not being actively tracked and is not located where it is anticipated when the SSA reverification occurs.[254] This problem is exacerbated by mega-constellations that use satellites all of the same size and shape because the SSA sensor cannot use this information to discriminate between several of the same satellites that are using the same or similar orbits.[255] Further, these maneuvers frustrate conjunction warnings that are based upon predictions made days in advance with no assumption of orbital changes or maneuvers.[256] According to one expert in the field, on-board automated propulsion and maneuver systems, similar to those being proposed for many mega-constellations, are "fundamentally incompatible" with the current SSA catalog, tracking, and conjunction warning system timeline.[257] According to a 2020 study of the SSA degradation effects of large constellations, an adversary could take advantage of the misassociation of orbits for mega-constellations to mask their actions.[258]

Exacerbating all of the above problems is the reduction in size of new satellites.[259] Swarm's 125 satellite 1/4 U SpaceBee constellation, for example, uses satellites the size of

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[252] *See ibid*.
[253] *See ibid* at 16–17; North et al, , *supra* note 249 at 17.
[254] *See* North et al, , *supra* note 249 at 17.
[255] *See ibid*.
[256] *See* Theodore J Muelhaupt et al, "Space Traffic Management in the New Space Era" (2019) 6:2 Journal of Space Safety Engineering 80–87, online: <linkinghub.elsevier.com/retrieve/pii/S246889671930045X> at 83.
[257] *Ibid*.
[258] *See* North et al, , *supra* note 249 at 18.
[259] *See* Lal et al, "SSA Global Trends", *supra* note 250 at 17.

hockey pucks which are near the minimum size of object detection and tracking for the SSN. The FCC originally denied Swarm's application to launch these satellites over concerns that they would be difficult to track by the DoD SSN.[260]

Despite these disadvantages, mega-constellations stand to significantly improve SSA through an increase in space-based SSA sensors. Currently, there are only a few space-based SSA satellites orbiting the Earth. The first is the United States Space Based Space Surveillance System which began operating in 2010.[261] This satellite was not a smallsat, weighing in at over 1000 kg., however, it has proven to be the most capable of the United States' SSA sensors.[262] Space-based SSA satellites have the benefit of operating day and night, above any weather interference, and without atmospheric distortion resulting in "a clear unobstructed view of resident space objects . . . ."[263].

Currently, the U.S. DoD SSN provides conjunction warnings when the risk of collision is greater than 1 in 10,000.[264] After analyzing several studies on the effects of mega-constellations, the Secure World Foundation reports that a single large mega-constellation could increase the number of conjunctions by a factor of 70; with up to a million conjunction warnings annually, depending on the success rate of post-mission satellite disposal.[265] The reason mega-constellations increase the conjunction warning frequency so much was explained this way by

[260] *See* Caleb Henry, "FCC Fines Swarm $900,000 for Unauthorized Smallsat Launch" *SpaceNews* (20 December 2018), online: <spacenews.com/fcc-fines-swarm-900000-for-unauthorized-smallsat-launch/>; Lal et al, "SSA Global Trends", *supra* note 250 at 17–18.
[261] *See* "SBSS (Space-Based Surveillance System) - Satellite Missions" (6 August 2020), online: *eoPortal.org* <eoportal.org/web/eoportal/satellite-missions/content/-/article/sbss>.
[262] *See* "Space Based Space Surveillance" (22 March 2017), online: *Air Force Space Command* <www.afspc.af.mil/About-Us/Fact-Sheets/Display/Article/249017/space-based-space-surveillance/>.
[263] *Ibid*.
[264] *See* "Space-Track.org", *supra* note 243; Amanda Morrow, "Why Tracking Space Junk is Big Business" *RFI* (19 September 2019), online: <www.rfi.fr/en/economy/20190918-northstar>.
[265] *See* Brian Weeden, "Insight - Small Satellites and Space Situational Awareness" (1 September 2016), online: *Secure World Foundation* <swfound.org/news/all-news/2016/09/insight-small-satellites-and-space-situational-awareness>.

Ted Muelhaupt, principal director for The Aerospace Corporation's Center for Orbital and Reentry Debris Studies (CORDS):

> *If you launch enough satellites to the same altitude, you create something like a shell. Anybody who crosses that shell, particularly if they cross it repeatedly, is going to come close to one of your satellites sooner or later. In one study, we were looking at dozens of conjunctions with the larger constellation per day.*[266]

On top of these potential cross-system conjunctions, large constellations will also have to contend with conjunction warnings within their own constellation.[267] Based upon an Aerospace Corporation study, a single mega-constellation operator could have more than 500,000 self-conjunctions annually, with 2-3 of which resulting in actual collisions if no action is taken.[268] This could lead to a "conjunction warning overload" requiring operators "to sort through an enormous haystack to find the needles . . . ."[269]

Another essential element of SSA is communication between operators. The best SSA systems combine both sensor data with data provided by satellite operators to create the most accurate depiction of satellite orbits and movement, to include planned on-orbit maneuvers. The lack of international legal regime covering SSA is an issue that is being highlighted by the mega-constellation movement. As such, it is important to determine what regulatory steps the U.S. can take unilaterally and what international actions should be sought to address SSA needs.

3) Space Debris

Closely related to SSA, and one of the hottest topics in space research at this time, space debris quantity and concentration has the potential to significantly impact space operations. During early space exploration, space was seen as vast and endless. Discarding rocket parts and

[266] Debra Werner, "Will Megaconstellations Cause a Dangerous Spike in Orbital Debris?" *SpaceNews* (15 November 2018), online: <spacenews.com/will-megaconstellations-cause-a-dangerous-spike-in-orbital-debris/>.
[267] *See* Muelhaupt et al, , *supra* note 256 at 83.
[268] *See ibid*.
[269] *Ibid*.

dead spacecraft did not seem like a large problem as there was so much space left to operate in. It is only in recent decades that the world has recognized that inner space (the area between the Earth and Moon), and particularly the most useable orbits, is becoming quite crowded with debris.[270] The mega-constellation proposals, with their plans to launch more spacecraft in the next decade than in all of history thus far, have brought this once discounted issue to the forefront.

There are already “many millions” of pieces of man-made space debris orbiting the Earth.[271] Just as with satellites, space debris must travel at very high speeds to stay in orbit, otherwise it would just fall to earth due to gravity. That means that these small pieces can be traveling at up to 18,000 mph, up to 7 times faster than a bullet.[272] When one of these pieces impacts a satellite, it can break that satellite into many pieces and send those pieced into higher and lower orbits. If there are other spacecraft nearby, these fragments can then impact those spacecraft causing even more fragments and impacts in a chain-reaction resulting in a cloud of debris. This is known as the Kessler Syndrome; a name based upon a paper published in the Journal of Geophysical Research in 1978 by NASA scientist Donald J. Kessler on *Collision Frequency of Artificial Satellites: The Creation of a Debris Belt*.[273] The Kessler Syndrome posits that if such a runaway domino effect of collisions is allowed to occur, it is possible that a cloud of debris could encircle the earth in LEO making all space travel and satellite launches too

[270] *See* “Curbing Space Debris in the Era of Mega-Constellations” (18 July 2018), online: <www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Curbing_space_debris_in_the_era_of_mega-constellations>.
[271] Garcia, “Space Debris & Human Spacecraft”, *supra* note 176.
[272] Keeter, , *supra* note 248.
[273] Donald J Kessler & Burton G Cour-Palais, “Collision frequency of artificial satellites: The creation of a debris belt” (1978) 83:A6 Journal of Geophysical Research: Space Physics 2637–2646, online: <https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/JA083iA06p02637>.

hazardous to undertake.[274] While the Kessler Syndrome is a worst case scenario, an increase in space debris would have significant effects on space activities, to include national security space activities.

There have been numerous collisions between space debris and satellites. One of the most notable collisions was between a non-operational Russian COSMOS 2251 satellite and the active Iridium 33 satellite in February 2009.[275] This collision destroyed the Iridium satellite and created thousands of pieces of space debris.[276] Smallsats are not immune to collisions with space debris; in 2013 an Ecuadorian cube-sat collided with debris from a Russian rocket.[277] The growth of mega-constellations only make such collisions more likely. In fact, the European Space Agency has already performed a collision avoidance maneuver by its Aeolus satellite to avoid a 1 in 10,000 chance of collision with a SpaceX Starlink satellite in September 2019.[278] In its official statement after the incident, the ESA said, "As the number of satellites in space dramatically increases, close approaches between two operated spacecraft will occur more frequently."[279]

A related issue is disposal of satellites post-mission. As discussed above, most smallsats operated at or below 600 km (where the majority of mega-constellations are proposed) will naturally deorbit due to residual atmospheric drag within 25 years. That being said, if the thousands of satellites being placed in orbit as part of mega-constellations remain in orbit the full 25 years, LEO will become very crowded. Thankfully, most of the LEO mega-constellation

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[274] *See* Karl Tate & 2013, "Space Junk Explained: How Orbital Debris Threatens Future of Spaceflight (Infographic)" *Space.com* (2 October 2013), online: <www.space.com/23039-space-junk-explained-orbital-debris-infographic.html>.
[275] *See* Jakhu & Pelton, *Small Satellites and Their Regulation*, *supra* note 232 at 9.
[276] *See ibid*.
[277] *See ibid*.
[278] *See* "ESA Spacecraft Dodges Large Constellation" (9 March 2019), online: *ESA* <www.esa.int/Safety_Security/ESA_spacecraft_dodges_large_constellation>.
[279] *Ibid*.

satellites currently being proposed have integrated propulsion systems that can be used to actively de-orbit in a much shorter timeframe; a requirement being imposed by the United States FAA launch licensing program. This requirement is not applicable worldwide, however. Neither are there international rules regarding close maneuvers to other spacecraft, nor the creation of space debris as part of launch vehicles or satellite operations. Indeed, when combined with the looming growth in mega-constellations, an increase in space debris is a growing risk. Thus, there is a legal issue in determining if U.S. regulations are keeping up with the space debris problem, but also a recognition that unilateral action may not be sufficient for the long-term.

