

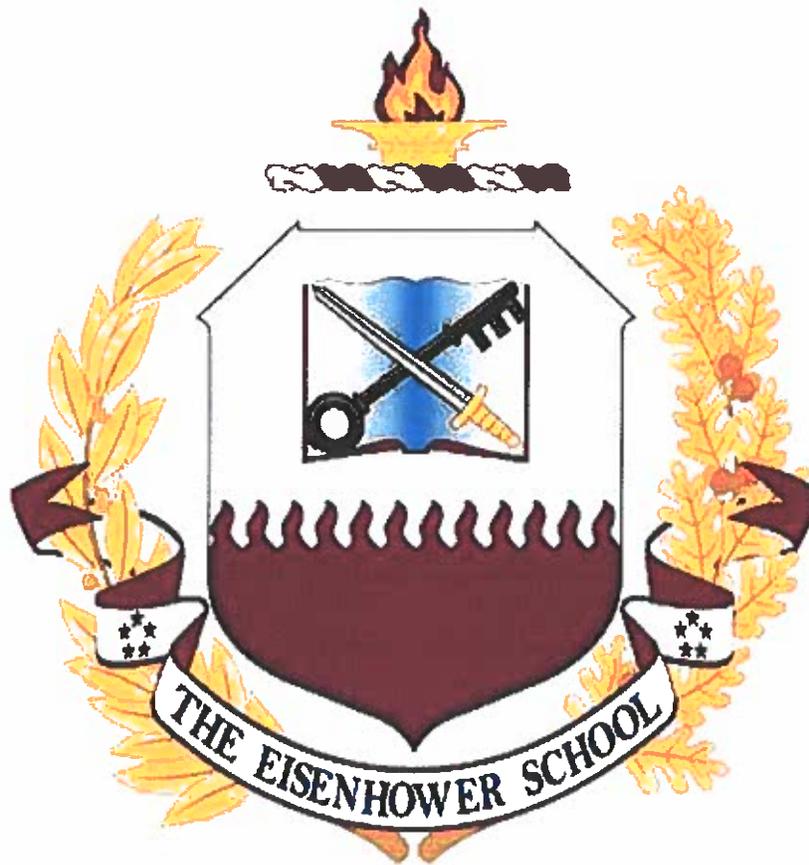
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Rallying Industry for Resilience

Abstract: The need for resilience in the competitive, congested, and contested space environment drives the need to develop surge capacity in the space industry. This paper provides focused analysis on ways to achieve resilience in the national security space (NSS) architecture, by capitalizing on emerging small satellite constellation markets, incentivizing and accelerating market maturity, communicating government priorities to industry, adopting select NSS structural changes, and increasing cooperation with allies and partners. Resilience must be planned as an enterprise solution over the long-term, while ensuring maximum innovative efforts in the short-term to provide security overlays for current systems and services. Existing commercial space-based markets provide opportunities to immediately access space services that augment current NSS means. In addition, emerging commercial markets provide models to develop long-term surge capacity, even in the specialized Defense Industrial Base space manufacturing market. This paper explores how the U.S. Government can “Rally Industry for Resilience” to ensure a robust, competitive commercial space sector able to support the space resilience critical to national security.

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Rallying Industry for Resilience

*“Our two greatest problems are gravity and paperwork.
We can lick gravity, but sometimes the paperwork is overwhelming.”*

– Wernher von Braun, Chicago Sun Times, July 10, 1958
commenting on the challenges of starting a space program

TODAY’S CONTEXT

The AY18 Space Industry Study approached industry analysis using the Harvard Business School framework of Structure, Conduct, and Performance. The framework was applied through academic analysis followed by gathering first-hand data in an extensive series of face-to-face interviews and on-site facility visits with leaders in the military, civil, and commercial space enterprise. This paper analyzes how to capitalize on the emerging small satellite constellation market based on its current and potential future capabilities to enhance resilience in the national security space (NSS) architecture.

Rise of Commercial Space

While the origins of military and civil space are well understood and can be traced to early ballistic missile development, expanding surveillance technologies, and Sputnik, the evolution of the United States’ commercial space policy demands closer examination to set the background for this industry study. The U.S. military and Intelligence Community (IC) have long relied on unique and exquisite satellites for services such as precision timing, navigation and weapons guidance, imagery collection, missile warning, and weather forecasting. In a growing number of areas, notably communications and imagery, commercial capabilities have become a vital adjunct to the military’s own assets for national security ends.¹ The importance of this role has been elevated given the increasing U.S. military dependence on space capabilities and emerging threats to U.S. Government-owned space assets. Commercial systems capable of supporting national security requirements, either in concert with or in place of, government assets augment and therefore enhance the resilience and robustness of U.S. space capabilities making the malign tasks of potential adversaries far more difficult.²

