The Impact of Small Satellites on U.S. National Security Space Architecture

Elsie Bjarnason, Tara Halt, Natalie Kauppi, Chase Tralka
ISTP Capstone – Spring 2017
8 May 2017

Executive Summary

Context overview:

As the capabilities of small satellites grow, so too do their national security uses and implications. Small satellites are hereafter defined as a satellite with a dry mass below 180 kilograms, although it is recognized that this is not an industry-wide definition. Small satellites are increasingly being used for a variety of missions related to national security, to include communications and Earth observation. Advantages of small satellites over regular satellites include their drastically reduced cost and increased ease of launch, which subsequently result in an increased ability to bolster capabilities through constellations. The commercial space sector has near-term plans to launch a significant number of small satellites, and it is expected that this will lead to further advancements in small satellite capabilities. Increased capabilities and use of small satellites is largely advantageous to the U.S. national security community, and the community has myriad opportunities to benefit from advancements made by the private sector. However, the rise in the use of small satellites poses two major challenges which must be addressed from a policy perspective before the full potential of small satellites can be realized.
First, increasing the number of small satellites in orbit increases the number of objects in orbit and therefore magnifies the existing challenge of space situational awareness. As of yet, companies in the commercial sector are generally highly capable of tracking the orbits of their own satellites but are generally unaware of the exact orbits of others’ satellites, meaning that there is an ever-increasing chance of collisions. Collisions with other satellites or space debris would result in increased orbital debris, as seen in China’s 2007 anti-satellite missile test and the 2009 collision of the satellites Iridium 33 and Kosmos-2251. This issue stems from the fact that existing registration practices - involving both the United Nations and individual nations - do not encompass detailed orbital information. While it is recognized that orbital information is sensitive for national security satellites, the national security risks posed by the planned drastic increase in the number of commercial and civil satellites in orbit cannot be ignored.

Secondly, the U.S. Government will be unable to realize the advancements made by the private sector unless the U.S Government develops new procurement mechanisms to leverage new datasets. It is recommended that CSF and its member organizations advocate for the government, specifically the General Services Administration (GSA), to develop additional contracting mechanisms. The National Geospatial-Intelligence Agency has already begun this process through the creation of the Commercial Initiative to Buy Operationally Responsive GEOINT (CIBORG) program with the General Services Administration (GSA), and this program should be used as a model.

**Policy recommendations:**

1. To address the growing issue of space situational awareness due to the growing number of small satellites in orbit, it is recommended that the Commercial Spaceflight Federation encourage its members and other satellite operators to voluntarily adopt registration
standards that would require detailed orbital information about the satellite to be registered with the United Nations. This requires collaboration between a registration entity (the United Nations) and a monitoring entity (public or private). It is also recommended that the Commercial Spaceflight Federation conduct outreach to the rest of the small satellite community to do the same.

2. To allow the U.S. Government to fully take advantage of the increasing small satellite capabilities of the private sector, it is recommended that the Commercial Spaceflight Federation and its member organizations advocate for the government, specifically GSA, to work to develop additional contracting mechanisms similar to the CIBORG program.
Introduction

The past decade has seen an explosion in the number of small satellites launched into orbit. These satellites, having a dry mass of less than 180 kilograms, utilize new technologies to combine capabilities of larger, more-traditional satellites with the cost-saving benefits of smaller, lighter platforms. The proliferation of small satellites will result in numerous effects on commerce, science, and national security, presenting both opportunities that can be exploited and challenges that must be mitigated.

From 2013 to 2016, 248 small satellites were launched into orbit and remain operational, according to the Union of Concerned Scientists Satellite Database.1 This represents over 40 percent of the total number of satellites launches during that period. 2017 stands to have the largest number of satellite deployments in one year ever, with 125 satellites launched in the first two months, most of them small satellites. The lower costs associated with small satellites offer nations, corporations, and institutions unprecedented opportunities to develop, build, and launch satellites.

This report will present a policy-based strategy for understanding the cost impacts of small satellites on the U.S. national security space architecture, provide a background on small satellite technologies and uses, and discuss the risks and opportunities presented by small satellites. The report will provide two policy suggestions applicable over the next four years that can be implemented by the Commercial Spaceflight Federation and its member organizations to influence the federal government and its industry partners to

---


Note: While NASA describes small satellites as having a dry mass of 180kg, the UCS database does not contain dry mass values for many satellites. To produce a more accurate number of satellites, this study will consider any satellite with a launch mass value of less than 205kg as a small satellite.
better utilize small satellites in ways that will both protect and enhance U.S. national security. The report also includes analyses of the technical, economic, political, and national security considerations of the proliferation of small satellites, based largely on published reports, books, articles, and news stories, as well as interviews with respected experts and practitioners.

**Background**

In order to understand the pressing national security, economic, and political issues facing the small satellite industry, it is important to have a basic technical understanding of small satellites and the regulatory frameworks which apply to them. The technical components are often overlooked in the policy community, and the policy components are often overlooked in the technical community, leading to friction between the two communities and ineffective policies. The regulatory environment is complex and difficult to navigate, as it is a medley of national and international regulations, as well as industry best practices. This paper will therefore provide basic background technical information and then provide policy analysis and recommendations.

Any policy which aims to address the use of any technology - to include small satellites - must include technical discussions about the characteristics and capabilities of the technology. Each small satellite in orbit today was designed and engineered to perform a specific function or functions, and each specification was chosen for a precise purpose; that purpose can therefore often be deduced and controlled by its technical specifications, such as class of orbit, type of orbit, perigee, apogee, eccentricity, and inclination. Although capabilities evolve quickly, the general concepts that underlie small satellites are largely the same as those that underlie regular satellites.
Defining “Small Satellites”

According to the National Aeronautics and Space Administration (NASA), a satellite is “a moon, planet, or machine that orbits a planet or star.” Small satellites (frequently called smallsats) are hereby defined as satellites with a dry mass less than 180 kilograms (kg). It should be noted that this is NASA’s definition for small satellites, and while not universally accepted, it is useful for distinguishing small satellites and will therefore be used throughout this paper. Other definitions for small satellites do exist; for instance the Aerospace Corporation classifies satellites with a mass less than 500 kg as small satellites. Dry mass is simply the mass of a satellite without fuel. The primary subsystems that determine a satellite’s dry mass are: structure, thermal, integration, contingency, and propulsion. Following NASA’s classification scheme, small satellites can be further differentiated by their mass as follows:

<table>
<thead>
<tr>
<th>Types of Small Satellites</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minisatellite</td>
<td>100-180</td>
</tr>
<tr>
<td>Microsatellite</td>
<td>10-100</td>
</tr>
<tr>
<td>Nanosatellite</td>
<td>1-10</td>
</tr>
<tr>
<td>CubeSat*</td>
<td>1-10</td>
</tr>
<tr>
<td>Picosatellite</td>
<td>0.01-1</td>
</tr>
<tr>
<td>Femtosatellite</td>
<td>0.001-0.01</td>
</tr>
</tbody>
</table>

*CubeSats are named for their standard size and form factor. They are typically measured

---

Satellite Databases

Several databases exist of satellites that are currently in orbit; each has its advantages and disadvantages. The Union of Concerned Scientists (UCS) publishes a satellite database each year that contains the most up-to-date, comprehensive open-source information about satellites currently in orbit; the latest version was published on 11 April 2017 and includes satellites launched through 31 December 2016. The UCS database provides a large amount of sortable technical information, to include dry mass, type of orbit, and purpose, and removes satellites from the database which are no longer in orbit. Due to the exclusion of classified and commercially sensitive information, as well as perhaps a lack of resources, the UCS database unfortunately does not include all of the satellites - to include small satellites - currently in orbit. Other satellite databases exist, but they are less useful for analysis than the UCS database. For instance, the United Nations Office for Outer Space Affairs maintains the Online Index of Objects Launched into Outer Space. This index will be further explained later, but it includes information such as the name, state/organization, date of launch, and status. It does not include any technical information such as dry mass, type of orbit, or purpose. The UCS database was therefore used in this paper for several analyses, and small satellites were selected by choosing only those with a launch mass less than 205 kg.

Small Satellites Currently in Orbit

According to the April 2017 UCS database, there were 1,459 satellites orbiting the Earth as of 31 December 2016, 382 of which were small satellites with a launch mass less than 205 kg.

---

than 205 kg. This launch mass was chosen because the dry mass for many satellites in the UCS database is missing; for instance, the launch mass of a Planet Labs Dove satellite is 4 kg and would be excluded from calculations by simply filtering the database for satellite with a launch mass below 205 kg because there is no dry-mass information for the Dove satellites.