4) Space Traffic Management (STM)

STM is a coordinated approach to standards of operation and norms of behavior to make space operations safer, reduce the risk of collisions, and ensure long-term space sustainability. Notably, however, there is not a single international controlling STM standard for safe and sustainable space operations. This results in space operators from different countries following different sets of rules. This is analogous to two drivers sharing a road but not having the same rules of the road or norms of behavior. Such a situation clearly increases the risk of something going wrong between the two drivers, just as the current system of patchwork STM leaves collision avoidance to the "pragmatism of the operators involved," as says Holger Krag, the Head of Space Safety at ESA.[280]

A unified STM policy has the potential to significantly decrease the risk of collisions, as well as behaviors that could increase the creation of space debris. This is yet another issue that can be addressed through legal means unilaterally and internationally.

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[280] *Ibid*.

5) Active Debris Removal

Active Debris Removal (ADR) is the phrase referring to the use of external means to deorbit space debris, or satellites that have reached end-of-mission. In recent years, as the risk of collisions in space have increased, companies have seen ADR as having potential commercial value to states and large companies to protect their satellites. Without onboard deorbiting capabilities or ADR, some satellites can remain in orbit for hundreds of years. These satellites create a higher risk of collisions and resultant space debris. This is particularly concerning for failed satellites that may have had a deorbiting plan but lost communication or propulsion services before deorbiting.[281]

There are several different proposed systems for ADR, each with their own advantages and disadvantages. Some of these include the addition of a *chaser* satellite launched along with the original constellation deployment that will take a close orbit, as proposed by an ESA study in 2017.[282] Once a satellite in the constellation fails, the chaser catches up to it, captures it using a net or other mechanism, and then uses onboard propulsion to take both satellites into the Earth's atmosphere to deorbit.[283] Another option proposed by the ESA study were specialized *cleaner* satellites affixed with robotic arms.[284] These satellites could be launched as needed, and each one could use its arm to capture and forcibly deorbit multiple pieces of debris before burning up itself. Other proposals use deployable nets to capture debris and send it back to Earth, attaching sails to debris, while others are considering the use of ground based lasers to reduce momentum of debris and cause it to deorbit.[285] The majority of these proposals require one satellite to come

[281] *See* "Curbing Space Debris", *supra* note 270.
[282] *See ibid*.
[283] *See ibid*.
[284] *See ibid*.
[285] *See* Tate & 2013, *Space Junk Explained*, *supra* note 274.

into close proximity of another object in space (proximity operations) which would require precision guidance, navigation, and control to safely operate so close to another object without causing an unintended collision itself.[286]

Closely aligned with ADR is on-orbit servicing. On-orbit servicing is using a specialized satellite to perform refueling, refurbishing, or reboosting of satellites already in orbit to extend their operational life.[287] This type of operation could extend the life of high-value satellites or be used to add new equipment and capabilities and has already been accomplished once by the Northrop Grumman Mission Extension Vehicle in February 2020.[288]

On the downside, however, both an ADR and an on-orbit servicing system are essentially the same as an anti-satellite weapon (ASAT), discussed further below. An ADR system would have the capability of removing an operational national security satellite in the same way it could remove debris or a defunct satellite. On-orbit servicing satellites that had the means to attach items to spacecraft or refuel satellites could pose just as much danger, if not more. In order to be capable of performing such detailed operations, the servicing satellite would need the ability to dock with a satellite and provide visual inspection information back to the controller.

All major space-faring nations have developed satellites with rendezvous and proximity operation (RPO) capabilities that can inspect other satellites from space. [289] Russia has developed several inspector satellites, to include Cosmos 2542, which released sub-satellite Cosmos 2543, to perform inspection of a U.S. National Reconnaissance Office KH-11 spy

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[286] *See* "ESA's e.Deorbit Debris Removal Mission Reborn as Servicing Vehicle" (21 December 2018), online: *ESA* <www.esa.int/Safety_Security/Clean_Space/ESA_s_e.Deorbit_debris_removal_mission_reborn_as_servicing_vehicle>.
[287] *See ibid*.
[288] *See* "Mission Extension Vehicle" (February 2020), online: *Northrop Grumman* <www.northropgrumman.com/space/mission-extension-vehicle>.
[289] *See* Malcolm Davis, "Spy Games in the Grey Zone of Outer Space" *RealClearDefense* (13 February 2020), online: <www.realcleardefense.com/articles/2020/02/13/spy_games_in_the_grey_zone_of_outer_space_115039.html>.

satellite in January 2020.[290] China's SJ-12 satellite bumped another satellite in 2010 and their SJ-17 satellite that was launched in November 2016 performed several RPOs with other Chinese satellites in GEO.[291] For the U.S., the X-37B space plane can perform inspections and has the ability to maneuver while in space.[292]

On-orbit servicing satellites use the same general type of proximity operations and inspection capability as inspector spacecraft.[293] These inspection capabilities can also be hidden within new space-based SSA satellites or into other legitimate commercial satellites or constellations.[294] As such, while on-orbit spying is already occurring, the advent of mega-constellations will encourage the development of new spacecraft with these capabilities, potentially allow inspection capabilities to be hidden within legitimate satellites, and increase the commercial availability of an inspection capability through on-orbit services.

6) Rapid Technology Refresh

The rapid development timeline is one of the largest benefits of smallsats. Additionally, constellations in LEO do not remain in service as long as larger satellites in higher orbits, as discussed above, thus meaning that they require replacement sooner. These replacement satellites can have greater capabilities than the original satellite they are replacing. This is the concept behind rapid technology refresh, which has both advantages and disadvantages for national security.

Rapid technology refresh, when paired with the ongoing development Defense-oriented smallsat mega-constellations like DARPA's Blackjack project, and the SDA's National Defense

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[290] *See ibid*; Trevithick, *Russian Inspector Sat Shadowing*, *supra* note 196.
[291] *See* Barry Blechman, "China Satellite SJ-17, Friendly Wanderer?", online (blog): *Breaking Defense* <https://breakingdefense.com/2018/04/china-satellite-sj-17-friendly-wanderer/>.
[292] *See ibid*.
[293] *See* Davis, *Spy Games*, *supra* note 289.
[294] *See ibid*.

Space Architecture, mean that national security satellites can be built quicker and placed in orbit knowing that updated technology can be placed in the next round of replacement satellites. In fact, the SDA motto is *Semper Citius*, or "always faster" as a nod to their goal to develop and launch new capabilities faster than traditional national security space systems.[295] Specifically, the SDA is hoping for "leap-ahead improvements" for each new tranche of satellites every two years that will "enable new capability layers to address other emerging or evolving warfighter needs."[296] Each of these satellites will be replaced every 5 years.

To further this goal, the Department of Defense, through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer programs, is encouraging small business innovators to engage in federal research and development programs focused on taking advantage of the rapid-development benefits of smallsats.[297] This program recognizes that the use of smallsats allows for "rapid development, rapid satellite refresh on-orbit, and shorter mission lifetimes" which can improve capabilities over current systems.[298]

Rapid technology refresh will also apply to commercial mega-constellations and adversary systems. This means that other space systems will also be rapidly updating. This will require the U.S. national security space systems to continually strive to keep ahead of competitors and the capabilities that are available commercially, which is a legal issue due to launch regulations.

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[295] "About SDA", *supra* note 92.
[296] "Space Development Agency Rolling Out Solicitations", online: <https://www.nationaldefensemagazine.org/articles/2020/1/21/space-development-agency-rolling-out-solicitations>.
[297] *See* "Next Generation Small Satellite Technologies" (20 April 2018), online: *SBIR.gov* <www.sbir.gov/node/1482421>.
[298] *Ibid*.

7) Harmful Frequency Interference (Unintentional)

All communications with satellites required the use of electromagnetic frequencies, which are a limited resource. Without an organized method to prevent conflict communication with a satellite would become impossible due to overlapping signals. As such, the International Telecommunications Union (ITU) has been involved with the regulation of space services through spectrum management and orbit usage since the Administrative Radio Conference in 1963 and continuing to this day.[299] The ITU system of registration is intended to help minimize risks of collision and harmful communication interference in space that has the potential to make space unusable for all.[300] The system relies upon the advanced application and international coordination for radio frequency and orbital use by satellite operators through their countries registration body. The approval of frequency use is only given if the proposed orbit and frequency usage is not preempted by already operating systems or frequencies reserved for equitable global distribution.[301] Once a system is approved, it is given international recognition and protection from harmful interference. The advent of mega-constellations means that there will be many more space systems operating that will require more frequencies for command, control, telemetry, and system operation.

Radio frequency interference occurs when an emitter broadcasts signals which interfere with another correct signal from reaching its intended target. While there is typically always some level of radio frequency interference or noise that is accounted for in a system, once an interfering signal is strong enough, it can completely disrupt communications. One of the contributing technological developments that is addressing, while also exacerbating, the risk of

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[299] *See ITU Radio Regulatory Framework for Space Services* (International Telecommunication Union, 2018), online: <www.itu.int/en/ITU-R/space/snl/Documents/ITU-Space_reg.pdf>.
[300] *See* Klein, *Understanding Space Strategy*, *supra* note 39 at 9.
[301] *See ITU Constitution*, *supra* note 179.

unintentional harmful interference is the integration of software-defined radios (SDR) into smallsats and mega-constellations. SDRs are radios that use software in place of traditionally physical radio parts.[302] By using software, the satellite radio is capable of in-flight reconfiguration of radio signal use. This capability can be used as a benefit to allow a radio to modify its signal usage to avoid interference, however, such changes can have unintended interference consequences on other systems.[303]

Multiplexing (the sharing of radio frequencies by time slot or frequency channel) and high-gain antennas capable of creating focused spot-beams of signal, allow for more systems to be used close to one another on the same radio frequencies.[304] These systems, like any other, are subject to error, misalignment, and improper programming that can lead to unintentional harmful interference with other systems.

While military systems are somewhat exempt from the ITU restrictions under Article 48 of the ITU constitution, harmful radio frequency interference that occurs to or by military systems can still have drastic effects on national security.[305] This interference can prevent communication with national security satellites which could be interpreted as nefarious action, or could simply result in an inability to use satellite capabilities. With the increasing number of satellites in orbit due to mega-constellations, even a small percentage in unintentional interference could create numerous incidents of conflict with national security systems.

How harmful interference is addressed legally is another matter that requires further discussion due to the mega-constellation movement.