The roots of commercial involvement in space date back to the Cold War competition between the Soviet Union and the United States. American interest in the commercial use of outer space can be traced to the National Aeronautics and Space Act of 1958.³ In it, Congress declared that it was to the benefit of the United States for the concurrently established National Aeronautics and Space Administration (NASA) to “seek and encourage, to the maximum extent possible, the fullest *commercial* use of space.”⁴

The concern that the geopolitical rivalry and nuclear arms race between the two superpowers would extend into outer space culminated in the 1967 Outer Space Treaty.⁵ The treaty addressed concerns between the U.S. and the Soviet Union regarding placing nuclear weapons in space. The signatories agreed to respect spacecraft and astronauts, and to accept accountability for the actions of their private entities. Furthermore, neither would claim sovereignty over celestial bodies nor would they place weapons of mass destruction in space.⁶

President Carter, in his National Space Policy (NSP) of 1978, reasserted that the U.S. would encourage domestic (commercial) use of space both for “economic benefit” and the “technological position of the United States.”⁷ By 1988, President Reagan’s NSP elevated commercial space to the same level as civil and NSS. The policy directed the government to purchase commercial capabilities, avoid crowding out private companies where possible, and take as light an approach to commercial space regulation as possible.¹³ The Clinton Administration expanded space policy further, advocating for government use of commercial space products and services “to the fullest extent possible.” Additionally, the Clinton Administration highlighted “free and fair trade” in commercial space launch as an American goal.¹⁴

Under President Obama, national use and reliance on commercial space products and services was also a major focus of the NSP. In particular, the Obama Administration pursued increased use of commercial launch services, including low Earth orbit (LEO) satellite launches and resupply missions to the International Space Station (ISS).¹⁵ The Trump Administration reactivated the National Space Council under the direction of the Vice President. The administration’s focus on domestic economic strength as a key to national security and a commitment to “partner with U.S. commercial space capabilities to improve the resiliency of our space architecture,”¹⁶ continues to support the commercial space industry. A fact sheet previewing the upcoming National Space Strategy states “the new strategy emphasizes dynamic and cooperative interplay between the national security, commercial, and civil space sectors.”¹⁷

Era of Contested Space

An inflection point in the historical concern about potential war in space came with the Chinese test of an anti-satellite missile in 2007. While this threat alerted the world to the potential for kinetic war in space, perhaps a more nuanced threat is the economic competition arising from China’s state-sponsorship of space firms and innovation contributing to the emerging great power competition with China.

In order to counter rising competition in increasingly contested and congested space,

Taxonomy

For the purposes of this paper, we will use the following definitions, and leave discussions about variations on taxonomy to other work:

Mission Assurance: A process to protect or ensure the continued function and resilience of capabilities and assets, including personnel, equipment, facilities, networks, information and information systems, infrastructure, and supply chains.⁸ In the space domain, mission assurance is comprised of three components: defensive operations—including off-board protection; reconstitution; and resilience—including on-board protection.⁹

Resilience: the ability of an architecture to support the functions necessary for mission success with higher probability, shorter periods of reduced capability, and across a wider range of scenarios, conditions, and threats, in spite of hostile action or adverse conditions. *Resilience may leverage cross-domain or alternative government, commercial, or international capabilities.*¹⁰ Space system resilience is comprised of disaggregation, distribution, diversification, protection, proliferation, and deception.¹¹

Constellation Model: an approach using many satellites to provide a service or capability from space. Can be any number more than one, in any orbit, and unconstrained by size of spacecraft. A ‘new space’ perspective is generally limited to small satellites in Low Earth Orbit (LEO). For the purposes of policy recommendations in this paper, we are using a broader approach.

New Space: the transformation of the space industry driven by commercial rather than government demand, focused on rapid innovation, opportunities for additional actors to participate in space, and greater transparency and competition.

Space Superiority: the degree of control in space of one force over any others that permits the conduct of its operations at a given time and place without prohibitive interference from terrestrial and space-based threats. The purpose and value of space superiority is to provide the freedom of action to apply space capabilities in the pursuit and defense of national security interests. The US ability to capitalize on and protect space systems, and to counter enemy capabilities, contributes to US space superiority.¹²

assuming no fundamental changes in the market, this analysis will recommend ways to achieve resilience architecture goals using alternative models from traditional NSS: emerging constellation markets, incentivizing and accelerating market maturity, communicating government priorities to industry, NSS structure change, and increased cooperation with allies and partners. The individual markets within the space industry are too unique to be accessed by a single approach or addressed by a single policy. Resilience must be planned as an enterprise solution over the long-term while ensuring maximum innovative efforts in the short-term to provide security overlays to current systems and service.

DEFINING THE INDUSTRY – SETTING THE STAGE

The space industry is a subset of the larger Aerospace & Defense (A&D) industry. The Aerospace Industries Association analysis indicates that “[in] 2016, the U.S. A&D industry supported 2.4 million American jobs, generated \$872 billion in sales, and reduced the U.S. trade deficit by a record \$90.3 billion.”¹⁸ The space industry is a relatively small industry by revenue and scale, with approximately \$300 billion in global revenue in 2016.¹⁹ Made up of three primary markets—satellite manufacturing, space launch, and satellite services—the industry is vitally important to the U.S.’s economic, military, and international competitive advantage. The U.S. Government is a primary customer of the industry through Title 10 Department of Defense (DoD) and Title 50 IC NSS missions, as well as NASA’s scientific civil space missions.