Of the 382 small satellites in orbit as of 31 December 2016, 248 were launched between 2013 and 2016; the entire number of small satellites remaining in orbit that were launched pre-2013 is 134. According to the April 2017 UCS database, 41 countries\(^8\) (including joint ownerships) had small satellites in orbit as of 31 December 2016. The United States owns and/or operates the most small satellites, with 172 in orbit as of 31 December 2016, China is second, with 43 small satellites in orbit, and Japan is third with 22. The purposes and quantities of small satellites currently in orbit can be broken down into the seven categories shown in Figure 1 by using the UCS database. Note that there is some overlap between the categories; these categories are chosen to allow for further analysis using the UCS satellite database.

---

\(^8\) Algeria, Argentina, Austria, Belgium, Brazil, Canada, Chile, China, Denmark, ESA, France, Germany, India, Indonesia, Iran, Iraq, Israel, Italy, Japan, Kazakhstan, Morocco/Germany, Multinational, Netherlands, Nigeria, Norway, Peru, Russia, Russia/USA, Saudi Arabia, Singapore, South Korea, Spain, Switzerland, Taiwan/USA, Turkey, Ukraine, United Arab Emirates, United Kingdom, Uruguay, USA, USA/Argentina, Vietnam
As broken down in the 2017 UCS database, four primary sectors use small satellites: government, commercial, civil, and military; some satellites, as will be discussed further later in this paper, are dual-use and therefore belong to more than one category. As shown in Figure 2, the commercial sector had the most small satellites in orbit as of December 2016, with 167. Governmental small satellites include meteorological and scientific small satellites. Civil satellites are primarily those used by academic institutions.
Figure 2: Users of the 382 Small Satellites in Orbit as of 31 December 2016. Data source is the April 2017 UCS satellite database.

**Constellations**

Small satellites operate both as single entities and in constellations with other small satellites. Similarly to what was common decades ago with large satellites, small satellite constellations are used to provide greater technical abilities than would be possible with a single small satellite - or often even a single regular satellite. For instance, a constellation of small satellites used for remote sensing offers significantly increased ground coverage, time resolution, and processing power over a single small satellite. Additionally, small satellite constellations can be used to bolster the capabilities of constellations of regular satellites.⁹ Planet co-founder Robbie Schingler states that his company’s products “provide

---

the ‘peripheral vision’ that then is able to inform more high-resolution imaging systems.” The peripheral capabilities of small satellites provide important context for the information provided by larger satellites.

The space community generally predicts that the number of satellites in orbit will increase over the coming decade, largely due to the increasing trend of launching small satellite constellations. Notably, Planet Labs recently launched 88 small satellites for imaging purposes. Several companies are planning to launch large fleets of relatively small (although perhaps not below 180 kg) satellites for internet connectivity purposes: SpaceX plans to launch 4,425 such satellites; Samsung wrote about launching 4,600 satellites; and Boeing requested a license to launch a network of between 1,396 and 2,956 V-band satellites.

Overview of relevant terminology

All satellites follow a regular, repeating path around an object in space, called an orbit; in this case, the satellites are small satellites, and the object they orbit is the Earth. The period is the length of time it takes the satellite to orbit the Earth once and is often measured in minutes. The eccentricity of a satellite’s orbit is a measure of how significantly the satellite’s orbit deviates from that of a perfect circle (deemed to be 0). That is to say, that the closer the eccentricity is to 0, the closer the satellite’s orbit is to a perfect circle. A “nearly circular orbit” is defined as having an eccentricity <0.14. Orbits with an eccentricity greater than 0.14 are elliptical orbits. There are only five smallsats in the UCS

---

database that have an elliptical orbit. The rest of the smallsats have a nearly circular orbit. Nearly circular orbits can be further classified by their altitude and/or inclination.

**Classifications by altitude**

- **Low Earth Orbit (LEO)** has an altitude between 80 kilometers and 1,700 kilometers. Most satellites, including the Hubble Space Telescope and the International Space Station, are in LEO. LEO is widely used for smallsats because it is the easiest and most inexpensive orbit to place a satellite into. Other advantages include high spatial resolution and polar coverage; disadvantages include low temporal resolution at low latitudes.

- **Medium Earth Orbit (MEO)** has an altitude above 1,700 kilometers but lower than 35,700 kilometers.

- **Geosynchronous Orbit (GEO)** has an altitude of approximately 35,700 kilometers, which yields an orbital period of approximately 24 hours; therefore, these satellites appear fixed over a given location. Advantages include high temporal resolution and the fact that it is always visible; disadvantages include cost and poor coverage of high latitudes. The location of a satellite in GEO can be defined by its longitude (position defined as degrees from the Greenwich meridian) because the satellite rotates with the Earth and therefore remains fixed over a given location.

**Classifications by inclination**

Inclination is the number of degrees of the angle between the equatorial plane of the Earth and the orbital plane of the satellite. Therefore, a satellite that orbits from the geographic North Pole has an inclination of 90 degrees, whereas a satellite that orbits around the equator has an inclination of zero degrees. This is shown below in Figure 3, courtesy of NASA.

---

19 Ibid.
21 https://earthobservatory.nasa.gov/Features/OrbitsCatalog/
There are four classifications based on inclination:

- Equatorial orbit has an inclination between 0 and 20 degrees.
- Nonpolar inclined orbit has an inclination between 20 and 85 degrees.
- Polar orbit has an inclination between 85 and 95 degrees, and >104 degrees.
- Sun-synchronous has an inclination between 95 and 104 degrees; the relationship between altitude and inclination is sun-synchronous; therefore, these satellites always pass the equator at the same local time each day.

As shown below in Figure 4, most small satellites in the 2017 UCS database are in sun-synchronous or non-polar inclined orbits. Sun-synchronous orbits are advantageous as they essentially remain fixed over a given location, and their orbits allow for high ground resolution, as well as easy radar and lidar measurements. Of the 216 small satellites in the 2017 UCS database in sun-synchronous orbit, the most common purpose is technology development, with 81 in orbit for this purpose. The second most common purpose of the small satellites in sun-synchronous orbit is earth observation, with 77, and the third most common is communications, with 28. Of the 122 small satellites in the 2017 UCS database in non-polar inclined orbit, the three most common uses are: earth observation (46 small satellites), communications (40 small satellites), and technology development (24 small satellites).

---

Non-polar inclined orbit is useful for communications as the inclined orbit significantly reduces bandwidth costs, as well as likely extends the operational lifetime.\textsuperscript{23}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{orbit_type}
\caption{Type of Orbit of the 382 Small Satellites in Orbit as of 31 December 2016. Data source is the April 2017 UCS satellite database.}
\end{figure}

\textbf{Power / Propulsion}

Power refers to the amount of usable electric power (measured in watts) produced by a satellite. On the system level, the power determines the end-of-life power, mission life, and altitude stabilization. On the subsystem level, power determines the array power capacity and the eclipse power.\textsuperscript{24} Most small satellites are powered by lithium-ion batteries and solar panels. Traditional lithium-ion batteries take up 20-35 percent of the “experiment” volume. Researchers are working to develop smaller and more efficient lithium-ion batteries, which would benefit every industry that utilizes batteries, from small satellites to

\begin{footnotesize}

\textsuperscript{24} Price, Kent M., David Pidgeon, and Alex Tsao. 1991. Mass and Power Modeling of Communication Satellites
\end{footnotesize}
electric cars. For instance, there is a new type of lithium-ion battery that would be about one-third the size of current small satellite batteries.\textsuperscript{25} Increasing the power of a satellite effectively results in linear increases in the land area on Earth which can receive communications from the satellite; that is to say, that if a satellite with a power of 25 watts could communicate to a land area of 125,000 square kilometers, an equivalent satellite with a power of 100 watts could communicate to a land area of 500,000 square kilometers.\textsuperscript{26}

Antennas are often used in communications satellites to increase the strength of the signal sent back to Earth, thereby allowing satellites to use less power to communicate at a comparable distance. One of the problems facing the incorporation of antennas into small satellites is that there is not enough space to incorporate a powerful antenna; subsequently, small satellites are often not able to communicate at the same distance as regular satellites which are less constrained by space and weight. Researchers are therefore actively developing new, creative ways to incorporate small, lightweight antennas into small satellites. For instance, a team of researchers at the Massachusetts Institute of Technology created an antenna which “inflates” once it is in orbit.\textsuperscript{27}

**Signals Intelligence**

Long the domain of major government agencies with massive satellites and accordingly massive budgets, the ability for organizations to benefit from signals intelligence (SIGINT) may also improve due to small satellites. In 2000, researchers at the University of Surrey proposed a design for a SIGINT collection satellite that would operate in LEO and be constructed from off-the-shelf parts and could be “implemented in a payload


for a small, inexpensive satellite.”28 While this report does not address further uses of small satellites for SIGINT collection, the potential for the United States, other national governments, or private organizations to field cost-effective SIGINT collection assets should be considered by the U.S. national security community.