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[302] *See* M R Maheshwarappa & C P Bridges, "Software Defined Radios for Small Satellites" 2014 NASA/ESA Conference on Adaptive Hardware and Systems (AHS)July 2014)172 [unpublished] at 1.
[303] *See* Maheshwarappa & Bridges, "Software Defined Radios", *supra* note 302.
[304] *See* Mark Harris, "Who Gets to Send Radio Waves in Space?" *MIT Technology Review* (26 June 2019), online: <www.technologyreview.com/2019/06/26/134533/spectrum-wars-satellite-communication/>.
[305] *See ITU Constitution*, *supra* note 179 at art 48.

8) Cyber-Security and Hacking

Cybersecurity of satellites has long been a priority for national security space assets. Ensuring that a satellite network cannot be penetrated was a key part of design and relied on multiple layers of security. With the growth of mega-constellations and the increased use of contracted space services for national security, there is a concern that the private entities will not be as concerned with cyber security.[306] In short, governments are afraid to use systems that could allow for cyber vulnerabilities when it comes to critical national security capabilities.[307]

The issue is that satellites are vulnerable to cyber-attacks.[308] Both satellites and their ground systems are computer-based and, therefore, are generally vulnerable to the same types of cyber-attacks as other computers.[309] The only caveat is system access. Unlike most computers that are connected to the internet, many satellite ground control systems are insulated from the internet. Thus, the only way to gain control is by physically gaining access, either in person or through the introduction of a virus through some other nefarious means.[310] Similarly, the only way to penetrate a satellites architecture is to send a signal from a special ground antenna and trick the onboard computer into believing you are the actual ground control system.[311]

According to a presentation at the 2019 RSA conference by Bill Malik, vice president of infrastructure systems at Trend Micro, there have been several actual takeovers or successful interference with satellite operations by cyber-attacks.[312] Five of these were attacks on U.S.

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[306] *See* Debra Werner, "Government, Industry Officials Share Small Satellite Cybersecurity Concerns" *SpaceNews* (5 February 2020), online: <spacenews.com/smallsat-cybersecurity-2020/>.
[307] *See ibid*.
[308] *See* Patrick Tucker, "The NSA Is Studying Satellite Hacking" *Defense One* (20 September 2019), online: <www.defenseone.com/technology/2019/09/nsa-studying-satellite-hacking/160009/>.
[309] *See* "The NSA Is Studying Satellite Hacking - Defense One", online: <https://www.defenseone.com/technology/2019/09/nsa-studying-satellite-hacking/160009/>.
[310] *See ibid*.
[311] *See ibid*.
[312] *See* William J Malik, "Attack Vectors in Orbit: The Need for IoT and Satellite Security" (Paper delivered at the RSA Conference 2019, San Francisco, CA, 4 March 2019) [unpublished], online: <published-

systems in 2007 and 2008, to include a trojan infection that impacted the ISS.[313] In 1999, hackers took complete control of a British military satellite and demanded a ransom after moving its position.[314] The reduction in cost of technology that is powering the growth of the satellite industry is also making jamming and take-over technology cheaper for hackers (whether State-sponsored or independent).[315] Our reliance on satellite systems is making cyber-attacks on these systems appear more lucrative. Malik explained that these attacks can take many forms; from ransom demands, to control of an imagery satellite, eavesdropping or duplication of communications, corruption or alteration of data, or simply disabling a satellite completely.[316]

Mega-constellations provide both a benefit in terms of resilience as well as a concern of increased vulnerability. By having a diverse architecture provide capabilities, no one satellite or satellite system is relied upon for the entire capability, thereby disincentivizing any attack. On the other hand, the increase in number satellites, as well as the number of manufacturers increases the risk that cyber security vulnerabilities will leave systems open to attack. These attacks can come in the form of in-built vulnerabilities in components used in satellites, or human factor vulnerabilities like such as improper system configuration, or accidental introduction of malware.[317]

9) Anti-Satellite Weapons (ASAT)

The launch of mega-constellations is likely to increase the threat of some of these weapon types but also provide noticeable benefits to national security. As discussed above, there are

prd.lanyonevents.com/published/rsaus19/sessionsFiles/13692/MBS-W03-Attack-Vectors-in-Orbit-The-Need-for-IoT-and-Satellite-Security.pdf>.

313 *See ibid* at 25.

314 *See ibid* at 26.

315 *See* Tucker, *NSA Satellite Hacking*, *supra* note 308.

316 *See ibid*.

317 *See* Mark Holmes, "The Growing Risk of a Major Satellite Cyber Attack" *Via Satellite* (1 November 2019), online: <interactive.satellitetoday.com/via/november-2019/the-growing-risk-of-a-major-satellite-cyber-attack/>.

several different types of ASAT weapons. These include kinetic, non-kinetic physical, electronic, and cyber ASAT weapons.[318] Smallsat mega-constellations have the potential to add many more ASAT-capable satellites to outer space.[319] These on-orbit systems could have the capability to employ any of the ASAT weapon means to temporarily or permanently disable or disrupt an adversaries satellite function.

For kinetic physical ASAT capability, a smallsat can just use its onboard propulsion and tracking systems to engage in RPO with another satellite causing a collision or deploying objects to cause damage.[320] An example of possible kinetic physical attack features have already been seen in the 15 July 2020 Russian satellite Cosmos 2543 expulsion of a "high-speed payload."[321] This form of ASAT capability would also include the RPO debris mitigation and on-orbit servicing space craft discussed in the space debris section above, if those satellites were used for nefarious purposes.

Small satellites in mega-constellations could also be fitted with electronic ASAT capabilities, too. Satellites could use attached lasers to dazzle a target satellite's sensors, a spray or sail system to blind a satellite, or use the onboard antennas to emit radio signals directed to jam or spoof communications.[322] It is speculated that China has already tested on-orbit jamming.[323] In 2010, Chinese satellite SJ-12 performed RPO operations in LEO of an older Chinese satellite in which SJ-12 made slow, methodical close-maneuvers over several weeks, and even made physical contact with the older satellite at low speeds.[324] This operation could have been

[318] *See* Harrison et al, "Space Threat Assessment 2020", *supra* note 190 at 6–7.
[319] *See* Roberts, Beischl & Mosteshar, *Small Satellite Constellations*, *supra* note 11 at 10.
[320] *See ibid*.
[321] *See* Hitchens, "Russian Sat Spits", *supra* note 195.
[322] *See* Roberts, Beischl & Mosteshar, *Small Satellite Constellations*, *supra* note 11 at 11.
[323] *See* Harrison et al, "Space Threat Assessment 2020", *supra* note 190 at 12.
[324] *See ibid*.

innocent RPO testing for legitimate purposes, however, the capabilities shown could also be used for ASAT operations in the future.

The concept of a space mines, or small, maneuverable satellites equipped with explosives, have tickled the imaginations of space enthusiasts since their use in Star Trek and other science fiction favorites.[325] The concept has been extrapolated from naval mining techniques and essentially is a form of kinetic proximity ASAT weapon. Such a space mine could be standalone satellite or could be launched from a larger satellite. This satellite would maneuver close to the target satellite, or even attach itself to the target, and then detonate or engage interference systems to destroy or disrupt operations of the target.[326] It is believed that if such a satellite were small enough, it might not be detected by the current SSA technology.[327]

Around 2001, a story surfaced in a local Chinese newspaper, that was reissued in a Hong Kong paper, that claimed China had produced a parasitic micro-satellite that could covertly attach itself to an enemy satellites and, upon command, destroy the satellite in less than one minute.[328] While the credibility of this report has been questioned, it did bring attention to the risks posed by smallsats that are capable of avoiding detection by SSA systems.[329]

Another potential use of mega-constellations is as a space barrier, or a system that can be used to prevent adversary spacecraft or satellites from passing through a certain orbital pattern.[330] The idea would be for the mega-constellation satellites to be equipped with propulsion systems that allow for them to be used as kinetic ASAT weapons or to maneuver in such a way as to

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[325] *See Force of Nature (Star Trek: The Next Generation)* (2020), Page Version ID: 968874569.
[326] *See* Roberts, Beischl & Mosteshar, *Small Satellite Constellations*, *supra* note 11 at 10–11.
[327] *See* Leonard Weiss et al, *Ensuring America's Space Security: Report of the FAS Panel on Weapons in Space* (Washington D.C.: Federation of American Scientists, 2004), online: <https://fas.org/pubs/_docs/10072004163734.pdf> at 17.
[328] *See ibid* at 15.
[329] *See ibid* at 19.
[330] *See* Klein, *Understanding Space Strategy*, *supra* note 39 at 113.

increase the risk of collision to an unacceptable level for an adversary system attempting to pass through a specific orbital area. Such a system would have the potential of delaying an adversary's launch of new satellites, repositioning of current satellites, or as a ballistic missile interceptor. This concept is very similar to a U.S. government ballistic missile defense program from the early 1990's known as Brilliant Pebbles.[331] The central concept of this program was to place thousands of small rockets with sophisticated tracking systems into outer space which could then be launched back down toward earth to intercept enemy ballistic missiles that have been launched toward the United States.[332]

While all of these ASAT attack methods are possible from mega-constellations, the resiliency benefits derived from such systems is likely to dissuade adversaries from using mega-constellations in this way.

10) Increased Counter-ASAT Resilience

One of the biggest advantages of mega-constellations to national security is the resiliency they provide in response to ASAT operations. First, LEO systems are naturally more resilient to electronic attacks, such as jamming, due to their relative closeness to Earth which allows for greater signal strength. Additionally, the use of high gain antennas capable of creating spot beams coupled with the relative speed at which they pass over the sky will increase the difficulty of attacks and limit the locations where successful attack could occur.[333]

More significantly, the proliferation or spread of capability between hundreds or thousands of satellites, where multiple satellites can serve most locations on earth at any one

[331] *See* James Gattuso, "Brilliant Pebbles: The Revolutionary Idea for Strategic Defense" (25 January 1990), online: *The Heritage Foundation* <https://www.heritage.org/defense/report/brilliant-pebbles-the-revolutionary-idea-strategic-defense>.
[332] *See ibid*.
[333] *See* Hallex & Cottom, "Proliferated Constellation Implications", *supra* note 10 at 24–25.

time, means that the system could withstand attacks on a relatively large number of satellites before losing significant capability.[334] Additionally, the majority of these constellations performing national security functions will still have backup alternate systems that could continue the capability despite an attack. This has the effect of reducing the value of each individual satellite to an adversary.[335] Further, these satellites are small, cheaper to build, and cheaper to replace, further disincentivizing attacks.