The space industry has strong overlap with other industrial sectors. The firms involved in the manufacturing of rocket launch vehicles, satellites, and space-related ground equipment have the greatest direct overlap with the broader A&D industry. However, space industry firms that provide space data services, such as satellite communications, satellite observation, satellite ground operations services, and direct to space broadcast consumer services (e.g., television, radio, and broadband data services) strongly compete with firms in the broader information and communications technology (ICT) market. ICT is a very large global market with \$4 trillion in annual revenues based primarily on terrestrially-based telecommunications and mobile and fixed broadband.²⁰ Based on the size of the ICT market, revenue potential for the emerging space-based direct-to-consumer broadband market has the promise of rapid growth if it can effectively scale to compete with terrestrial broadband providers. In this section, we will briefly assess the state of the U.S. space market, discuss the structure of competition in both manufacturing and services, identify how the market is changing, and compare the U.S. domestic market to other international competitors.

Structure and Dynamics of U.S. Space Market Segments

Market Structure

The space industry is also often discussed in terms of mission types and orbits. Spacecraft mission types consist of commercial communications, civil/military communications, navigation, military surveillance, Earth observation (EO), meteorology, specialized scientific missions, developmental/research missions, and manned spacecraft.²¹ Most spacecraft operate in LEO, medium Earth orbit (MEO), highly elliptical orbit (HEO), and geosynchronous/geostationary Earth orbit (GEO).

Due to the unique nature of space market products, limited number of customers, high capital investment, and special expertise required to compete, the space industry is defined by oligopolies and monopolies. Customers are subject to providers' pricing power and overall supply since there are few providers. In contrast, space data service providers trend toward competitive market activities in specific market segments. The overall scale of the market, however, is currently small compared to other market sectors—limiting attractiveness to entry.

Currently spacecraft typically perform only one of the primary missions discussed above, and in one type of orbit. Satellites are specifically designed for their payloads, especially small satellites (uni-taskers). This leads to specialization among manufacturers. Most major space firms focus on a small number of spacecraft mission types and limit themselves to satellite manufacturing (integration or payload systems), launch, or services. This strategy is changing and offers potential for national security and space industry implications.

The U.S. and other governments directly participate in their respective domestic space industries. In the U.S. this results in a hybrid of public-private partnerships rather than a pure free-market. The public-private partnerships are reflected in the National Security Innovation Base (NSIB). "NSIB is the American network of knowledge, capabilities, and people—including academia, National Laboratories, and the private sector—that turns ideas into innovations, transforms discoveries into successful commercial products and companies, and protects and enhances the American way of life."²² The vast majority of U.S. participation, and bulk of revenue in the U.S. domestic space market, comes from national security, IC, and civil spacecraft manufacture, launch, and satellite telecommunication (SATCOM) requirements.

The space industry has historically been dominated by large established defense firms that operate within government frameworks. The firms are willing to pay the transactional costs associated with doing business with the government, specifically with the DoD and IC. The government has the ability to direct these firms' efforts through demand signals that tell them what the customer needs/wants, as demonstrated with defense and national security related requirements. New entrants are looking to compete in space markets but their business models may not align with government or defense requirements. However, the current economics of the industry are such that even these new entrants are often strongly motivated to pursue government contracts to operate at a profit, offset high capital investment costs, and sustained operations during commercial downturns.

Unique human capital expertise is difficult to find and expensive to retain. In the space industry it requires that the U.S. Government clearly communicate requirements early enough for firms to hire experts or establish partnering arrangements. Firms operate efficiently when these experts are consistently employed but have insufficient spare capital to retain such skilled workforces during times of limited revenues. This is problematic for the space industry due to the nature of public-private partnerships in the space industry and the need for specific knowledge of space systems and complex licensing and regulatory requirements. U.S. domestic firms are sensitive to inconsistency in demand—especially U.S. Government demand, as it provides over 70% of domestic space manufacturing revenues.²³

During field study interviews, industry executives highlighted a continuing challenge to find, recruit, and retain employees skilled in science, technology, engineering, and math (STEM) to mitigate a graying workforce.²⁴ The demand signal and assistance required to ensure adequate education to support the U.S. industrial base has an even longer lead time than that needed to hire

those who are already skilled. Suppliers' success in this market is predicated on well-developed internal processes, the ability to take advantage of government contracts, subsidies, and grants, having the ability to expand or curtail operations in line with market demand, and access to the latest and most efficient technologies and techniques.²⁵

Field Study Observations for U.S. Domestic Satellite Manufacturing

Satellite manufacturing in the U.S. is carried out primarily by private sector firms, with the government retaining some organic capacity in NASA and the defense labs. In general, the satellite manufacturing segment of the market faced a difficult year in 2016, with significant reductions in orders for large GEO satellites. U.S. firms were able to capture a dominant share of global revenues for this reduced market, but continued limited demand for GEO satellites challenges manufacturing firms to remain solvent in light of high fixed costs in human capital and infrastructure. Based on field study observations, the satellite manufacturing industry is undergoing a variety of changes to weather this downturn. Firms are vying to better position themselves for upcoming opportunities through vertical integration (Maxar), acquisitions and mergers (Northrop Grumman with Orbital ATK), and expanding into additional mission areas (Space Systems Loral).