The first successful use of what is now called SIGINT was done by the British intelligence services during World War I, when they tapped underwater cables to intercept German communication. SIGINT has since kept pace with technological advancements, and the United States now has a well-developed capability that is able to collect intelligence from the ground, sea, sky, and outer space.29 The National Security Agency (NSA) and the National Geospatial-Intelligence Agency (NGA), two Department of Defense (DOD) intelligence agencies, have collaborated closely on SIGINT missions through programs such as GEOCELL, which aimed to integrate intelligence collection and analysis at the tactical level.3031 Small satellites will enable SIGINT missions due to their attractive economics and their technical capabilities.

There are three primary forms of SIGINT: communications intelligence (COMINT), telemetry intelligence (TELINT), and foreign instrumentation signals intelligence (FISINT, also sometimes called electronic intelligence). COMINT involves intercepting communications and is generally what is referenced when SIGINT discussed.32 As discussed previously, most small satellites are used for communications purposes; therefore, it is likely that the majority of small satellites used for intelligence purposes would gather COMINT and would be positioned in LEO. TELINT is intelligence gained from weapons

---

29 Lowenthal, M. (2014). Intelligence: From secrets to policy (Sixth ed.).
30 Tenet, J. "Clapper was ‘Risk-Taker, Visionary and Leader’." Pathfinder.
32 Lowenthal, M. (2014). Intelligence: From secrets to policy (Sixth ed.).
during testing, and FISINT involves gathering electronic emissions from weapons and both military and civil tracking systems.\textsuperscript{33} Some small satellites are also capable of collecting TELINT and FISINT.

COMINT provides the context that is often missing from geospatial intelligence (GEOINT). Much information can be obtained by intercepting communications. Analysis of COMINT takes many forms, from simply analyzing the content, to determining the frequency, volume, and location of communication. The latter is referred to as “geospatial metadata analysis” and notes the location when monitoring changes in communications.\textsuperscript{34}

For instance, this is very useful for monitoring troop movement.

**Dual-Use Technologies**

Dual-use technologies are technologies that can be used for both civilian and military purposes. They include those that are currently only used for civilian applications but can, in principle, be used for military purposes as well.\textsuperscript{35} Given the vast technical capabilities encompassed by space technologies, nearly all space technologies are inherently dual-use, including small satellites designed for commercial purposes. A single small satellite could host multiple dedicated transponders; for instance, it could have one transponder for commercial applications and one transponder for military applications.\textsuperscript{36}

There is a large amount of overlap between the capabilities demanded by the military and those demanded by the commercial sector, and sharing a satellite can be beneficial for both parties.

Some examples of dual-use technologies are unintentional, however. While small satellites may be launched for a single application in the near future, the information

\textsuperscript{33} Ibid.
\textsuperscript{34} Ibid.
gathered could still be important to the intelligence community. According to Dr. Jeff Foust, a Senior Staff Writer at Space News, it may be more likely that small satellites will carry out a single application, whether commercial or governmental.\(^{37}\) This is advantageous in that dual-use satellites often face design compromises, whereas single-use satellites are designed with a specific application in mind.

It is important to note that single-use technologies can still have dual-use purposes. For instance, commercial data imaging could be used by the intelligence community for military applications. Planet Labs’ (a major manufacturer of small satellites) goal is to “image everywhere very frequently, for everyone.”\(^{38}\) Commercial Earth-imaging small satellites such as Planet Labs Flock 1 Doves are designed to take images of the Earth for use in “humanitarian, environmental, and commercial applications,” and these images can be strengthened by use of the Doves in conjunction with high-resolution technologies such as unmanned aerial vehicles. Images used for “humanitarian, environmental, and commercial applications” can just as easily be used for military applications, such as GEOINT on enemy territory. The data captured by Flock 1 will be accessible to anyone who wants it.

For U.S. national security purposes, imagery gathered by the private sector can be both an asset and a liability. It is an asset because it allows the U.S. to obtain additional intelligence with little effort, but it is a liability because it means almost anyone else can obtain the same intelligence, even those previously unable to due to the high barrier into entry of space - such as non-state actors. For one researcher at Rand, the best course of action at this time is to continue to launch U.S. small satellites in order to maintain greater

---

37 Foust, Jeff. Senior Staff Writer at Space News/ "Interview about Small Satellites and National Security." Interview March 26, 2017.
regulatory control of this dual-use technology:

“The concern is if we sell small satellites to foreign nations or non-state actors and they put them up. We [The United States] wouldn’t have regulatory authority. Small satellites in large numbers have national security implications, so our best solution is to be first, which is what we always want to do when it comes to space. Ultimately, we can’t stop others from using small satellite constellations and their imagery, so if we launch first, we have a greater argument for why we should regulate the data, should a problem arise”39

Furthermore, the technologies required to develop and build launch systems for space technologies - including small satellites - are nearly identical to those required to develop and build launch systems for nuclear weapons and ballistic missiles.40 It is therefore possible that a nation would claim to be developing launch systems for space technologies, when in fact they are developing launch systems for military purposes.

Because space technologies are inherently dual-use, they pose a risk of military escalation, whether they are targeted intentionally or unintentionally. As stated by Jeff Foust: “A satellite supporting HBO can also help with drone operations. If there are hostilities with a country with ASAT capabilities, does that mean that the HBO satellite is fair game to disrupt?”41 National security architecture must address the fact that small satellite technology is inherently dual use, is an asset and a liability, and threats and opportunities will arise with what small satellites can do, not necessarily what they were designed to do. Furthermore, satellites are used for nuclear command, control, and communications (NC3) purposes. As the United States and most other nuclear powers do not publish unclassified details regarding the satellites that are used for NC3, it is possible than an adversary could attack such an satellite with the intent to disable its commercial use - or potentially even its non-nuclear military use - without realizing that they escalated the

41 Foust, Jeff. Senior Staff Writer at Space News/ "Interview about Small Satellites and National Security." Interview March 26, 2017.
conflict to the nuclear domain. While it is unlikely that small satellites are used for NC3 purposes, it is clear that small satellites have the capabilities necessary to be used for both civilian and military applications.

**Cost Analysis**

In recent years, the amount of investment in small satellites has dramatically increased in civil, commercial, and military space. Over the past decade, approximately $2.5 billion has been invested in the small satellite industry. Companies like SpaceX and OneWeb have plans to put hundreds or possibly thousands of small satellites into orbit. The amount of government investment also continues to grow. In December 2016, the White House announced $110 million in new investments by the Department of Defense and NASA. Out of that $110 million investment, the U.S. Air Force committed $100 million to “demonstrate the ability to command and transfer critical data through commercial networks, safely and securely; devise and provide infrastructure to support a rapid payload prototyping approach for smallsat experimentation, with the objective of designing, building, and testing devices for use aboard small satellites in just weeks or months.” This investment by the Air Force demonstrates the DOD’s interest in increasing its use of smallsats for governmental activities.

In 2015 the U.S. Institute of Electrical and Electronics Engineers (IEEE-USA) released a report encouraging the U.S. government to support and incentivize development of the remote sensing industry. The report stated that “Carefully targeted investments in space-based remote sensing and geospatial imaging technologies are urgently needed to enhance

---


the operational effectiveness of public and private sector earth observation programs that
advance scientific knowledge, promote economic growth, improve public safety and ensure
national security in increasingly competitive global markets.”

The remote sensing industry is growing rapidly and most of the new remote sensing constellations are made up of small satellites. Companies like Spire, Planet, and Terra Bella (now owned by Planet) all launched small satellite constellations to do remote sensing. A British Broadcasting Corporation report predicted that “the space-based conventional platforms segment of the industry is expected to grow from $3.3 billion this year to $4.3 billion in 2021.”

National Security Space is one of the most prolific users of remote sensing data and has developed an interest in using small satellites for this purpose.

The General Services Administration and the Defense Information Systems Agency (DISA) released the first contract awards under a combined IT Schedule 70 commercial satellite communications acquisition program. The IT Schedule 70 program is a long term contract to a commercial technology vendor, and shortens procurement cycles and ensures best value for technology to federal, state, and regional customer agencies. This ability to purchase satellite technology from pre-approved vendors allows agencies and vendors to cut administrative costs, avoid red tape, and receive goods and services faster.

Last year, NGA signed an introductory contract with Planet Labs, a remote sensing satellite operator based in San Francisco. Planet Labs currently has over 175 of its “Dove” small satellites in orbit, with its most recent deployment happening in February 2017. The “Dove” satellites are 3U cubesats and weigh about 5 kg. The contract between NGA and Planet Labs is valued at $20 million and includes a seven-month period of performance.