On whole, these mission sets and satellites are critically important to the United States National Security program. These systems help government officials meet political and national ends by using the ultimate high ground for intelligence, command and control, and situational awareness. Use of these systems provide a distinct advantage to those nations with access to these capabilities.

d. CONCLUSION

Space continues to play an ever-increasing role in everyday life in America but also in regard to National Security. The capabilities satellites can provide are unmatched by terrestrial alternatives. Further developments in technology that have made space more accessible by more actors, to include other nations and non-state actors, have also increased the risks associated with outer space operations. These risks include collisions with other satellites or orbital debris, but also the increased risk of intentional interference by adversaries. More nations are developing kinetic, non-kinetic, electronic, and cyber ASAT weapons that pose a risk to peaceful continued use of national security space assets. The United States has responded to these risks with a multilayered approach ranging from diplomatic engagements to the standing up of a new military

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[334] *See ibid* at 24.
[335] *See* Sandra Erwin, "On National Security | The promise and perils of LEO constellations" *SpaceNews* (4 July 2020), online: <spacenews.com/the-promise-and-perils-of-leo-constellations/>.

branch and combatant command with the sole focus of ensuring space security. The DoD is even pursuing a potential LEO mega-constellation of their own to address the increasing risk of interference in space. In light of these developments, as well as the numerous proposals for mega-constellations currently in development or testing, it is important to undertake a full analysis of the risks and benefits of smallsats and mega-constellations from a national security point of view.

Part III: Some Legal Aspects of Mega-Constellations Related To National Security

The belief in their actions can mend entire constellations.
The ambition in their thirst for knowledge can both create and destroy
every structure which has been built or is still to be made.
– *Excerpt from* Burning Fools, *Poem by F.K. Preston*.[336]

The impending boom of smallsat, LEO mega-constellations is about to change the space operational environment by leaps and bounds. Not only will it make new capabilities possible, but it will also change risk calculations for all actors wishing to use outer space. These concerns take on extra gravity when considered from a national defense perspective. While there are several United States and Western nation mega-constellation projects, both China, Russia and other adversary nations are pursuing proliferated LEO constellations, too.[337] These foreign mega-constellations will potentially give these nations access to similar capabilities. Given China's willingness to work with other U.S. adversaries, these systems could be used to the disadvantage of U.S. national security.[338] While the fruitfulness of the mega-satellite boom is yet to be known, now is the time to assess the relevant current legal landscape applicable to mega-constellations that protects U.S. national security before we fully commit to a path where we, as the F.K Preston poem says, "destroy every structure which has been build or is still to be made" in space.

a. RAPID LAUNCH AND TECHNOLOGY REFRESH

In the National Security context, rapid launch capability will provide an advantage to resilience allowing reconstitution of degraded or damaged systems, both commercial and government owned. Legally, the question is whether the current regulatory regime can

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[336] FK Preston, "Burning Fools" (Undated), online: *PoemHunter.com* <https://www.poemhunter.com/poem/burning-fools/>.
[337] *See* Hallex & Cottom, "Proliferated Constellation Implications", *supra* note 10.
[338] *See ibid*.

accommodate this new update in capability and technology. Regulation of space launch is not governed internationally but is left to States under their "authorization and continuing supervision" requirement of Art VI of the OST.[339] Regulatory and licensing authority over space launch in the United States was vested in the Department of Transportation, Federal Aviation Administration (FAA), Office of Commercial Space Transportation in 1984 by the Commercial Space Launch Act.[340] Under this act, launch of any commercial space vehicle is prohibited without the required licenses: hence, the FAA regulations require licenses for launch of a space vehicle, operation of a launch site, and reentry activities.[341] Further, there are five review-subparts applicable to space launches: policy, payload, safety, economic and environmental.[342]

In several of these licensing subparts, national security is considered. For example, national security is one of the main considerations during the policy review portion of the licensing review.[343] During a payload review the FAA consults with the DoD, Department of State (DoS), NASA, and other agencies to determine if the payload presents any risk to national security, international obligations, safety, or foreign policy interests.[344]

Interestingly, "national security" is not defined within the act or regulations, nor are the evaluation criteria for determining when a launch or payload generates an unacceptable risk. The purpose of the act and regulations is to encourage the development of commercial space launch, while still ensuring the safety of the American public and protection of national security.[345] This balancing approach is apparent from the language of the regulations and

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[339] *See OST*, *supra* note 132.
[340] *See Commercial Space Launch Act*, 98 Pub L No 575, 98 Stat 3055 (codified as amended at 51 U.S.C. Chapter 509 (1984)); 51 U.S.C. § 50901(b)(3); 14 C.F.R. § 401.01 (1988).
[341] *See* 14 C.F.R. § 415.9.
[342] *See* 14 C.F.R. § 415, 420, & 430.
[343] *See* 14 C.F.R. § 415.21.
[344] *See* 14 C.F.R. § 415.51.
[345] *See generally* 51 U.S.C. § 50901(b)(7).

controlling act, but analysis of this text shows that the current regime favors more in-depth and lengthy review over commercial encouragement and speed. This can most plainly be seen through the multiple layers of review and licensing required for any single space launch under the current law.

The legal issue raised by the mega-constellation movement and rapid launch is that this review process is not particularly well matched to the speed at which launches and technology refresh will be occurring commercially. Currently, the FAA regulations provide for a 120 – 180 day review period per license, depending on the type of application, and each launch requires multiple licenses, as noted above.[346] The 180 day maximum review period is prescribed by law in 51 U.S.C. § 50905. On top of the launch licenses and payload review, a separate safety approval must also be received prior to space launches.[347] The combination of these multiple reviews and license requirements significantly hampers the ability to quickly field new satellites using new emerging technology. For example, some new smallsat launch vehicles have the potential to launch from many different locations and do not require significant supporting infrastructure. This means that these launch vehicles can choose different launch locations to support particular orbital paths. For each location and launch, the commercial launcher would require a launch site license, space vehicle license, and, possibly, a reentry license. Each of these would have a 180-day review timeline from submission that can be tolled if the FAA or a coordinating agency requests further information.[348]

The Trump administration has identified these regulations as burdensome to the commercial space industry and directed a review of ways to simplify the launch licensing

[346] *See* 14 C.F.R. § 413.15.
[347] *See* 14 C.F.R. Part 414.
[348] *See* 14 C.F.R. § 413.15.

process in the 2018 Space Policy Directive-2 (SPD-2).[349] Section 1 of SPD-2 lays out the purpose of the directive, namely: to ensure that "regulations adopted and enforced by the executive branch promote economic growth; minimize uncertainty for taxpayers, investors, and private industry; protect national security, public-safety, and foreign policy interests; and encourage American leadership in space commerce."[350] Section 2 of SPD-2 required the Department of Transportation to review all current regulations to ensure that they meet the intent listed above, with a further requirement to consider consolidating licensing into a "single license for all types of commercial space flight launch and re-entry operations," as well as "replacing prescriptive requirements in the [. . .] licensing process with performance-based criteria."[351] This requirement to streamline regulations is tempered, however, by Section 2(d) of the directive. This paragraph recognizes that requirements for public safety and national security are not to be minimized.

In March 2019, the FAA announced a Notice of Proposed Rulemaking (NPRM) on *Streamlined Launch and Reentry Licensing Requirements* as directed by SPD-2.[352] These proposed rules have yet to be adopted but attempt to streamline the processes currently in place.[353] Unfortunately, while these regulations do streamline the application itself, clarify requirements and allow for more flexibility to meet those requirements, the proposal does not significantly reduce the necessary time for licensing review. These proposed regulations maintain the multi-part license review process that includes policy, payload, safety, economic,

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[349] *See Space Policy Directive-2, Streamlining Regulations on Commercial Use of Space* (Washington, D.C.: The White House, 2018), online: <www.whitehouse.gov/presidential-actions/space-policy-directive-2-streamlining-regulations-commercial-use-space/>.
[350] *Ibid*.
[351] *Ibid* at 2.
[352] *See Streamlined Launch and Reentry Licensing Requirements*, 84 FR 15296 (2019); "Commercial Space Transportation Regulations" (11 June 2020), online: *Federal Aviation Administration* <www.faa.gov/space/licensing_process/regulations/>.
[353] *See ibid*.

and environmental reviews for each license.[354] The FAA provided that their average review time for 10 licenses issued through 2018 was 141 days, with a median of 167 days.[355] Specifically, the NPRM states “the FAA does not propose to reduce by regulation the statutory review period of 180 days to make a decision on a license application.”[356]

In the end, the current law and regulations related to rapid launch and technology refresh require further revision to keep pace with the needs of industry and national security for satellite reconstitution and technology refresh associated with mega-constellations. With the current advancements in other Nations launch technology and streamlined licensing, failing to address this obstruction to rapid licensing for national security purposes within the U.S. system may drive international companies to use international launch opportunities. In such an instance, the U.S. government loses the opportunity to perform the national security reviews on some of these satellites limiting the benefit sought by the regulation. Further, it would place those that are required to use U.S. launch providers at a disadvantage as compared with international competitors, which poses a risk to the goal of national security through technological superiority.

b. SPACE SITUATIONAL AWARENESS (SSA) DATA SHARING

As noted above, SSA will be majorly affected by the mega-constellation movement due to the exponential increase in objects to track and their smaller size and new capabilities making tracking more difficult. Internationally, there is no legal obligation to participate in SSA activities or share SSA data outside the requirement to register GEO orbital positions with the ITU and the general requirements to undertake space activities with “due regard to the corresponding interests of all other [Nations].”[357] In the United States, the DoD current operates

[354] *See* 84 FR 15297.
[355] *See* 84 FR 15302.
[356] *Ibid*.
[357] *See* OST, *supra* note 132 at Art IX.

the official SSA system for the nation, which is perhaps the most sophisticated SSA system in the world. In the early 2000s the federal government started a pilot program to share SSA data to attempt to avoid collisions.[358] This program now shares SSA data publicly on an ad-hoc basis through Space-Track.org as authorized under 10 U.S.C. § 2274.[359] This system provides a significant amount of SSA information publicly but is not fully open to commercial entities or other nations, however, as the enacting legislation limits sharing based upon national security.[360]