The most significant trend in the satellite manufacturing market is investment in manufacturing capability to produce small satellites in large numbers. This trend has the potential to shift a portion of the market away from the historical norm of production of low annual production numbers (single digits) of high-unit-cost products (hundreds of millions of dollars per satellite), high annual production numbers (hundreds) of lower-unit-cost products (tens of millions of dollars per satellite). Many satellite manufacturing firms are pursuing the market for smaller LEO and MEO satellites. OneWeb has partnered with Airbus to produce hundreds of LEO satellites at manufacturing facilities in Florida and France beginning in 2018. Boeing is producing MEO satellites for O3b (Other 3 billion) Network's broadband constellation. Space Exploration Technologies Corporation (SpaceX) has plans for a multi-thousand satellite constellation (Starlink) to be produced in Washington State. Lockheed Martin is building a new manufacturing facility in Colorado to meet projected demand for large and small satellites. The viability of the down-stream business plans for these planned satellite constellations has not been confirmed, and most have either yet to launch prototypes or will take time to complete their orbital constellations. However, the expectation is that the emerging small satellite constellation market will become an enduring part of the commercial space market.

Field Study Observations for U.S. Domestic Launch Providers

The launch segment of the space market represents the smallest dollar percentage in the industry but is the critical link that enables spacecraft and satellites getting to orbit. The technologies underlying space launch are challenging and create high barriers to entry. When considering launcher size and propulsion source (liquid or solid propellant), there are competing advantages and disadvantages, but they are technically distinct enough that launch providers and manufacturers tend to specialize in one or the other. Additionally, large infrastructure requirements for launch complexes, ranges, advanced manufacturing systems, payload integration, and transportation carry extremely high start-up and significant recurring costs that must be borne before firms may be able to realize any economies of scale.

In the past, both government and commercial launch demand drove the market to primarily provide capacity to lift large satellites to GEO. This significantly concentrated the number of viable firms. The introduction of competition in the military and national security launch market between United Launch Alliance (ULA) and SpaceX clearly has now inspired multiple additional players to work toward solutions that allow them to compete in the market. In a related propulsion market, the expected growth of ballistic missile production associated with the U.S.'s Intercontinental Ballistic Missile recapitalization (Ground Based Strategic Deterrent program) will provide a strong demand signal for solid rocket production in the next 10-15 years. Blue Origin is developing orbital-class rocket motors (for itself and ULA) while Orbital ATK is investing and working on its Next Generation Launch vehicle that is both scalable and tailorable based on the size and weight of the payload spacecraft. Both firms plan to be capable of launching the full range of national security and civil space missions required by the U.S. Government.²⁶ These firms plan to use these launch vehicles to compete with SpaceX's Falcon 9 and Falcon Heavy, and ULA's Delta and Atlas launch vehicles. Additionally, numerous launch providers plan to compete in a growing small launch market (Orbital ATK Pegasus, Rocket Lab, Virgin Orbit, Vector Launch Inc., Stratolaunch). Launch complexity, infrastructure requirements, development timelines, and integration complexity all challenge the success of these providers, and there may be limits to how many launch providers will survive over long-run.

Field Study Observations for U.S. Domestic Satellite Service Providers

Satellite services are dominated by communications and direct-to-consumer television. Revenue from services is the largest component of the overall global space industry, with U.S. firms representing approximately 40% of the market segment share.²⁷ Revenue growth in the SATCOM services market has been flat, with direct-to-consumer satellite television and fixed transponder services declining, while satellite radio, broadband, managed services, and mobile communications have shown growth.²⁸ Due to the high fixed costs required to provide satellite services, over time the market tends to settle into monopolistic or oligopolistic markets by service category, as has been demonstrated by the satellite radio and television segments. The U.S. Government is the largest consumer of commercial SATCOM (by dollar amount) based on its demand for worldwide connectivity which exceeds its organic capacity in dedicated military or secure SATCOM.

The commercial market for EO data grew by 11% in 2016 but was only \$2 billion in revenue worldwide with U.S. firms also capturing roughly 40% of the market.²⁹ The EO data market has attracted investment recently with the possibility of satellite constellations capable of producing low resolution EO data for business intelligence. These constellations can be used to measure structure height and for materials intelligence to support the optimized build of terrestrial towers for the 5G network or other business analyses.³⁰

Through field study observation, competitive advantage in the satellite services market centers on the quality of a firm's ground operational software, ability to load-manage demand, and expertise in collaborating with satellite manufacturers and suppliers to acquire and advance spacecraft design in support of their service business plans. The Industry Study team observed software development and satellite constellation control means far beyond U.S. Government capabilities in both efficiency and effectiveness.