---

46 Furthermore, previous satellite contracts were hampered by specific frequency bands, whereas GSA can add new bands in its transponded contract SIN (special item number). "IT Schedule 70." GSA.gov., https://www.gsa.gov/portal/content/104506.
Planet Labs would provide the NGA with a global imagery refresh every 15 days of most of Earth’s landmass.\(^{47}\)

The cost of small satellites can be broken down into four different categories: development/construction, launch, operations, and overall life cycle cost. Development cost is defined as “the total of all costs, including construction of facilities and employee costs, from the period beginning with the approval to proceed to implementation through the achievement of operational readiness.” Launch costs are all the cost related to launching the satellite. Life cycle cost is defined as “total of the direct, indirect, recurring, and nonrecurring costs, including the construction of facilities and employee costs, and other related expenses incurred or estimated to be incurred in the design, development, verification, production, operation, maintenance, support, and retirement of a program over its planned lifespan.”

Traditionally, the U.S. national security community has relied on larger satellites for communication, surveillance, and intelligence. DOD satellite systems are very expensive to acquire. A 2016 GAO report found that “Unit costs for current DOD satellites can range from $500 million to over $3 billion, and ground systems can cost as much as $3.5 billion. The cost to launch just one satellite can climb to well over $100 million.”\(^{48}\) The DOD has been plagued by cost overruns in many of its satellite programs. The figure below shows the original cost of the project, the current cost, and any schedule shifts that have occurred. In 2013 GAO reported that the “DOD’s Space Based Infrared System (SBIRS) would cost $18.3 billion, up 297.4 percent from a total program cost projected at $4.6 billion in

---


Cost overruns are usually coupled with delays in schedule as well and this was no exception. The first SBIRS satellite was launched in May 2011, approximately 9 years later than originally planned.

### Figure 5: Status of Major DOD Space System Acquisitions (GAO Report)

A 2010 Government Accountability Office (GAO) report stated that there were

---


several causes of these costs overruns and schedule delays. Figure 5 gives an overview of major DOD programs and compares their original program cost to the current program. For most of the programs the current cost is higher than the original cost. The GAO found that “DOD starts more weapon systems than it can afford, creating a competition for funding that encourages low cost estimates, overly optimistic schedules, a reluctance to convey bad news and, for space programs, forsaking the opportunity to identify and assess potentially more executable alternatives.” The flexibility of small satellites allows the DOD to cut down on costs and adhere to the original schedule.

One of the most driving factors of overall life-cycle cost is the launch cost. Small satellites have more launch options than traditional satellites. For example, small satellites are able to be launched as cargo to the ISS and then deployed through the Kibo module or they can be launched through a rideshare program or as a hosted payload. The cost of launching traditional satellites can range from $50 million to $400 million. SpaceX has reported that a Falcon 9 cost $62 million per launch. The cost to launch a traditional satellite on Ariane V is approximately $100 million after subtracting out the subsidies from the European Space Agency.

India’s PSLV rocket is one the cheapest ways to launch satellites into space because of the subsidies the Indian Space Research Organization receives from its government. A PSLV costs only $15 million, which is a stark decrease from the price of Falcon 9 or Ariane V. In February 2017, ISRO launched 104 small satellites on its PSLV rocket. ISRO reported that over half of the cost of the launch vehicle was covered by the satellite manufacturers. There is concern from organizations like the Commercial Spaceflight Federation (CSF) that ISRO is distorting the launch market by offering rides to

space at the fraction of the cost of commercial companies. In an April 2016 testimony to Congress, Eric Stallmer, President of CSF, stated that “CSF opposes efforts to facilitate a government-subsidised foreign launch company—in this case, ISRO—to compete with US companies. Such a policy runs counter to many national priorities and undermines the work and investment that has been made by government and industry to ensure the health of the US space launch industrial base. At the same time, we have to be cautious not to squeeze out the US satellite manufacturers and operators that have immediate launch needs which cannot yet be served by the aforementioned US launch vehicles that are still in development.”

As dedicated small satellite launchers enter the market, cost of launch for small satellites will decrease. Rocket Lab advertises the cost of its electron rocket as $5.5 million with a nominal payload of 150 kilograms. Virgin Galactic is developing its own dedicated small satellite launcher called LauncherOne. LauncherOne will launch a payload of 200 kg to a sun synchronous orbit for under $10 million. When satellites hitch a ride on a larger rocket or are deployed from the ISS, they are often unable to choose the destination orbit because they are normally equipped with little or no propulsion. A dedicated small satellite launcher would allow the national security sector to select the orbit based on the needs of the mission rather than the destination of the primary payload.

When examining the characteristics of satellites, small satellites are extremely cost efficient in most areas. The analysis below was completed by the Aerospace Corporation during the development of their Small Satellite Cost Model (SSCM).
Small satellites can create huge cost reductions for a satellite manufacturing company. Since the development time of small satellites is decreased through the use of existing technologies and software reuse, small satellites are able to easily adhere to a launch schedule. During operations, small satellites can rely more on simplified or autonomous system which require fewer personnel to operate. Since small satellites are produced and sometimes deployed differently than traditional satellites, The Aerospace Corporation has released a Small Satellite Cost Model to help people better understand the true costs of small satellites. The model “estimates development and production cost of a spacecraft bus for small (<1000 kg total wet mass) Earth-orbiting or near-Earth planetary missions by using subsystem-level Cost Estimating Relationships (CERs) derived from technical and cost database of historical small spacecraft.”

The model is updated every 52

---

2017 Capstone Course: Masters Program in International Science and Technology Policy
couple years with new data from the industry. The most recent release in 2014 and the next
release is expected in 2017. The images below are examples of cost distributions produced
by the model.

Figure 7: Cost Distribution for a 300 kg small satellite (SSCM 2014)
Figure 8: Cost Distribution for a 150 kg small satellite (SSCM 2014)

Traditional satellites can cost millions of dollars. Small satellites are only a fraction of the cost. The small satellite cost model estimates that a 300 kilogram satellite would cost
2017 Capstone Course: Masters Program in International Science and Technology Policy

approximately $65,236 and a 150 kilogram small satellite would cost $41,505. The low cost of small satellites makes the development of large constellations more economically feasible. For national security purposes, a large constellation is more ideal because it reduces the revisit time and increases redundancy in the event of a failure or an attack.

Key Players in National Security Space

Congressman Mike Rogers, in a speech at the 33rd Space Symposium on April 4, 2017, noted that the DoD provided him with a list of 60 organizations involved in national security space as a response to a request for an organization chart of “who was involved with making decisions in the national security space enterprise”. While this report will not detail all 60 organizations cited by Representative Rogers, several key players are described below.

Within the Department of Defense, two major organizations are involved in developing space policy, and managing the construction, launch, and operation of the Department’s satellite fleet: the Deputy Assistant Secretary of Defense for Space Policy (DASD-Space) and the United States Air Force (Air Force), respectively. Within the Air Force, Air Force Space Command serves as the primary space force for the United States military. Air Force Space Command manages the launch and operation of the military’s satellites, conducts space situational awareness, and command and control operations for Defense Department. The Deputy Assistant Secretary of Defense for Space Policy is tasked with developing policy and strategy for the Defense Department, implementing those policies and strategies across the Defense Department, and coordinating with other sectors

of the U.S. government, industry, and allies to establish norms.

The other key component of the national security space community is the United States Intelligence Community, with four key space-focused agencies. The National Reconnaissance Office (NRO) is tasked with designing, building, launching, and operating the nation’s classified satellite programs. The Defense Intelligence Agency (DIA), the National Geospatial-Intelligence Agency (NGA), and the National Security Agency (NSA) are the primary recipients of the data provided by NRO satellites. DIA, NGA, and NSA receive, process, and analyse measurement and signature intelligence, geospatial (or imagery) intelligence, and signals intelligence, respectively.

**Existing Small Satellite Registration and Legal Frameworks**

Existing small satellite registration mechanisms and regulatory frameworks coexist on both the international and the national scales. Internationally, the United Nations (UN) has several legal instruments which apply to small satellites. Generally, UN regulations do not differ based on the size or mass of a satellite; they simply refer to “space objects,” and therefore, small satellites are subject to the same regulations as regular satellites. Secondly, states have the responsibility to register small satellites with the UN, and many states have regulatory frameworks of their own to follow. Following an overview of existing UN legal instruments which are relevant to small satellites, the regulatory framework for small satellites in the United States will be introduced.

**United Nations**

As previously mentioned, there are no separate legal frameworks set by the UN for
small satellites; rather, small satellites are subject to the same legal framework as regular satellites. The legal framework for small satellites therefore consists of UN resolutions, UN space treaties, and a few additional UN instruments, such as those provided by the UN Office for Outer Space Affairs. The relevant UN resolutions and treaties are summarized below.