There is inherent conflict in the current military-run system: namely, the protection of national security SSA information balanced against open SSA data-sharing for global space safety. The fact that the system is run by the U.S. military also causes hesitation by some foreign governments and companies in deciding to share SSA information or in relying on access to the system.[361] Much of this distrust is based on the lack of transparency in the DoD system.[362] As a result, many nations are developing their own SSA systems or partnering with other nations to share SSA data: the major providers being the U.S., EU, China, and Russia.[363] There are also non-profit and for-profit SSA groups attempting to fill the need for accurate SSA data. As a result of this regionalization and the continued need for more SSA data for safe space activity, there is renewed discussion of the role international law should play in SSA.[364]

With regard to international governance of SSA, there are two main camps: those that believe in a top-down binding international rules and those that promote harmonizing domestic

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[358] *See Pilot Program for Provision of Space Surveillance Network Services to Non-United States Government Entities*, 108 Pub L No 136 § 913, 117 Stat 1565 (codified as amended at 10 U.S.C. 2274 (2003)).
[358] *See* 14 C.F.R. § 415.9.
[359] *See* "Space-Track.org", *supra* note 243.
[360] *See* 10 U.S.C. § 2274.
[361] *See* Lal et al, "SSA Global Trends", *supra* note 250 at 21–23.
[362] *See ibid* at 21.
[363] *See ibid* at 71.
[364] *See ibid* at 74–75.

laws through cooperation on best-practices and standards.[365] It appears that most space-faring Nations in both camps recognize that the current political climate will make it difficult to create a new international agreement anytime soon.[366]

The U.S. position supports the bottom-up approach to establishing SSA cooperation as shown in SPD-3 regarding space traffic management.[367] It envisions an "Open-Architecture SSA Data Repository" (OADR) that incorporates civil, commercial, international and other data using U.S. developed standards and protocols for data integration.[368] This repository would still be maintained, and access reviewed, by the DoD for national security purposes but would transfer the responsibility for public operations to the Department of Commerce (DoC).[369] While this move of SSA responsibility to DoC has not been approved by Congress, such a move may help build trust with foreign companies and governments regarding SSA data sharing.

While the details of the OADR modifications are still in the works, such a transition could have the desired benefits to national security in the coming mega-constellation boom by shifting the increased burden of SSA data dissemination to a civil organization while allowing the military operators to focus on national security SSA issues. This will also improve the accessibility and trustworthiness of the system to space users (particularly foreign companies and governments) which will facilitate more inputs further increasing the accuracy and usefulness of the system. The U.S. bottom-up approach will require new laws and regulations creating the new civil SSA organization and setting up data sharing operations, but this system is best suited

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[365] *See ibid*.
[366] *See ibid* at 77.
[367] *See* "SPD-3", *supra* note 222.
[368] *See ibid*.
[369] *See ibid*.

to create internationally accepted SSA sharing norms in the current international political environment under the looming mega-constellation boom.

c. SPACE DEBRIS

Space debris is one of the biggest concerns associated with the mega-constellation movement. Legally, the issue has begun to be addressed internationally but there are no binding international rules specifically addressing space debris mitigation. In particular, the Inter-Agency Space Debris Coordination Committee (IADC), an international governmental forum which includes NASA and other national space agencies, issued a set of consensus guidelines for debris mitigation in 2007.[370] These guidelines are only recommendations and are not binding on IADC member agencies.[371] These guidelines were the basis for the soft law UNCOPUOS space debris mitigation guidelines endorsed by the UN General Assembly in December 2007[372]

A full analysis of these guidelines is not essential to this thesis, however, the general goals of these guidelines are to reduce or limit debris creation from launch or normal operations, minimize risk of collisions and the likelihood of space object failure and breakup, and limit the long term presence of satellites in the useful orbits by either deorbiting or moving satellites into graveyard orbits. In 2017, the IADC issued a "Statement on Large Constellations in Low Earth Orbit" which made specific recommendations on constellation design, orbital use, satellite

[370] *See U.S. Government Orbital Debris Mitigation Standard Practices* (NASA, 2001), online: <orbitaldebris.jsc.nasa.gov/library/usg_od_standard_practices.pdf>; "IADC-Home" (5 August 2020), online: *IADC* <www.iadc-home.org/what_iadc>; "Clean Space" (5 August 2020), online: *ESA* <www.esa.int/Safety_Security/Clean_Space>; UNCOPUOS, *Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space* DOI.org (Crossref) (United Nations Office For Outer Space Affairs, 2007), online: <https://www.unoosa.org/pdf/publications/st_space_49E.pdf>.

[371] *See* David D Murakami et al, "Space Traffic Management with a NASA UAS Traffic Management (UTM) Inspired Architecture" (Paper delivered at the AIAA Scitech 2019 Forum, San Diego, California, 7 January 2019) [unpublished], online: <arc.aiaa.org/doi/10.2514/6.2019-2004> at 10.

[372] *See Report of the Committee on the Peaceful Uses of Outer Space*, UNGAOR, 62nd Sess, Supp No 20, UN Doc A/62/20 (2007), Annex 1, para 1, adopted by the UNGA in *International Cooperation in the Peaceful Uses of Outer Space*, GA Res 62/217, UNGAOR, 62nd Sess, UN Doc A/RES/62/217 (2007)

design, operations, and disposal which would help mega-constellations meet the 2007 guidelines but did not create new guidelines for such constellations.[373] One of the problems with these guidelines, however, is they were developed in the time of exquisite, one-off satellites or small constellations. These guidelines are partially based upon an 'acceptable failure rate' for satellites, which were developed upon the assumption that space activities would continue in a manner similar to what had come thus far.[374] While this rate may have made sense for single satellite programs or constellations in the single or double digits, when applied to a constellation of thousands of satellites, the risk created is much greater than intended by the drafters.[375] Further, as these international guidelines are entirely voluntary and non-binding they lack efficacy against the coming mega-constellation boom.

In light of the non-binding nature of the international space debris guidelines, nations must implement space debris mitigation domestically. In the United States, space debris mitigation guidelines are implemented on government satellites through the promulgation of the U.S. Government Orbital Debris Mitigation Standard Practices (ODMSP) which were established in 2001 and updated in 2019 by NASA.[376] These guidelines inform the debris mitigation standards included in licensing requirements imposed by the FCC, the primary space debris management agency for commercial space operations.[377] The FCC just updated the space debris mitigation guidelines used for licensing review in April 2020 while also seeking

[373] *See IADC Statement on Large Constellations* (IADC, 27 Sept 20178), online: <www.iadc-home.org/documents_public/file_down/id/4096#:~:text=At%20its%2033rd%20meeting%20in,on%20the%20population%20of%20man%2D> at 6–11.
[374] *See* Muelhaupt et al, , *supra* note 256 at 86.
[375] *See ibid*.
[376] *See* "U.S. Debris Mitigation Standards", *supra* note 370; "2019 U.S. Debris Mitigation Standards", *supra* note 34.
[377] *See Mitigation of Orbital Space Debris in the New Space Age Report and Order and Further Notice of Proposed Rulemaking* (Washington, D.C.: Federal Communications Commission, 2020), online: <docs.fcc.gov/public/attachments/FCC-20-54A1.pdf>.

comments on further proposed updates.[378] NASA and the U.S. Government have both promulgated orbital debris policies directing that satellites placed in LEO be deorbited within 25 years after mission completion.[379]

Both sets of these U.S. debris mitigation rules go further than the international guidelines with regard to mega-constellations. The ODMSP requires a higher probability of successful post mission disposal than other spacecraft and a clear preference for immediate deorbit of LEO satellites.[380] The FCC update included similar provisions based upon the NASA ODMSP.[381] The FCC also includes further requirements for smallsats smaller than the 1U CubeSat standard, such as the SpaceBee, to submit information on the trackability, unique satellite identification transmissions, and registration of the satellites during the license application process to ensure SSA can be maintained on the satellite.[382]

With regard to national security, this system of debris mitigation is already in the process of addressing the complications of looming mega-constellations. An expectation of increased reliability of post-mission disposal for mega-constellation satellites has been included in the licensing regime of the FCC. The FCC is considering further regulations of mega-constellations to ensure the long-term effects on the environment are minimized. While these standards to not apply internationally and there is a possibility that debris will increase due to mega-constellations, the U.S. regulations on the matter are developing in the best direction to protect the continued use of outer space for national security purposes.

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[378] *See ibid*.
[379] *See* "U.S. Debris Mitigation Standards", *supra* note 370.
[380] *See* "2019 U.S. Debris Mitigation Standards", *supra* note 34 at 7–8.
[381] *See* "FCC Updated Orbital Debris Rules", *supra* note 377 at 18.
[382] *See ibid* at 26–27; *CubeSat Design Specifications* (California Polytechnic State University, 2014), online: <static1.squarespace.com/static/5418c831e4b0fa4ecac1bacd/t/56e9b62337013b6c063a655a/1458157095454/cds_rev13_final2.pdf> (1U or 1 Unit of a cubesat is a 10cm cube. Cubesats regularly come in 1U, 3U, 6U, and 12U configurations based upon the CalPoly Cubesat Standard developed in 1999).

d. SPACE TRAFFIC MANAGEMENT (STM)

A unified Space Traffic Management (STM) policy has the potential to significantly decrease the risk of collisions, as well as behaviors that could increase the creation of space debris. Just as with SSA, however, there is no current international STM policy outside GEO governance by the ITU.[383] Under the freedom of exploration principle of the OST, Nations are free to authorize launch satellites into any non-GEO orbit without concern for congestion.[384] Since STM is not set internationally, space operators from different countries follow different sets of rules imposed by their national licenses. Thus, the mega-constellation movement is increasing the urgency to create international agreement upon STM.