It is important to consider that space data providers must compete with the large and highly competitive terrestrial ICT industry. Competition from terrestrially based providers and advancements in data technologies threaten space-based providers. The current long life-cycles of satellites, significant capital requirements for market entry, and inability to service or upgrade space systems once on orbit make it difficult to adapt as quickly as terrestrially based systems. The space services market is not highly regulated by the U.S. Government, compared to launch and satellite manufacturing, but is exposed to intense global competition. The structure in this market tends to be more competitive because it is subject to true global competition. U.S. space service firms' ability to compete in global markets are challenged by international downlink rights/arrangements, national security restrictions on EO locations and resolution, and export restrictions.

Analysis & Trends

Significant capital investment by traditional space firms, combined with new entrants vying for market share, create the potential for long-term overcapacity in the market. How many firms will remain viable over the long-term is unknown. Spacecraft manufacturing currently has overcapacity due to reduced demand for traditional, large GEO satellites. Established satellite manufacturing firms are unable to indefinitely maintain human and infrastructure assets in this situation. Launch has the short-term potential for global overcapacity thanks to new entrants, while ironically the oligopoly that currently serves national security launch in the U.S. does not have excess margin. Satellite service providers will develop overcapacity in response to increased future market potential, with many new entrants hoping to be on the leading edge of the emerging small satellite constellation market opportunities. The greatest risk for U.S. firms is that expected demand or revenue from these opportunities fails to materialize or that U.S. firms are unable to gain a competitive advantage. This could ultimately lead re-concentration and a return to oligopoly, duopoly, or monopoly markets. The loss of any key firms could be damaging to U.S. domestic space industrial capability, even as foreign industrial competition is on the rise. This is especially true from China.

There are also reasons for optimism. The U.S. Government, through its market participation, dominates current commercial domestic demand. As discussed in the next section, the potential exists through complementary and emerging markets for domestic firm revenues to grow significantly. The U.S. Government, as the customer, partner, and regulator, can use its market power and influence to benefit both the established commercial space market firms and the new entrants.³¹

In the realm of the art of the possible, opportunities for growth and increased strength in the U.S. space industry, as well as national security through space resilience, exist if U.S. domestic firms can take advantage of their technological advantages, market flexibility, and latent domestic capacity. U.S. Government demand and market potential complement commercial activities and can also take advantage of emerging and growing commercial markets to bend the cost curve for space access, manufacturing, and services. As discussed next, there is enormous potential for the space industry to tap into the \$4 trillion ICT market, if each of the space industry market segments is properly poised to support demand at the right time, price, and capability.

Effects of Rise of Complementary Markets

Fueled by continued miniaturization of electronics, vast new capabilities to process big data, increased access to high-speed networks, and more opportunities for greater numbers of nations and firms to access space, we assess that all space markets are poised for growth in the next ten years.

The \$4T ICT market, of which space is only a small part today, offers an enormous economic market to tap into, and thus further grow space-based markets. Additionally, today's big data analytical capabilities provide the ability to process vast amounts of information that can be gathered by constellations of EO systems. These two opportunities will allow space industry segments to grow in scale and be a larger, more enduring commercial industry.

Each of the market segments in the space industry can benefit from a virtuous cycle of growth. Large constellations of smaller-sized satellites allow for economies of scale and increase the potential for modularity and flexibility in design. This offers more opportunities for payload customers and service providers to get aboard spacecraft for their needs, be it civil, commercial, or national security. Increased providers should help advance technological development and provide greater capabilities. With greater numbers of satellites necessary on orbit, both large and small launch providers have an opportunity to develop and close business plans for orbital launch—be it large numbers of satellites on a single launcher at once or smaller numbers of smaller systems put on orbit with flexible time, location, and frequency providers. Finally, the services provided by the satellites on orbit create greater demand for broadband, EO, and SATCOM. Reducing the price of worldwide interconnectivity and persistent real-time observation creates larger markets for connectivity while big data analytics provides the means to exploit the vast amount of data now available. This virtuous growth in space markets will increase the complementary markets, and further increase demand in the space market, with a resulting increase in the number of potential entrants into manufacturing, launch, and service. While space capabilities have been primarily a government driven market, the technological and market precipice in ICT and big data capabilities today, opens new ways of looking at and utilizing the space industry.

The reduction in costs, the potential of new providers and entrants, and expected leaps in technology and data all provide different means that U.S. policy makers may leverage for national security resilience and capability. Each segment of the space market, and their submarkets, provide options to support resilience. Though no single part of the growth of 5G communications, unblinking EO, or big data analytics offers a panacea to U.S. NSS resiliency concerns, they do provide avenues that may be exploited contractually or directed through clear and appropriately funded government requirements. Identifying which sub-markets require governmental focus verses what may be relied upon from commercial markets allows us to prioritize efforts to enhance space resiliency across the ground, link, and space-based architectures. These options and prioritization will be discussed further below.