- **UN Resolution 1721B (XVI) on International Co-operation in the Peaceful Uses of Outer Space**, adopted on December 21, 1961, is the first international requirement for registering objects launched into outer space. The resolution “calls upon States launching objects into orbit or beyond to furnish information promptly to the Committee on the Peaceful Uses of Outer Space, through the Secretary-General, for the registration of launchings,” and also “requests the Secretary-General to maintain a public registry of the information furnished [...].”\(^5^4\)

- **UN Resolution 1962 (XVIII) Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space**, adopted on December 13, 1963, formed the basis for the Outer Space Treaty. Specifically, Principle 7 states that, “The State on whose registry launched into outer space is carried shall retain jurisdiction and control over such object, and any personnel thereon, while in outer space.” Principle 8 addresses liability, stating that, “Each State which launches or procures the launching of an object into outer space, and each State from whose territory or facility an object is launched, is internationally liable for damage to a foreign State or to its natural or juridical persons by such object or its component parts on the earth, in air space, or in outer space.”\(^5^5\)


\(^5^5\) UN General Assembly. 1963. Declaration of Legal Principles Governing the Activities of States in the Exploration and use of Outer
• UN Resolution 2222 (XXI) Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, entered into force on October 10, 1967, and is frequently referred to as the “Outer Space Treaty.” It is important because, unlike UN Resolution 1962, it is essentially legally binding to all states, even those that have not ratified it. The Outer Space Treaty includes slightly modified versions of Principle 7 and Principle 8 from UN Resolution 1962 (as Articles VI and VII, respectively). Article XI states that, “States Parties to the Treaty conducting activities in outer space, including the moon and other celestial bodies, agree to inform the Secretary-General of the United Nations as well as the public and the international scientific community, to the greatest extent feasible and practicable, of the nature, conduct, locations and results of such activities. On receiving the said information, the Secretary-General of the United Nations should be prepared to disseminate it immediately and effectively.”

• UN Resolution 3235 (XXIX) Convention on Registration of Objects Launched into Outer Space, frequently called the Registration Convention, was adopted in 1975 and entered into force on September 15, 1976. Article II states that nations are obligated to register objects launched into outer space and inform the Secretary-General of the UN. Article III states that the “Secretary-General of the United Nations shall maintain a Register” that includes the information below, which is given in Article IV.

---

58 Ibid.
(a) name of launching State or States;
(b) an appropriate designator of the space object or its registration number;
(c) date and territory or location of launch;
(d) basic orbital parameters, including:
   (i) nodal period;
   (ii) inclination;
   (iii) apogee;
   (iv) perigee;
(e) general function of the space object.

- **UN Resolution 62/101 Recommendations on enhancing the practice of States and international intergovernmental organizations in registering space objects**, of December 17, 2007, provides registration recommendations to states, as well as requests to the UN Office of Outer Space Affairs (UNOOSA). Specifically, it requests that UNOOSA provide a model registration form, publish contact details of focal points on its website, and publish links on the website to available registries. These resources, as of April 2017, can be found on UNOOSA’s website.

- **UN Resolution 68/74 Recommendations on national legislation relevant to the peaceful exploration and use of outer space**, adopted on December 11, 2013, provides eight recommendations regarding the creation of national space legislation. The sixth recommendation is the most relevant to registration and the creation of a national registry of objects.

**United States**

- **Department of State**: As the lead U.S. foreign affairs agency, the overarching purpose of the U.S. Department of State is to represent the United States at more than 270 diplomatic locations around the world, including embassies, consulates, and missions to international organizations. This representation is meant to shape a
free and secure world through formulating and implementing the President’s foreign policy, while supporting and protecting American interests and citizens abroad. Within the Department of State is The Office of Space and Advanced Technology (OES/SAT). OES/SAT ensures that U.S. space policies and multilateral science activities support U.S. foreign policy objectives, space, and technological competitiveness. Established in 1959, OES/SAT has primary responsibility for U.S. representation to UNCOPUOS. More recently UNCOPUOS “has been a vital forum for U.S. efforts to develop new international guidelines on emerging issues such as minimizing the generation of orbital debris and ensuring safe space operations and sustainable access to space.”

It is important to note that OES/SAT maintains the official U.S. registry of objects launched into outer space, oversees implementation of the 1998 Intergovernmental Agreement on the International Space Station, and leads U.S Government consultations with other countries and international organizations on space policy and law. The stated missions of the Department of State and its Office of Space and Advanced Technology cover a wide range of international activities.

- **Department of Commerce**: The mission of the Department of Commerce is to create the conditions for economic growth and opportunity. By working with businesses, academic institutions, and other communities, the twelve bureaus within the Department cover five goal areas: operational excellence, data, environment, innovation, and trade and investment. The Department of Commerce is the data agency of the United States, managing data that is “comprehensive, consistent, confidential, credible, and accessible.”

---

• **Domestic Registration Consideration**: The two descriptions above provide a window of analysis for whether the Department of State is the best place to maintain the domestic registry of objects launched into outer space. The mission of State has a focus on diplomacy, and many bureaus within State do not have the manpower to process and monitor additional data should the amount of registration information increase, as recommended by this report. One interviewee questioned how, with a proliferation of small satellites and their information, the current structure of State can effectively utilize this registration information for SSA purposes.\(^{63}\) Furthermore, an analyst at Rand underscored that “State focuses on diplomacy. The only reason they’re involved in space is that [satellites] fly over other countries. If more information means the same group of people doubling their time, that isn’t good.”\(^{64}\) If licensing is already done through Commerce, and it has a goal of a data-driven government, Commerce might be a viable option for registration. The role of Commerce and CSF members as registering and monitoring entities will be addressed in greater detail in the first policy recommendation.

**Policy Analysis**

In order to examine policy opportunities for the next four years, it is important to take a brief look at the space policy climate in the early stages of the Trump administration, as well as recent space policies that address the role of satellites in national security interests. The Harnessing of Small Satellite Revolution initiative, the 2010 Space Policy directive, and the American Space Renaissance Act provide a context for current initiatives in commercial space and small satellites.

---

\(^{63}\) Interviewee 1. “Interview on Domestic Registration Considerations.” April 21, 2017.

The Space Policy Climate in the Early Stages of the Trump Administration

The focus of the Trump Administration at this time is on re-establishing a National Space Council and leveraging commercial space capabilities for military purposes and missions beyond LEO. With a paradigm shift in the White House, the new leadership has made the point that government should facilitate private companies to lead the way in space exploration.

The Commercial Sector

The current focus of the Administration is to use the commercial sector for military defense and missions beyond LEO. Working hand in hand with industry has been acknowledged as a way to gain advantage over adversaries in the military context of space infrastructure. According to Major General Roger Teague, Director of USAF Space Programs: “America's adversaries are perfectly aware of the potential military advantages of space infrastructure: including secure and ubiquitous communications networks; sophisticated intelligence, surveillance and reconnaissance (ISR) capabilities.” As for opportunities beyond LEO, a Congressional staffer states: “I’m curious about the next four years. Prior to Trump, any commercial moon effort was silly, but with Blue Origin and SpaceX making noises in this direction, I believe it has really opened up the aperture in a new way on the proper domain of commercial stuff: . . [it] could be flash powerpoint, but to the extent that anything materializes, this could be interesting to see if [this] changes conversation at all. The way private industry is doing things that used to be just government-only, such as SIGINT and monitoring, is exciting.”

Re-establishment of the National Space Council

A National Space Council (NSpC), chaired this time by Vice President Mike Pence, will likely be established by executive order for the first time since 1993. This “[imminent] executive order has been written. It's all set to go. . . I can tell you firsthand that Vice President Pence is extremely excited about his ability to be the chair of that council, and I expect it to be a very active part of this administration.” said former congressman Robert Walker, who served as an advisor on space policy to the Trump presidential campaign. According to Jeff Foust, the NSpC is a narrow window of opportunity to push forward changes in a comprehensive way: “That would be interesting. Otherwise, it will be piecemeal here and there.” It would depend on how the formation of NSpC is, but to bring together various players, DoD, NOAA, and commercial sector and this would be to include more players under the tent who provide advice at the executive level.

**Recent policies**

The Harnessing the Small Satellite Revolution initiative, announced October 21, 2016, requires the Office of Science and Technology Policy (OSTP), NASA, DoD, the Department of Commerce (DoC), and others to work on the use of small satellites for remote sensing, communications, and exploration of space. Highlights include the establishment of a Small Spacecraft Virtual Institute to “provide a ‘one-stop shop’ for technical knowledge in the rapidly burgeoning small spacecraft technology fields” and the Commercial Initiative to Buy Operationally Responsive GEOINT (CIBORG), which, as noted earlier, will match capabilities and intelligence problems. This underscores an

---


initiative to establish a framework for small spacecraft operations in USG agency procurement operations and the desire to acquire new products on an as-needed basis.