When it comes to national security, STM principles create norms of behavior that can be used to hold space user's accountable. Because space exploration is inherently international, STM at the international level would have significant benefits over domestic STM. For example, once norms of behavior and notice requirements regarding proximity operations are developed, it will be much easier to identify nefarious activities in outer space, such as the Russian "inspector" satellite ASAT test discussed above. A violation could then be taken to the U.N. or another international adjudicative body. [385]

These rules also have the ability to increase international satellite ephemeral data sharing to improve SSA and coordinate conjunction communications to reduce the risk of collisions.[386] While such an international STM system may require sharing of information currently kept close hold for security purposes, the system would apply equally to all nations, thus creating a level of

[383] *See* Lal et al, "SSA Global Trends", *supra* note 250 at 77.
[384] *See* Murakami et al, "STM with UAS", *supra* note 371 at 9–10.
[385] *See* Lal et al, "SSA Global Trends", *supra* note 250 at 20; Murakami et al, "STM with UAS", *supra* note 371 at 5.
[386] *See* Lal et al, "SSA Global Trends", *supra* note 250 at 79.

transparency that could bolster international diplomatic cooperation to ensure safe and sustainable space activity.[387]

Some of the potential STM rules that could be employed to ensure mega-constellations and smallsats are deployed safely as concerning space debris include requirements of onboard propulsion systems for active deorbiting if a satellite is to orbit above 400km (an altitude that would allow for relatively quick natural deorbiting); requiring extensive data sharing regarding orbits and maneuvers, requiring satellites to carry an onboard automatic identification system transponder similar to maritime vessels to assist in SSA; setting defined rules on automated collision avoidance; creating standardized communication channels for conjunctions, and/or requiring satellites to have a component to facilitate active debris removal.[388]

Again, there are two main views of the best way to implement STM internationally: a top-down binding international set of rules or a bottom-up harmonization of national STM rules. As to top-down approaches, one proposal is to give full STM authority to the ITU which currently practices some top-down STM regarding radio frequency and orbital slot assignment and distribution. An international bottom-up proposal is to use the International Civil Aviation Organization (ICAO) to cooperatively develop STM principles which can be voluntarily implemented domestically just as ICAO harmonized national aviation regulations by development of international standards.[389]

While these proposals exist, implementation of an international STM policy would require Nations to relinquish National control of rules of behavior and expected standards of care

[387] *See ibid* at 23, 61–62.
[388] *See* "NORTHSTAR - Empowering Humanity to Preserve our Planet" (25 July 2020), online: *NorthStar Earth & Space Inc* <northstar-data.com/>.
[389] *See* Lal et al, "SSA Global Trends", *supra* note 250 at 78.

and conduct to an international body.[390] Such a relinquishment could have significant effects on national security, commercial growth, and liability through the implementation of new rules and enforcement mechanisms.[391] As such, there is currently, little momentum toward an international STM solution.[392] As a result, Nations and regional groups are all developing STM policies to govern domestic space activities with the hope that their framework could become the lead framework in future international discussions.[393]

Domestically, the current legal regime governing STM in the United States is an amalgamation of different laws and regulations all directed toward the safe use of space by the commercial space industry.[394] These include the above-mentioned legal instruments on space launch, and others pertaining to remote sensing and communications satellites as well as space debris.[395] These programs are administered through several federal bodies to include the DoD, DoC, DoT, and NASA. Until recently, there was no lead agency to coordinate U.S. STM policy, rather the regulations required significant cross-agency coordination and collaboration to ensure that commercial space activities are carried out in a safe and sustainable fashion through the various licensing processes.[396]

President Trump has placed renewed emphasis on a domestic STM policy in his Space Policy Directive-3 (SPD-3).[397] SPD-3 defines STM as “the planning, coordination, and on-orbit synchronization of activities to enhance the safety, stability, and sustainability of operations in the space environment.”[398] It places the responsibility to develop a coordinated approach to

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[390] *See ibid* at 77–78.
[391] *See ibid* at 79.
[392] *See ibid*.
[393] *See ibid*.
[394] *See generally National and Commercial Space Programs*, 51 U.S.C. 101 et seq (2010).
[395] *See ibid.*
[396] *See* “SPD-3”, *supra* note 222; Muelhaupt et al, , *supra* note 256 at 84.
[397] *See* “SPD-3”, *supra* note 222.
[398] *Ibid*.

standards of operation and norms of behavior to make space operations safer, reduce the risk of collisions, and ensure long-term space sustainability on the Department of Commerce.[399] This directive does not give total control to the DoC but rather envisions DoC would be the public face of the STM program that will be developed in cooperatively between DoC, DoD, DoT, DoS, and others.[400] The goal of the realignment and renewed focus on STM is to ensure that the United States maintains leadership in STM to help shape the STM standards and best practices to protect U.S. interests, to include national security, and promote them "across the international community."[401]

While the growth of mega-constellations may just be the catalyst necessary to bring the nations of the world together to create international provisions for STM, the current U.S. movement to be an international leader in STM through transparent STM development and promotion provides the best protection of U.S. national security under the current international environment. As the standards are developed collaboratively, they can be implemented to all U.S. operators through FCC licenses. They can be further implemented to foreign satellite operators that use U.S. launch providers through the launch license requirement of the FAA. In this way, the U.S. will be able to use domestic STM to influence international space safety and sustainability.

e. HARMFUL FREQUENCY INTERFERENCE (UNINTENTIONAL)

While some technological advancements will help minimize harmful frequency interference, the increase in the sheer number of satellites that comes with the mega-constellation boom will make the likelihood of unintentional interference greater. As discussed above, the

399 *See ibid*.
400 *See ibid*.
401 *Ibid* at 3.

current legal regime covering electromagnetic field communications has both an international and domestic part due to its nature as a limited resource, the sovereign nature of radio transmissions over a country but the international nature of satellites.[402] The purpose of these regulations is to prevent unintentional interference through coordination and registration, but, despite these rules, harmful interference still occurs.

In the U.S., the FCC governs interstate and international satellite communications through authority granted in the Communications Act of 1934 (as amended).[403] This Act and its enacting regulations expressly prohibit the sale, use, or import of intentional interference devices.[404] The FCC regulations specifically condition that radiofrequency emitting devices may cause no harmful interference, otherwise they are subject to an order to cease operations.[405] The FCC Enforcement Bureau (EB) is responsible for spectrum-related interference investigation and enforcement.[406] The EB works in conjunction with FCC field offices across the United States when harmful interference is reported.[407] The EB uses technical detection methods, as well as legal methods such as letters of inquiry, subpoenas, and compulsory testimony, to close investigations that could lead to sanctions, loss of license, fines, criminal actions, or other remedies.[408] The FCC EB harmful interference resolution process is only effective for interference occurring within the U.S. or by a licensed U.S. radio emitter within FCC jurisdiction.

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402 *See* Constitution of the International Telecommunication Union, *supra* note 179, preamble and article 44 (2).
403 *See The Communications Act of 1934*, 73 Pub L. 416, 28 Stat 1064 (codified at as amended at 47 U.S.C. 151 *et seq* (1934)).
404 *See* 47 C.F.R § 2.803, 2.805, 2.1203.
405 *See* 47 C.F.R. § 2.102 & 15.5.
406 *See Enforcement Bureau: Enforcement Overview* (Washington, D.C.: Federal Communications Commission, 2020), online: <www.fcc.gov/sites/default/files/public_enforcement_overview.pdf> at 4.
407 *See ibid* at 7.
408 *See ibid* at 9–10.

If harmful interference occurs through a foreign source, the matter must be referred to the ITU for resolution. Article 15 of the ITU Radio Regulations discusses interference resolution which is based upon "goodwill and mutual assistance" of nations.[409] Once international harmful interference of space station communications is detected, it must be reported to the national spectrum governing administration and the source of that interference should be determined. If the source cannot be identified, the national administration may submit the information to the ITU Radio Bureau for assistance.[410]

If the source of the foreign interference is known, the National administration governing radio communications shall communicate the details of the interference to the country with jurisdiction over the source of the interference and request the ephemeral satellite location data from the source country.[411] The two countries are expected to work out the matter cooperatively, if possible. If mutual cooperation on the matter is not successful, the ITU Radio Regulations contemplate a report of infringement of the ITU Constitution which is addressed through negotiations under Article 56 of the ITU Constitution or compulsory Arbitration under Article 41 of the ITU Convention.[412]

Legally, the biggest shortfall in both the domestic and international system is the lack of a threshold level to distinguish harmful interference from normal expected interference that doesn't give rise to a claim. The definitions in both systems are highly subjective by the use of phrase "*seriously* degrades, obstructs, or repeatedly interrupts."[413] This subjectivity increases the workload of determining what is acceptable interference and what is not. This subjectivity could

[409] *ITU Radio Regulations* (International Telecommunication Union, 2016) at Art 15.22.
[410] *See ibid* at Art 15.43.
[411] *See ibid* at Art 15.31, .33, .34.
[412] *See ITU Constitution*, *supra* note 179 at Art 56; *Convention of the International Telecommunication Union* (Geneva: International Telecommunication Union, 2019) at Art 41.
[413] ITU RR No. 1.169; 47 C.F.R. § 2.1(c).

be eliminated by a specific 'harm claim threshold', which has been contemplated by the FCC Technological Advisory Council but has never been implemented.[414] Despite this limitation, the current FCC and ITU systems work fairly efficiently and should be able to accommodate the mega-constellation impacts on harmful interference.

F. INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE (ISR)

While there is no binding international instrument on remote sensing by satellite, the General Assembly of the United Nations did unanimously adopt a resolution on the *Principles Relating to Remote Sensing of the Earth from Outer Space* in 1986.[415] This soft law instrument essentially confirmed that States have freedom to explore and use outer space, to include remote sensing of other nations territory on the earth's surface. As a protection for national interests of sensed States, the resolution provides that the sensing must be done in a manner that is not "detrimental to the legitimate rights and interests of the sensed State."[416] This resolution is limited, however, in that it only covers remote sensing of the earth "for the purpose of improving natural resource management, land use and the protection of the environment," and not all remote sensing purposes.[417]

Based upon the duty of authorization and supervision contained in the OST and the soft law commitments outlined in the UN General Assembly Resolution, as well as the national security concerns, the United States government has issued laws and regulations governing remote sensing satellite systems. Commercial remote sensing in the United States is governed by the Land Remote Sensing Policy Act of 1992 which gives regulatory supervision authority to

[414] Lynn Claudy et al, *Interference Limits Policy: The Use of Harm Claim Thresholds to Improve the Interference Tolerance of Wireless Systems* (FCC Technological Advisory Council, 2013), online: <transition.fcc.gov/bureaus/oet/tac/tacdocs/WhitePaperTACInterferenceLimitsv1.0.pdf>.
[415] *See Principles Relating to Remote Sensing of the Earth from Outer Space*, GA Res 41/65, UNGASPC, 41st Sess, UN Doc A/41/751 (1986) at 115.
[416] *See ibid* at Princ IV.
[417] *See ibid* at Princ I.

the U.S. National Oceanic and Atmospheric Administration's (NOAA).[418] One of the main provisions of the Act is a requirement that all systems must be operated in a "manner as to preserve the national security of the United States and to observe the international obligations of the United States. . ."[419] The 2006 version of the regulations describe their purpose as to preserve national security in compliance with international obligations by maintaining US leadership in remote sensing space activities through encouragement of private companies to develop new systems whose "operational capabilities, products, and services are superior to any current or planned foreign commercial systems."[420] The policy continues with the caveat that "because of the potential value of its products to an adversary, the U.S. Government may restrict operations of the commercial systems in order to limit collection and/or dissemination of certain data and products to the U.S. Government or to U.S. Government-approved recipients."[421]

To implement this policy, NOAA requires anyone under U.S. jurisdiction wishing to operate a remote sensing satellite system to receive a license prior to operation.[422] NOAA recently updated its regulations on this matter to streamline the licensing process in accordance with SPD-2.[423] This new regulation significantly reduces the amount of application review coordination with the DoD regarding licensing conditions necessary to meet national security by replacing the every-application review process with a standardized set of conditions for systems not designated as new or novel (Tier 3).[424] Systems categorized as Tier 3 will still receive increased scrutiny and review by the DoD regarding appropriate license conditions to protect

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[418] *See Land Remote Sensing Policy Act*, 15 USC § 5601 (1992) (recodified at 51 USC § 601).
[419] 51 USC § 60122(b)(1).
[420] *See* 15 CFR § 960.1(c) (2006 version).
[421] *Ibid*.
[422] *See generally Licensing of Private Remote Sensing Systems*15 C.F.R. Part 960 (1992).
[423] *See Licensing of Private Remote Sensing Space Systems*, 84 Fed Reg 21282 (2019).
[424] *See* 15 C.F.R. § 960.6, 960.10.

national security.[425] Another change in this regulation is that if there are multiple entities involved in operating a new remote sensing system, the new regulations only apply to the entity with ultimate decision authority over collection based upon a definitional update to the term "operate."[426] Under this new definition, only the primary operator of a remote sensing system must receive a license, whereas under the previous system all partners were required to be reviewed through the application process by both NOAA and the DoD.

While the streamlined provisions will help ensure the United States commercial remote sensing industry remains competitive with foreign providers, the updated provisions generally reduce the effectiveness of national security oversight built into the previous version of the regulations. When it comes to the national security implications of remote sensing from mega-constellations, most of these systems will fall within Tier 3 categorization as new and novel capabilities subject to further scrutiny, to include DoD coordination on additional license conditions. However, once the first system of its type is licensed, any subsequent system with substantially the same capabilities will move both systems to a lower Tier category subject to reduced licensing conditions.

The U.S. remote sensing regulation has two conflicting purposes: to maintaining remote sensing technical superiority through encouraging commercial system development and using license conditions to limit and control the collection of sensitive remote sensing data by commercial systems to protect national security. The new NOAA regulations strike a balance of these priorities while leaning more toward the encouragement of commercial development. These regulations will make it easier for more operators to get licenses, to include mega-constellations, which may increase the quality and availability of remote sensing images that

[425] *See* 15 C.F.R. § 960.10.
[426] *See* 15 C.F.R. § 960.4.

could be used for adversary ISR purposes. That being said, the new regulations also maintain national security restrictions on the newest technology to ensure U.S. superiority for U.S. ISR purposes.

g. ON-ORBIT SPYING/ RENDEZVOUS AND PROXIMINTY OPERATIONS

Presently, there is no law directly concerning on-orbit spying or rendezvous and proximity operations (RPO) internationally or in the United States. While STM proposals will likely address standards of behavior for RPOs to ensure safe operations, no further legal developments are likely given that the OST prohibits the claim of sovereignty over space "by use or occupation, or any other means."[427] This means that States and companies can't claim the space around their satellites as protected space to legally prohibit another satellite from traveling in close proximity. The application of this principle to the increase in mega-constellations means that the amount of on-orbit spying and inspections is likely to increase. Satellites can use onboard optical and electromagnetic sensors to look at adjacent satellites and examine their functions and capabilities.

In response to these risks, DARPA provided the initial funding for the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS), an industry-led initiative to identify and publish non-binding technical and operational best practices and standards for RPO.[428] These standards will be valuable in ensuring safe RPO operations, while also allowing for differentiation between on-orbit servicing operations and spying or other nefarious RPO. While the CONFERS standards will be non-binding, the U.S. could require U.S. satellite

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[427] *OST*, *supra* note 132 at Art II.
[428] *See* "CONFERS: Fostering the Satellite Servicing Industry" (2020), online: *CONFERS* <www.satelliteconfers.org/>; "Consortium for Execution of Rendezvous and Servicing Operations" (2020), online: *DARPA* <www.darpa.mil/program/consortium-for-execution-of-rendezvous-and-servicing-operations>.

operators to comply with the provision by including them in the current FCC or FAA licensing regime.

h. CYBER-SECURITY AND HACKING

When it comes to national security risks through cyber-attacks or hacking, mega-constellations provide both a benefit in terms of resilience as well as a concern of increased vulnerability based upon the sheer number of satellites. In the end, the increase in the sheer number of satellites, ground-stations, and operators will increase the number of targets of opportunity for cyber-attacks. Until recently, there are no international legal instruments dealing specifically with cyber security. The closest provisions were the recognition of a right to privacy in the Universal Declaration of Human Rights and the International Covenant on Civil and Political Rights.[429] In 2001, the Convention on Cybercrime was instigated by the Council of Europe.[430] This treaties aim is to protect society from cybercrime through legislation and international cooperation.[431] The United States has signed and ratified the treaty and implemented its provisions domestically. Additionally, scholars have analyzed how other pre-cyber era international laws impact national security cyber operations in the Tallinn Manual.[432]

In the U.S., cyber-attack and hacking is criminalized by federal law.[433] This includes criminalizing unauthorized access to government and national security systems, as well as damage, fraud, and financial crimes related to cyber-attacks on all systems.[434] These laws will

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[429] *See Universal Declaration of Human Rights*, GA Res 217A (III), UNGAOR, 3rd Sess, Supp No 13, UN Doc A/810 (1948) Art 12; *International Convention on Civil and Political Rights*, 19 December 1966, 999 UNTS 171, Art 17 (entered into force 23 March 1976).
[430] *Convention on Cyber Crime*, 23 November 2001, T.I.A.S. No. 13174, E.T.S. 185 (entered into force 1 July 2004).
[431] *Ibid* at preamble.
[432] *Tallinn Manual 2.0 On the International Law Applicable to Cyber Operations* (Cambridge University Press, Michael N. Schmitt ed., 2017)
[433] *See e.g. Fraud and Related Activities in Connection with Computers*, 18 U.S.C § 1030 (2018); *Interception and Disclosure of Wire, Oral, Or Electronic Communications Prohibited*, 18 U.S.C. § 2511 (2018).
[434] 18 U.S.C § 1030.

apply equally to satellite system cyber-attacks and will provide the legal protection for cyber-attacks against mega-constellations. As such, the current legal system in the United States is well situated to address cyber-crimes if the mega-constellation boom does increase the number of attacks through an increase in vulnerabilities.

i. ANTI-SATELLITE (ASAT) OPERATIONS

The ASAT threat to national security will be increased by the mega-constellation movement. There are three legal issues that should be discussed related to this risk: 1) The laws on weapons in space, 2) The right to self-defense, and 3) Targeting.

1) Weapons in Space

As discussed above, the international space law prohibits placing weapons of mass destruction in orbit or on any celestial body in space, but there is no outright prohibition on placing weapons in space.[435] Thus, new mega-constellations are currently allowed to carry weapon systems if authorized by the controlling Nation.

Over the past several years, Russia and China have been seeking an international treaty banning certain weapon-systems in outer space. In 2008, Russian and China submitted a draft Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force Against Outer Space Objects and revised the text of the draft in 2014.[436] The United States has declined to participate in such a treaty formation as it believes that such action is problematic definitionally and verifiably.[437] In short, it would be difficult to define space weapons in such a way as to create an effective prohibition without also impacting novel and useful technologies that serve civil and commercial purposes; the treaty allows for the continued

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[435] Part II, b, 2 *supra*.
[436] *See* Rajeswari Pillai Rajagopalan, “Russian ASAT Test: More Trouble for Space Security”, *The Diplomat* (31 July 2020), online: <thediplomat.com/2020/07/russian-asat-test-more-trouble-for-space-security/>.
[437] *See* “US, Russia hold talks in Vienna on security in space”, *Aljazeera* (27 July 2020), online: <www.aljazeera.com/news/2020/07/russia-hold-talks-vienna-security-space-200727101057675.html>.

use of ground-based anti-satellite weapons; and such a treaty would be very difficult to verify.[438] In 2019, Ambassador Robert A. Wood, the U.S. Permanent Representative to the Conference on Disarmament gave a statement reaffirming the position and also noting that the actions of Russia and China seem to contradict their stated intent of the treaty.[439]

As such, it is unlikely that a new international law barrier to weapons in space is developed in the near further, nor international cooperation on the matter, leaving open the possibility of mega-constellations with weapons as a legally unaddressed threat to National Security.