Comparison with International Structures

The U.S. Government is the largest customer in the U.S. domestic space market but encourages and utilizes market competition, industry self-sorting, and partnering to supply required space services. On the international stage, there are significantly different approaches to providing defense-related, science, and commercial space capabilities.

Europe offers a few examples of disparate methods of acquiring and supporting the space industry. The European Space Agency (ESA) civil space efforts totaled approximately \$6.3 billion in 2017³² and are directed to specific countries, and then national firms, based on the requirement for ESA spending percentages in proportion to national contributions in each program. In contrast, European Union (EU) space-efforts—combined defense, commercial, or civil—are awarded competitively, based on both price and specialization in firms' capabilities, not necessarily national origin. The United Kingdom (UK) is at an interesting juncture based on the recent "Brexit" initiative. Almost all EU funded efforts have been pulled from UK firms which creates a strategic challenge for

cross-channel firms. But the UK maintains its contributions and participation with ESA. Additionally, the UK chose not to prioritize an individual national space program through much of the Cold War and has relied on partner countries and commercial firms to provide capabilities and services. There is a new emphasis in the UK to grow its domestic capabilities and become a provider as well as partner in capabilities, but its government and military corporate knowledge needs to be regrown to effectively provide requirements and oversight to space firms.³³

In contrast, France chose to maintain an organic capacity in all space markets and larger stakes in multiple national firms to directly influence commercial, civil, and defense space efforts. Because of this focus on capability, France is the direct recipient of many EU space programs for manufacture and launch and it has great interest in maintaining those inherent capabilities: the most visible is French Government investment in Arianespace (64% shareholder) for launch and Airbus Defence and Space (25% shareholder) for satellite manufacturing.

Finally, direct government control of space industries is inherent in most of the other space-faring nations: Russia, India, and China. China presents a special case to consider, as Russia's capability and attractiveness for launch and manufacturing is on the downslope while China's is increasing.³⁴ During interviews and site visits, European and some U.S. firms identified China as a growing major competitor in both satellite manufacturing and launch. While providing less to domestic space industry in actual dollar investment than the U.S. Government, China has made huge gains with roughly \$5 billion annual spending in dual-use efforts.³⁵ Efforts to be a first-mover may make them the international provider of choice for global SATCOM or broadband for markets untapped by U.S. domestic or European firms. The willingness of the Chinese Government, through its command-economy, to strongly support its space industry by accepting losses or subsidizing multiple firms in order to gain market share presents a challenge to the global space market as a whole. In addition to being a manufacturer and service provider, China's 1.4 billion citizens offer an enormous market base for satellite services, second only to the U.S. in revenue for ICT.³⁶ Due to large barriers to entry in both manufacture and launch, if Chinese firms drive prices below profitability, U.S. and European firms may lose significant market share unless there is a compelling competitive advantage they can provide to international customers.

Multiple international export credit agencies are also active in the space market providing loans and attractive financial support for customers of their respective nations' firms. Since 2015, the U.S. Export-Import (Ex-Im) Bank has been sidelined and unable to make loans of the size required for space industry activities. During field studies, several U.S. firms noted that they had lost deals and business opportunities because the Ex-Im Bank was not available as a financing option.³⁷ The U.S. A&D industry creates positive trade balance as the second largest gross exporter among major U.S. industries,³⁸ but the domestic space industry is unable to participate as effectively as international firms because of this obstacle. Additionally, the 1999 imposition of International Traffic in Arms Regulations (ITAR) on satellites and related technology exports significantly hurt U.S. competitiveness and capacity but was partially offset by the regulations' easing in 2014. U.S. and European Government policy, regulation, and restrictions can play a strong role in countering or offsetting China's continued market and capability growth, while offsetting its potential to undercut international market-share.

U.S. policy makers must consider the benefits and trade-offs associated with the comparative international structures across both the long- and short-term. Across the long-term, the market driven

nature of the U.S.'s science and technology advancements have maintained the country's competitive advantage in space capabilities and in overall economic growth. However, with the potential near-term growth of satellite constellation capabilities, services, and market revenue, the government needs to clearly define requirements, prioritize capabilities, and apply resources to rally U.S. industry in support of space resilience.

ALIGNING EVOLVING SPACE MISSION REQUIREMENTS AND MARKET CAPABILITIES

Figure 1 provides a concept visualization to show how decision makers can help align government requirements with the art of the possible emerging in industry. The United States must determine the capabilities and capacities it requires to achieve mission assurance in space. When materiel solutions are identified, the DoD and the IC set priorities for the NSIB to field required capabilities to deter and defeat future adversaries. This concept can be used to help the United States field useful capabilities and help ensure we continue to reap the benefits of space-based functions that have become part of our way of life. When combined with an assessment of the ability of segments of the space industry to contribute to resilience, this concept will assist DoD and IC decision makers in prioritizing and communicating requirements to the commercial sector.