A second policy is the 2010 Space Policy directive, which takes the position that: “The United States is committed to encouraging and facilitating the growth of a U.S. commercial space sector that supports U.S. needs, is globally competitive, and advances U.S. leadership in the generation of new markets and innovation-driven entrepreneurship.”\(^{69}\) This includes encouraging commercial sources in addressing SSA and object detection, modifying existing commercial capabilities to meet government requirements, and actively promoting the export of space goods and services from small and medium U.S. enterprises (as long as it is consistent with U.S. technology transfer guidelines). This directive is important because it emphasizes the role of non-governmental bodies in the economic development.

A third piece of policy, introduced in April 2016, is H.R.4945: American Space Renaissance Act, which has the key objectives of: projecting military strength and protecting space based capabilities, providing certainty to encourage commercial space innovation, and promoting stability, accountability, and mission clarity at NASA. According to Dr. Jeff Foust, Representative Bridenstine (the sponsor of the bill) is not missing an opportunity to talk about these issues that he wants to hear about, even if these issues do not affect his constituents.\(^{70}\) The Space Renaissance Act was referred to the applicable House Committees, but was not voted on during the 114th congressional session (2015-2016). In March 2017, Dr. Foust wrote in Space News that, “[w]hile the bill did not pass, some of its provisions were incorporated into other legislation.”\(^{71}\) These recent


\(^{71}\) Foust, Jeff. "Pence Confirms Plans to Reestablish the National Space Council." SpaceNews., last modified March 21, accessed May,
policies underscore the fact that there is interest and initiative to procure and incorporate small satellites into governmental and non-governmental activities.

National Security Implications

The continued proliferation of small satellites will affect national security in both positive and negative ways. The decreased cost to field a constellation with a large number of satellites will improve access to new sources of data that improve upon persistence-related issues, such as imagery revisit time and communications gaps. The proliferation of commercially owned and operated constellations allows for public access to the collected data, enabling a wider range of users to benefit.

That said, increasing numbers of commercial satellites also provide certain threats to U.S. national security. For example, the data commercial satellite providers can provision to the U.S. government can also be used by its adversaries. Restrictions currently placed on U.S. satellite operators in the name of national security are rarely sophisticated and often entail the prohibition of certain capabilities being sold to the general public or even included on a satellite at all. Additionally, constellations with increasingly larger numbers of satellites pose threats to satellites already in orbit, especially since most small satellites lack maneuvering capabilities.

These threats have not stopped the U.S. government from looking for ways to take advantage of small satellites. The National Reconnaissance Office has launched more than 15 cubesats as of 2016, and anticipates smaller satellites becoming an increasingly important component of its satellite fleet.72 Additionally, the U.S. military believes that

---

2017 Capstone Course: Masters Program in International Science and Technology Policy

small satellites will increase the resiliency of the U.S. constellation in a wartime scenario.\textsuperscript{73}

This section will discuss overall threats and vulnerabilities posed by small satellites, as well as provide more detailed information on three specific areas in which small satellites will affect national security.

\textbf{Vulnerabilities and Threats of Small Satellites}

Although small satellites bring numerous advantages to the national security community, they also present national security concerns. The vulnerabilities and threats posed by small satellites should therefore be examined and considered in light of existing policies to understand how small satellites may be used to undermine U.S. national security. The low cost and ease of launch of small satellites means that small satellites can and will be used by a larger number of countries. Developing countries, and potentially eventually non-state actors, will soon be able to possess similar satellite capabilities to what the U.S. currently possesses. This section addresses key vulnerabilities and threats, and other sections address how these threats and vulnerabilities are addressed in existing policies.

Vulnerabilities of small satellites are generally of a technical nature and include concerns such as cybersecurity and physical security. Cybersecurity threats to small satellites exist in two main categories: 1) that an adversary could disable, destroy, or modify a U.S. national security small satellite by cyber means; or 2) that an adversary could gain control of a small satellite currently in orbit by cyber means to access, steal, and/or modify the data being collected and transmitted without the owner’s knowledge or consent.

Cybersecurity concerns are amplified for small satellites for two primary reasons: 1) small satellites designers generally prioritize decreasing cost and time to launch over security; and 2) small satellites are increasingly being used in constellations, and

constellations provide increased cyberattack surfaces. Prioritizing cost often means that
designers choose cheap and readily available off-the-shelf hardware and software
components. These components often have extraneous features and known and unknown
security vulnerabilities, which, due to the pressure to launch as quickly as possible, are
often not adequately tested to determine exactly how they interact with and threaten the
integrity of the satellite. Furthermore, once the satellites are in orbit, it is often difficult to
install security patches and software updates even when vulnerabilities are identified.

Physical threats exist in two categories: 1) threats to small satellites; and 2) threats
posed by small satellites. The first category includes an increased risk of collision (due
primarily to the increasing number of objects in orbit and, generally speaking, the inability
of small satellites to maneuver) and also vulnerabilities due to developments in anti-satellite
(ASAT) weapons. For instance, small satellites are vulnerable to laser weapons, which can
target objects in LEO. The second category includes the weaponization of small satellites;
weaponized small satellites could cause damage to other small satellites or regular satellites
through physical or cyber means. As early as 2001, it was reported that China was
developing a “parasitic satellite,” which is a nanosatellite ASAT weapon. Physical
vulnerabilities of small satellites exist due to their small size and, generally speaking, their
lack of defensive systems.

Satellite Imagery

While small satellites are making their mark in all areas of satellite capability, no
capability has been more affected than satellite imagery technology. The U.S. national
security community is a primary consumer of commercial satellite imagery, with the
National Geospatial-Intelligence Agency (NGA) alone spending over $350 million in FY18

---

on commercial satellite imagery, with $335 million paid to DigitalGlobe, Inc., and $20 million to Planet Labs, Inc.\(^{76,77}\) While NGA has contracted with DigitalGlobe since 2003, 2016 was the first time that Planet received funds from the spy agency. This marks a shift in NGA’s collection strategy away from utilizing a small number of very high-resolution satellites provided by the National Reconnaissance Office and DigitalGlobe, towards integrating medium-resolution imagery from a large number of small satellites provided by multiple vendors.

The National Geospatial-Intelligence Agency, as the executive agent for geospatial intelligence, has attempted to tackle this shift, and released its *Commercial GEOINT Strategy* in November 2015 to describe how it intends to work with commercial providers of both types of systems. The strategy noted that the Agency “does not envision a one-size-fits all contract with small-satellite companies, but instead individualized contracts with differing price tags, lengths and requirements.”\(^{78}\) Then, in May 2016, NGA announced plans to work with the General Services Administration on a new contracting effort known as the Commercial Initiative to Buy Operationally Responsive GEOINT, or CIBORG. CIBORG aims to provide NGA with the ability to accept funds from other interested government agencies and procure imagery from multiple vendors in a rapid, flexible contracting mechanism.\(^{79}\)
Communications

Developments in small satellite technology have reduced the payload sizes for communications satellites to where powerful high-speed data transfer can be offered via a satellite weighing less than 500kg. While larger than the previously discussed “small satellites”, which are defined as less than 180kg, these sub-500kg platforms are a substantial decrease in mass from traditional communications satellites, which typically weigh in excess of 1,000kg. For example, the Space Exploration Technologies Corporation (SpaceX) has filed plans with the Federal Communications Commission for a fleet of 4,425 small communications satellites (weighing 380kg) aimed at providing broadband internet coverage worldwide beginning in 2019.\textsuperscript{80,81} This type of large-scale satellite constellation (approximately quadruple in number of the total amount of currently operational satellites in orbit) would provide benefit to the market though reduced latency due to its lower orbit as well as lower access prices due to lower upfront costs associated with developing and deploying a satellite constellation. While not explicitly intended for the national security community, a world-wide, high-speed internet connection would likely be of use to the military and intelligence communities in support of operations in remote areas.

As shown previously in Figure 2 on page 5, the large majority of small satellites in orbit today are communications satellites. According to the 2016 UCS database, of the 41 small satellites with a communications function (expanded more broadly to include communications, communications / technology development, and communications / maritime tracking), all are in LEO.

Space Situational Awareness

The term Space Situational Awareness (SSA) refers to the ability to view, understand, and predict the physical location of natural and manmade objects in orbit around the Earth, with the objective of avoiding collisions. Information on small satellites will continue to be important to national security as the number of small satellites launched increases. Indeed, “an estimated 3,800 new satellites are projected to be launched between 2016 and 2020, which, if realized, would almost quadruple the population of active satellites from the 1,400 currently in orbit.”

Interest and Uncertainty: The Current State of SSA

Numerous people who were interviewed for this report stated that near-term policy regarding SSA is unclear, but that interest is picking up.