2) Self-Defense

If an ASAT were used against the United States, depending on the severity of the effect of that weapon, the international law on self-defense would be applicable. Under Article 51 of the U.N. Charter, Nations are entitled to an inherent right of self-defense in response to an attack.[440] U.S. Policy reflects this rule in that President Trump's NSS refers to "peace through strength in the space domain."[441] The NSS specifically reaffirms that the United States retains the right and will respond to any attack or harmful interference on national space systems with "a deliberate response at a time, place, manner, and domain of our choosing."[442]

3) Targeting

As more of the military capabilities are shifted to commercial providers through contract or hosted payload, the issue of protecting and defending these dual-use satellites from intentional

[438] *See* "Statement by Ambassador Wood: The Threats Posed by Russia and China to Security of the Outer Space Environment." (14 August 2019), online: *US Mission to International Organizations in Geneva* <geneva.usmission.gov/2019/08/14/statement-by-ambassador-wood-the-threats-posed-by-russia-and-china-to-security-of-the-outer-space-environment/>.
[439] *See Ibid*.
[440] *See Charter of the United Nations*, 24 October 1945, 1 UNTS XVI.
[441] "2018 NSS", *supra* note 220.
[442] *See ibid*.

and unintentional threats becomes murky under the international law of armed conflict. The Law of Armed Conflict (LOAC) is a set of international laws that regulate the use of force during warfare and are derived from both treaty law and customary international law. Two of the main treaty sets that define LOAC are the Hague and Geneva treaties.[443] Additional Protocol I to the Geneva Convention, Article 48, requires the participants in combat operations "distinguish between . . . civilian objects and military objectives and accordingly shall direct their operations only against military objectives."[444] Terrestrially, objects that are civilian and have a military purpose are known as "dual-use", although this term is not explicitly included in international humanitarian law.[445] These objects can be civilian owned and operated but also legitimate military objectives under Article 52 of the Geneva Protocol I and subject to "total or partial destruction, capture or neutralization".[446] In essence, under international humanitarian law, a "dual-use" object can completely lose its civilian nature and right to protection if it is minimally used for a military purpose and that purpose is determined to be an effective contribution to military action. This concept has already been examined in the context of cyberspace with noted risk to infrastructure.[447]

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[443] *See generally: Geneva Convention (I) for the Amelioration of the Condition of the Wounded and Sick in Armed Forces in the Field,* 12 August 1949, 75 U.N.T.S. 31, Article 13 [Geneva I]; *Convention (II) for the Amelioration of the Condition of the Wounded, Sick and Shipwrecked Members of Armed Forces at Sea,* 12 August 1949, 75 U.N.T.S. 85; *Convention (III) Relative to the Treatment of Prisoners of War,* 12 August 1949; 75 U.N.T.S. 135; *Convention (IV) Relative to the Protection of Civilian Persons in Time of War,* 12 August 1949, 75 U.N.T.S. 287; *Protocol Additional to the Geneva Conventions of 12 August 1949, and Relating to the Protection of Victims of International Armed Conflicts* [Geneva Protocol I], 8 June 1977, 16 I.L.M. 1391; *Hague Convention (V) Respecting the Rights and Duties of Neutral Powers and Persons in Case of War on Land,* Oct. 18, 1907, 36 Stat. 2310, U.S.T. 540 [Hague Convention V].
[444] Geneva Protocol I, *supra* note 443, Article 48.
[445] While this term is not found in International Humanitarian Law, it is reflected in military operational guides and handbooks regarding the law of war and is part of the operational considerations when determining the appropriateness of using force.
[446] Geneva Protocol I, *supra* note 443, Article 52.
[447] See e.g. Cordula Droege, "Get Off My Cloud: Cyber Warfare, International Humanitarian Law, and the Protection of Civilians" (2012) 94 Intl Rev Red Cross 886.

This concept becomes murkier when the ownership, registration, and control of the satellite system being used is through neither of the participants in the conflict. Such a situation invokes the neutrality principles of international humanitarian law. Under the Hague Convention V of 1907, States involved in conflict must respect the neutrality of declared neutral nonparticipants in warfare.[448] Such nonparticipants are immune to attack as long as they are not supporting any of the involved parties by allowing use of its territory.[449] However, if a neutral party does lend support or allow the use of its territory by one of the adversaries, the other has the right to request the neutral to stop. If the neutral country does not, then that countries territory can be subject to attack. [450] There is an exception contained in Article 8 of the treaty for the use of a neutral party's communications infrastructure. This article states that "A neutral Power is not called upon to forbid or restrict the use on behalf of the belligerents of telegraph or telephone cables or of wifeless telegraphy apparatus belonging to it or to Companies or private individuals."[451]

As applied to the coming commercial mega-constellation boom in space, and military plans to use those satellites, the level of complexity rises once more. International humanitarian law applies to the countries that have signed the treaties, and not to non-state actors or companies.[452] While this would seem to free commercial satellite operators from application of the convention, Article VI of the Outer Space Treaty makes the "appropriate States" responsible for the acts of non-governmental entities operating from their countries or by their nationals.[453] In such a case, the use of commercial remote sensing, weather, or even PNT satellites by one

[448] *See* Hague *Convention* V, *supra* note 443.
[449] *See* Hague Convention V, *supra* note 443, Arts 1-6.
[450] *See Ibid*.
[451] *See* Hague Convention V, *supra* note 443, Art 8.
[452] *See* Hague Convention V, *supra* note 443, Art 20.
[453] *See OST*, *supra* note 132 at Art VI.

belligerent during conflict put the appropriate nation responsible for the company running the system in a difficult position. The disadvantaged belligerent could ask that the support be stopped or even attack the asset providing the service under the rules of Hague V.

This same analysis does not appear to apply to communications satellites, however, due to the exception in Article 8 of Hague V. Under this provision, States are not required to prevent the use of "telegraph or telephone cables or of wifeless telegraphy" as long as the services are available equally to both sides.[454] As such, mega-constellations that provide commercial communications to a belligerent force would not create neutrality issues for its responsible State.

In the national security context, this neutrality issue creates increased complexity for military satellite operators considering defensive operations against civilian satellites which may be performing operations on behalf of an adversary. This problem could be exacerbated if the target satellite is using a hosted payload to perform aggressive actions while the main portion of the satellite provides civilian services. In such a situation, it will be important to examine the ownership and usage of all portions of the satellite in order to understand the possible collateral effects of defensive operations that interfere with the satellite's operations. For example, the hosted payload portion of a satellite may be performing offensive jamming of a national security satellite, but the main portion of the target satellite may be an essential PNT satellite used to operate a national powergrid or other essential service. Disruption of the offending satellite for defensive purposes, even if that disruption is only temporary, could have disastrous and wide-spread implications for hospitals, transportation, and other essential services for an entire nation of people.

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[454] *Hague Convention (V) Respecting the Rights and Duties of Neutral Powers and Persons in Case of War on Land*, U.S.T 1907, 540 at Art 9.

j. CONCLUSION

This discussion w of some of the legal regimes currently in place that will govern mega-constellations shows that this movement has not gone unnoticed by international and domestic regulators. The growth of the smallsat industry and the increasing connectivity across the globe has led to many new international and domestic laws in the past decade that have placed the United States in a good position to address the challenges that will come with the launch of thousands of more satellites into space. Several areas, such as launch licensing, STM, space debris mitigation, and RPO will require further legal development in short order to keep pace with mega-constellation deployments and the associated risks to national security. The regulation of SSA and harmful interference appear to be in the middle of changes that should address the coming challenges. Other areas, such as cyber security and ISR appear to have sufficient regulations in place.

Conclusion

The mega-constellation boom has begun. As of today, between just the main two commercial mega-constellation proposals, more than 90,000 satellites will be added to space in the coming years.[455] These two mega-constellations alone have the potential of launching nearly ten-times the total number of satellites ever launched in the history of man-kind. The growth of LEO, smallsat mega-constellations in the next decade has the potential to create worldwide high-speed internet access parity like never before, as well as numerous other benefits.

These mega-constellations are made possible by technological developments and industry trends for the smallsat industry. These include miniaturization of components, use of COTS components, and the development of standardized form-size for some smallsats. The newest wave of smallsats benefit from industry developments and focus on reducing launch costs and reduced regulation. In the end, these LEO smallsats can be manufactured quicker and cheaper, put into orbit quicker and cheaper, and provide global coverage with quicker communication speeds.

The U.S. currently relies on space assets to provide essential capabilities in support of national security. The capabilities include SATCOM, ISR, weather and environmental monitoring, PNT, missile warning, SSA, and nuclear deterrent operations. The integration of capabilities provided by mega-constellations into the national security architecture, through commercial contract or government-fielded constellation, has the potential to provide many benefits. The main benefits stem from the technological improvements and capabilities of new smallsats working in concert together and the improved resilience mega-constellations provide by the sheer number of satellites. That said, these mega-constellations also pose increased risk to

[455] *See* Harris, "40,000 Satellites", *supra* note 2; "48,000 for OneWeb", *supra* note 2 at 00.

national security use of space, as it currently stands. One of the major negative consequences of mega-constellations currently is the potential for an exponential increase in space debris. More potential negative consequences include unintentional harmful frequency interference, cyber-security risks, and ASAT weapon risks.

These new capabilities and risks to national security raised several legal issues addressed by this research. International space law has not developed much in the past 50 years since the five main treaties related to space were signed. While international cooperation on issues such as space debris, space traffic management, and space situational awareness would be the best solution, the international environment does not appear conducive to serious binding agreements on these issues in the next decade. As such, the majority of development has been and will be completed domestically. The U.S. has long been a leader in the regulation of space activities and will need to continue that role in order to protect national security in light of the mega-constellation movement.

In particular, the current space launch laws and regulations administered by the FAA are cumbersome and slow, not keeping pace with industries movement toward rapid launch and rapid technology refresh. Space situational awareness laws and policy are currently in the very beginning of a transition to split public SSA duties away from the military which should have the effect of increasing international trust and cooperation. Space debris and space traffic management guidelines are also being updated currently but both truly need international cooperation to be most effective. These are two of the most critical issues in light of the mega-constellation movement. While the ITU and FCC appear to have a workable process for harmful interference resolution, having a threshold definition and more international adjudicative power would improve the process immensely. The recently updated remote sensing regulations for

ISR, as well as cyber-security rules appear well suited to manage the coming mega-constellation movement, while the rules on rendezvous and proximity operations are currently non-existent. Last, the application of the international Law of Armed Conflict will be difficult, with new complexities, due to the mega-constellation movement. This captures many of the legal issues and shortcomings that should be addressed here at the beginning of the mega-constellation boom to ensure U.S. national security remains protected during this exponential change to the space environment.

In the end, the increased risks posed by mega-constellation to national security may have an unintended positive effect: the increase of these risks to all the nations of the world may be the catalyst needed to begin serious international discussions toward binding rules of space debris mitigation, space traffic management, harmful interference accountability and more that can be used to increase national security of all Nations through improved coordination, communication, and rule-based procedures that improve safe and sustainable space operations. If we are diligent, we may avoid being the burning fools who destroy humanities opportunity for continued exploration beyond out terrestrial home.

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