The government determines "Requirements-Driven" capabilities and capacities by examining strategic plans, current operations, and modelling and simulation as identified in Figure 1 area A. The "Art of the Possible" to deliver these capabilities and capacities is determined through communication between the government and NSIB, reflected in Figure 1 area B. Within available funding, the capabilities and capacities are delivered to the government. The level of communication and interaction between these communities necessary to deliver capabilities within certain markets depends on the likelihood those markets can evolve from the status quo and when. If markets are poised to evolve quickly, less interaction will be required for government to apply those capabilities and vice versa.

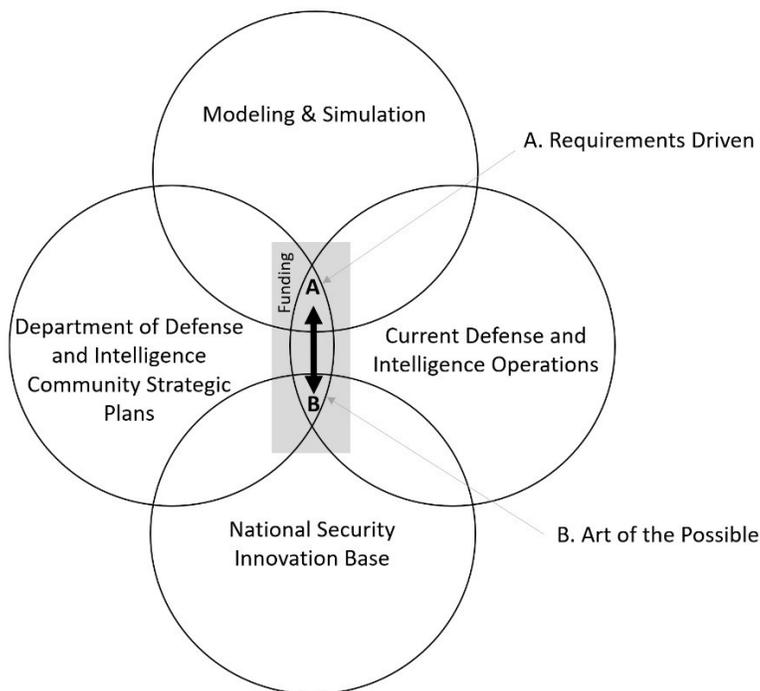


Figure 1 - Requirement Alignment Model

Traditional Space Capability and Resilience

Resilience for space missions is a nuanced concept that, when not fully understood, can lead to misunderstandings about national security strategic objectives. Depending on the individual space services³⁹ and mission types,⁴⁰ achieving resilience may require entirely different approaches. This confusion contributes to the lack of clarity within government and among industry partners about U.S. Government demand signals and its influence on business strategies. It also partially explains the inconsistent approaches to space resilience articulated by firms within the space industrial base. To more effectively manage risk associated with emerging threats and assure space mission capabilities, the U.S. Government should change how it communicates the concept of resilience, adopting a more direct approach that applies elements of resilience across threats, mission types, space services, and their various components.

To appreciate why ambiguity about space resilience distracts from the broader point about assuring mission capability, it is helpful to review how government frames the concept of resilience. Published policy documents provide strategic frameworks and serve as authoritative sources identifying national security priorities and objectives. For space, those overarching policies include the following:

- Presidential Policy Directive (PPD) 4 – National Space Policy (June 2010)
- National Security Space Strategy (January 2011)
- Space Domain Mission Assurance: A Resilience Taxonomy (September 2015)
- Department of Defense Directive 3100.10 – Space Policy (November 2016)
- Executive Order on Reviving the National Space Council (June 2017)
- National Security Strategy (December 2017)
- Space Policy Directive 1 (December 2017, an update to PPD-4)
- National Defense Strategy (January 2018)
- National Space Strategy (March 2018)

While this list is not all-inclusive, it provides a comprehensive overview of space policy while capturing the renewed focus on national security implications of space. Policy documents are high-level by design, but three of these nine documents fail to mention resilience at all and two only reference it in broad terms. Three others provide some granularity to further define resiliency and how to achieve it, but these references are not complete.⁴¹ The ambiguity this presents often leads to confusion within government and with partners in the Defense Industrial Base (DIB) about what the government really hopes to achieve. Executives from multiple space firms, across all markets and missions, conveyed different opinions on what the government means by resilience or noted that they did not know because the requirements are not clear.⁴² This confusion could lead to hesitation, wasted resources, and/or missteps. Hesitation leaves the government and firms waiting to react to market developments, squandering opportunities and relinquishing competitive advantages. Ambiguity could result in conduct that disrupts the market or creates unviable business or acquisition strategies, exposing organizations to unnecessary risks or gaps in capabilities.