“How current treaties on collisions, in general, are enforced, and do they have a role in the future of small sats? That’s mildly unresolved right now. My suspicion is that, in the next two to three years, there will be a fair amount of movement on that. I see the current frameworks as being a placeholder. Sort of consensus in community that it’s temporary and something will have to emerge on that. Right now, it’s essential unanswered.”

“Various companies aren’t assembling the same information. When you think about the broader context [of SSA], it is very much a moving target.”

“Essentially, it is a matter of a group of actors establishing a civil society and norms, which sometimes ad hoc grows into long terms. There is nothing wrong with letting things emerge and evolve on their own.”

83 Interviewee 1. "Interview: Opinion on Small Satellites and National Security." April 21, 2017. under condition of anonymity
These opinions beg the question: With this level of uncertainty, how can CSF and its members influence the dialogue around SSA security issues? There are two security areas associated with SSA that will need to be addressed.

First, as the number of small satellites in low earth orbit increases, the security architecture that monitors those satellites must handle more data and identify satellites at high risk for collision. It is important to process the information and provide conjunction notices that are as accurate as possible. One example of a conjunction notice failure was the collision of an active Iridium satellite with a deactivated Russian Kosmos satellite in 2009. It was the first accidental collision between two intact satellites in low earth orbit, and the fourth biggest fragmentation event in history, with Irium producing 628 pieces of catalogued debris, of which 364 pieces of tracked debris remain in orbit as of January 2016. What does this collision say about conjunction notices? As noted by one reporter:

“Events where two satellites approach within several kilometers of each other occur numerous times each day. . . Iridium-Kosmos was a big sky theory: ‘Space is so big, we will not really have a problem running into something’. . . maneuver and you use fuel, so you have to take these warnings with a grain of salt. . . Iridium didn’t act on time. Since then, satellite companies take these conjunction notices more seriously, but they also want greater accuracy in the notices that they get so they don’t have to use fuel for too many false alarms. You have to separate the sound from the noise”

This means there is a burden on monitoring authorities, such as the DoD and the Joint Interagency Coalition Space Operations Center (JICSpOC) in the United States and European Space Agency in Europe, to observe and accurately track a growing number of objects.

---

1 Interviewee 1. "Interview: Opinion on Small Satellites and National Security." April 21, 2017. under condition of anonymity
This is connected to the second security implication: the lack of maneuvering capability seen in most small satellites today. What happens if it is determined that maneuvering capabilities must be implemented? Already, small satellites and small satellite constellations have necessitated collision avoidance from other satellites. According to the United States Air Force, “cubesats have forced other satellites to maneuver and avoid a collision three times [in 2016], twice in 2015 and three times in 2014.” As noted earlier, small satellite constellations are important because they increase coverage, time resolution, and processing power over one small satellite and enhance capabilities of larger satellites. However, constellations can mean more warnings. If there is a warning, the onus is often on the larger satellite with maneuvering capabilities to make the adjustment, thereby using fuel and cutting down life performance. This can lead to a tension between the cost and capability of small and large satellites when a potential collision is detected. According to Jeff Foust, the cost to develop and launch small satellites that have maneuvering capabilities within the next four or five years is likely to be too fast of a timeline.

In conclusion, what do these two points on SSA mean for small satellite policy recommendations over the next few years? These two points underscore the importance of providing information. In terms of tracking more objects, small satellite operators have an opportunity to provide as much information as possible. A staff member at Congress argues that small satellite operators best know where their assets are, which can provide greater accuracy if they choose to share more information. Better accuracy in warnings will mean a greater chance to take action. A reasonable chance to take action means a reduction in false alarms, which could help avoid another Iridium-Kosmos. In terms of maneuvering capabilities, if it is not an actionable request to have all small satellites equipped with

---

maneuvering capabilities within the next four to five years,\textsuperscript{90} and if most of the large satellite constellation members aren’t members of CSF, there should be outreach from CSF to the rest of the satellite community to encourage as much information sharing as possible about small satellites in order to reduce the number of unneeded maneuvering operations. The importance of sharing information about small satellites will be addressed in more detail in the policy recommendations.

\textsuperscript{90} Congressional Staffer. “Interview: Opinion on SSA.” April 24, 2017.
Policy Statement

This report gives two recommendations for the Commercial Spaceflight Federation and its members to suggest to the United States federal government to implement in order to better address the proliferation of small satellites: improving registration standards to enhance space situational awareness, and improving contracts for procurement of small satellite-produced data. Each of these proposals is explained in detail below and is followed by an analysis of the strengths, weaknesses, opportunities and threats posed by each recommendation.

1. Better Registration Standards to Enhance Space Situational Awareness:

The first policy goal is to improve registration standards in the area of space situational awareness, thereby allowing launched commercial and civil satellites to be easily identified and located. This is increasingly important as the number and frequency of small satellites launched into orbit continues to grow and the risk of collision increases.

Specifically, it is recommended that the Commercial Spaceflight Federation encourage its members and other satellite operators to both voluntarily adopt enhanced registration standards and conduct outreach to the rest of the small satellite community to do the same. For this recommendation to be truly successful there needs to be two entities involved; a registration entity and a monitoring entity. The registration entity will be in charge of maintaining registration information. The second entity will be in charge of monitoring SSA data and notifying operators when there is a potential for a conclusion. Internationally, the registration entity should continue to be the United Nations. The United Nations’ *Outer Space Objects Index* contains information on satellites launched
from 1957 to present but does not include information on debris or non-functioning objects. This information should be shared in real-time with Joint Interagency Coalition Space Operations Center (JSPOC) in the United States, and other relevant bodies. Domestically, the Department of Commerce could collect more detailed registration information when operators submit an application. The registration information, both domestically and internationally, should include - at a minimum - the satellite’s identity, dry mass, position, velocity, acceleration, and health status.

The monitoring entity could either be a civil agency or a commercial company. Analytical Graphics, Inc. (AGI) is a CSF member company and has been working for years to improve how SSA data is collected and used. In 2014, it opened the Commercial Space Operations Center (ComSpOC), which is the first and only operational commercial SSA center of its kind in the world. AGI has stated that its data is more accurate and is on par with the data collected by the U.S. Air Force. In 2014, the U.S. Air Force awarded AGI an $8.4 million contract for a subscription service for its ComSpoc data. In the satellite community, many people have recognized the need for more advanced SSA data as more satellites are launched into LEO and GEO. Satellite operators may be uncomfortable with a solely commercial venture for SSA data. The ideal scenario would be a monitoring entity that is a blend of civil and commercial operations. Our recommendation is that the FAA Office of Commercial Space Transportation take over SSA operations from the U.S. Air Force and become the government face of SSA data.

---

91 The use of a form is important because it standardizes information: “Do you want standardized information, or different ten page reports that have to be interpreted by humans? You want a web form that only accepts information in certain metrics and formats. You want the administrative burden to be on the people applying. Make the information specified in a way that doesn’t involve humans.” Ohlandt, Chad. “Interview on Small Satellites.” May 3, 2017.
with large amounts of the data coming from experienced companies like AGI.94

Satellites operators are the experts when it comes to satellite operations and should know what data could help prevent future collisions. The registration and monitoring entities will never be successful if companies are not willing to give all the required information. If companies do not create their own standards, then overly eager government agencies may deem it necessary to overburden companies with regulations.

Satellite operators should adopt several best practices or standards to ensure that the registration process and SSA operations are efficient and effective. Firstly, satellite operators should install a radio broadcaster that repeatedly (over a short mandated time interval) broadcasts via an unencrypted message the required status information while in orbit. Secondly, satellite operators should follow the U.S. Government Orbital Debris Mitigation Standard Practices and when possible equip their satellites with deorbiting capabilities. Ideally, these best practices for satellite operators would become regulations that have consequences for operators not in compliance.

Improved registration standards and SSA data will have benefits for all satellite operators. Long term success will be difficult to measure but will be evident through increased space situational awareness and decreased collisions.

2. Improved Contracts for Procurement of Small Satellite-Produced Data:

As more and more organizations announce plans for small satellite constellations, the U.S. Government will need to develop new procurement mechanisms to leverage these new datasets. Historically, the U.S. Government would purchase a pre-set capability from a satellite, such as the total collection from DigitalGlobe’s imagery satellites, regardless of

---

94 This point was echoed during the interview with Chad Ohlandt. A note was made that, “for years, the Air Force guarded this authority, so now they might be more amenable to not being the regulators of space. The FAA might be a good choice, as they have more control over space launch these days.” (May 3, 2017).
future capabilities or evolving needs. With the growth of operators and the continued
decline in budget appropriations, government agencies will need to become more flexible
in their procurement operations.

A 2013 GAO report advocated for the use of hosted payloads and shared launch
vehicles for government-funded missions in order to cut “hundreds of millions of dollars
over the life of the projects”. This paper recommends agencies further reduce data
acquisition costs by encouraging the use of flexible contracts that allow government
agencies to procure satellite-produced data on an as-needed basis. As discussed previously,
the National Geospatial-Intelligence Agency has already begun this process through the
creation of the CIBORG program with the General Services Administration (GSA).
Additionally, GSA added satellite services to its IT Schedule 70 contract vehicle in 2010,
providing government customers a flexible contracting mechanism for procurement of
data.

It is recommended that CSF and its member organizations advocate for the
government, specifically GSA, work to develop additional contracting mechanisms similar
to the CIBORG program. In particular, flexible mechanisms for obtaining non-GEOINT
data provided by small satellites are needed. For example, the development of global
broadband internet access via small satellite constellation could see situations where the
U.S. military could benefit from a global high-speed internet connection, and would require
the ability to spin-up and spin-down access as operational requirements dictate. Increased
contracting flexibility will allow for the government to more-effectively utilize the
capabilities of and data from small satellite constellations, improving national security.

95 US GAO. 2013. 2013 Annual Report: Actions Needed to Reduce Fragmentation, Overlap, and Duplication and Achieve Other
Strengths, Weaknesses, Opportunities, and Threats (SWOT) of Recommendations

Recommendation 1 SWOT

**Strengths:** Having all of the information in one place and owned by an international organization will benefit all member states. As the number of small satellites continues to increase, this will particularly be beneficial for national security applications as space situational awareness becomes more important. As the United States currently has a large percentage of the small satellites currently in orbit and planned for launch, merely having the information from the U.S. will greatly benefit space situational awareness.

**Weaknesses:** It is unclear whether other nations will have the ability, desire, and resources necessary to implement and enforce these regulations to the extent that the U.S. Department of Commerce does.

**Opportunities:** This is an opportunity for the United States Department of Commerce to lead the way in this endeavor by example and by offering technical assistance to its international counterparts in creating and maintaining the database. Furthermore, if this model is successful, it can be extended to include all types of satellites. While there are only a few of episodes of collision avoidance per year, the increasing number of actors operating small satellites in LEO over the next few years means that national security interests must include supporting the physical safety of U.S. satellites and legal protection in the event of a collision. According to one congressional staffer, SSA is one of the biggest threats to space security, and therefore, to national security.  

With so little legal precedent, the idea of following Outer Space Treaty (OST) protocol is mildly unresolved. Each collision or potential collision could have parties with different

---

agreements, and, according to another congressional staffer, the next two to three years will see a fair amount of movement on this front. The bottom line is that collision between objects in Earth orbit remain relatively rare, but such collisions can have major consequences. “Therefore, it is in the U.S. national strategic and economic interests to have an improved domestic space traffic safety governance framework… that specifically aims to mitigate and reduce the risk of possible space traffic safety incidents, while at the same protect the economic vitality of the space industry.”

**Threats:** Companies and governments may not wish to share the requested information with the United Nations. They may oppose the three proposed regulations and/or refuse to comply with the regulations if they are unable to be enforced. International equivalents of the U.S. Department of Commerce may not take an active role in requiring its licensees to submit the requested information. Furthermore, the United Nations may not have the technical ability or resources necessary to manage such a database.

**Recommendation 2 SWOT**

**Strengths:** Improving contracts for procurement of data from small satellites ensures that government entities maintain access to continuously developing commercial satellite data offerings. This also provides government agencies the flexibility to “spin-up” or “spin-down” contracts as needed, allowing for more efficient use of funding streams. Furthermore, this encourages commercial providers to become more cost-efficient, as government customers cannot be relied upon for continuous funding.

**Weaknesses:** On the other hand, improving contracts for procurement of data from small satellites increases uncertainty for commercial providers, who cannot rely on continuous streams of government funds to subsidize operational costs. The small satellite market will likely see consolidation, as less cost-efficient corporations are unable to turn profits without government

---

lagesse.

**Opportunities:** A more-efficient marketplace for satellite data will encourage commercial providers to streamline operations and seek additional customers outside the government sphere. This will likely produce a more stable marketplace, which will enable further innovation by corporations, and result in the development of new technologies which the federal government can leverage.

**Threats:** Too much uncertainty from the lack of consistent government acquisition of satellite data from commercial market could cause multiple satellite operators to close, limiting the government’s access to new satellite data sources.

**Summary and Assessment**

This report discussed the technical and cost aspects of small satellites. It is clear that small satellites have the potential to play a large role in the overall national security space architecture. Like any form of technology there are advantages and disadvantages to small satellites. For national security purposes, one of the most critical aspects is the resilience of small satellites when they operate in large constellations. The commercial industry is investing a significant amount of money in small satellite technology which is expected to lead to significant advancements in the near future. There are many policy challenges that arise from small satellites and this paper explored several options so that the full potential of small satellites can be achieved.

The increase of the number of small satellites in orbit increases the number of objects in orbit and therefore intensifies the existing challenge of space situational awareness. Companies often have the ability to track their own satellites but do not have much information about the location of other satellites. Collisions with other satellites or space debris would result in large amount of debris, furthering endangering other operational spacecraft. All relevant parties need to have detailed orbital information. While it is recognized that orbital information is sensitive for
national security satellites, the national security risks posed by the planned drastic increase in the number of commercial and civil satellites in orbit cannot be ignored.

The U.S. government needs to reevaluate its procurement mechanisms so that it does not miss out on new advancements in the commercial sector. It is recommended that CSF and its member organizations advocate for the government, specifically the General Services Administration (GSA) to develop additional contracting mechanisms. The National Geospatial-Intelligence Agency has already begun this process through the creation of the Commercial Initiative to Buy Operationally Responsive GEOINT (CIBORG) program with the General Services Administration (GSA), and this program should be used as a model. It is imperative these actions are taken preemptively rather than reactively to prevent a disaster in space. If enacted, these recommendations would benefit both the commercial sector and the national security sector.

Bibliography

"IT Schedule 70." GSA.gov., https://www.gsa.gov/portal/content/104506.


UN General Assembly. 1963. Declaration of Legal Principles Governing the Activities of States in the Exploration and use of Outer Space . 18 sess. (December 13,).


Interview on Domestic Registration Considerations 2017c., edited by Employee at State Department.
Interview on Launch Costs 2017d., edited by Rand Researcher.

Interview on Registration and Security of Small Satellites 2017e., edited by Jeff Foust.

Interview on Small Satellites 2017f., edited by Chad Ohlandt.

"Investing Big in Small Satellites." National Archives and Records Administration.,
https://obamawhitehouse.archives.gov/blog/2016/12/22/investing-big-small-satellites.

"Next Generation Batteries could Provide Power to Microsatellites, CubeSats " NASA., last modified Feb 10, accessed Feb 28, 2017,
https://www.nasa.gov/feature/next-generation-batteries-could-provide-power-to-microsatellites-cubesats.

"NGA Contracts with Planet for Small Satellite Imagery." Geospatial Solutions., last modified Mar 27,

Opinion on SSA 2017i., edited by Congressional Staffer.

"Polar Orbiting Environmental Satellites (POES)." San Francisco State University., last modified Sept. 22, accessed April, 2017,
http://tornado.sfsu.edu/geosciences/classes/m415_715/Monteverdi/Satellite/PolarOrbiter/Polar_Orbits.html.

"UCS Satellite Database User’s Manual&nbs"," last modified Jan. 1,

"United Nations Register of Objects Launched into Outer Space: Resources and Reference Material for States & Organizations " United Nations Office for Outer Space Affairs., accessed December 19, 2017,

AGI COMSPOC. "COMSPOC Operational." Commercial Space Operations Center (ComSpOC),. accessed May, 2017,


Acknowledgment

The authors of this report would like to extend their sincere thanks to the Commercial Spaceflight Federation, George Washington University, and the many analysts and researchers who took the time to provide their insights on the role of small satellites in national security space architecture.
Author Biography

Elsie Bjarnason
Elsie is graduating with an MA in International Science and Technology Policy from the Elliott School of International Affairs at George Washington University in May 2017. She has a B.S. in Chemical Engineering from North Carolina State University.

Tara Halt
Tara is a second year graduate school at the Space Policy Institute at The Elliott School of International Affairs at George Washington University. She graduated in 2015 from Embry-Riddle Aeronautical University with a B.S. in Commercial Space Operations. She currently works at Bryce Space and Technology as an Aerospace Analyst.

Natalie Kauppi
Natalie is a second year graduate student at the Space Policy Institute at The Elliott School of International Affairs at George Washington University. She was General Course student at the London School of Economics and Political Science and has a B.A. in International Relations and Comparative Politics from Bryn Mawr College.

Chase Tralka
Chase is graduating with an M.A. in International Science and Technology Policy from the Elliott
School of International Affairs at George Washington University in May 2017. Chase has a B.S. in Information Sciences and Technology from Pennsylvania State University.