The Future of Resilience in Space – Clear Communication and the Constellation Market

Avoiding the negative implications of ambiguity requires a more detailed approach to communicating resilience across the variety of dynamic space services and missions. The definitions below are taken from the OSD Space Domain Mission Assurance: A Resilience Taxonomy.⁴³ It supports an analytic framework to identify and prioritize resilience approaches within various space missions and services that involve direct material solutions enabled by a constellation market architecture. The framework aligns threats across the three major components of each space-enabled system, then overlays combinations of the above assurance approaches across the range of matrixed situations. While most threats fit into one of three bins – e.g. kinetic/destructive, cyber, and disruptive/non-destructive – the framework can accommodate additional threats. System architecture includes space, link, and ground components of each mission/service. When applied across the various missions/services, this matrixed model offers a unique, dynamic approach to identify tailored assurance solutions.

The Space Domain Mission Assurance: A Resilience Taxonomy defines space resilience with considerable granularity. The taxonomy outlines multiple approaches to achieve resilience and should serve as a guide when defining, assessing, and articulating mission requirements and capabilities.

- *Defensive Operations*: Activities or operations undertaken to interrupt an adversary kill chain or provide warning or insight to the targeted mission system in support of defensive actions.
- *Reconstitution*: Plans or operations to bring new assets on line (e.g. launching replacement satellites or activating new ground stations) in order to replenish lost or diminished functions to an acceptable level for a particular mission, operation, or contingency after an attack or catastrophic event.
- *Disaggregation*: The separation of dissimilar capabilities into separate platforms or payloads.
- *Distribution*: Utilizing a number of nodes, working together, to perform the same mission or functions as a single node.
- *Diversification*: Contributing to the same mission in multiple ways, using different platforms, different orbits, or systems and capabilities of commercial, civil, or international partners.
- *Protection*: Active and passive measures to ensure those U.S. space systems, and those of our partners upon which we rely, provide the required quantity and quality of mission support in any operating environment or condition.
- *Proliferation*: Deploying larger numbers of the same platforms, payloads, or systems of the same types to perform the same mission.
- *Deception*: A longstanding practice by which commanders hide both their strengths and weaknesses from their adversaries.

Table 1 below categorizes resilience approaches by opportunities to exploit market-based solutions. First, the OSD resilience approaches are categorized by threat type (kinetic, cyber, and non-destructive) and space component area (space, link, and ground). A given resilience approach in a category is then labeled with an asterisk (*) if it involves a materiel solution. It is further labeled with a chevron (^) if it is likely to be assisted by including small satellites in the architecture. Those items with both an asterisk and a chevron should be seriously examined for exploiting the emerging small satellite market to increase resilience.

Table 1 - Space Services Resilience Approaches

SATELLITE SERVICES		Components				
		Space			Link	Ground
Adversarial Threats	Kinetic/ Destructive	Satellite Telecom	Earth Observation / Navigation	DOD/IC Global Surveillance	N/A	Deterrence Deception Defensive Ops.* Protection*
		Reconstitution*^ Distribution*^ Diversification*^ Proliferation*^ Deterrence	Reconstitution*^ Distribution*^ Diversification*^ Defensive Ops.*^ Proliferation*^ Protection* Deterrence Deception	Distribution*^ Disaggregation* Defensive Ops.*^ Protection* Deterrence		
	Cyber	Deterrence Deception Protection			N/A	Deterrence Deception Protection* Distribution* Diversification*
	Disruptive / Non-Destructive	Protection Disaggregation*^ Deterrence			Deterrence Distribution*	Protection Disaggregation* Deterrence

*Approach involves a direct material solution ^Direct material solution enabled by hybrid constellation architecture

Satellite Telecommunications

SATCOM services include government and commercial communications; direct-to-consumer television, radio, broadband; and in-flight and maritime mobility services, among others. These systems typically utilize small to moderate constellations of large satellites operating in GEO or MEO.

However, the SATCOM segment is currently at an inflection point, particularly in satellite broadband services. Commercial firms are looking to make the leap to non-geosynchronous Earth orbit (NGEO) constellations comprised of hundreds, if not thousands, of small satellites. This allows them to exploit the increased capability afforded by lower latency orbits and tap into emerging mass consumer markets for global access to broadband networks. Current revenues for satellite broadband, operating almost exclusively in GEO, are approximately \$2 billion.⁴⁴ Some industry estimates project the new NGE0 market to reach annual revenues of \$30 billion by 2025.⁴⁵ New entrants backed by venture capitalists hope to gain portions of this new market share, but established DIB firms are hesitant to enter the market because they are uncertain about the market's viability.⁴⁶

Meanwhile, the national defense community sees these emerging markets and the trend to small satellites as an opportunity to hedge against emerging threats to existing national security systems. These opposing views from the DIB and national security community lead to delay and uncertainty on the way forward. Naturally, government acquisition personnel might prefer to work with established DIB firms, but those firms are hesitant to pivot in their strategies without specific direction and incentives from the U.S. Government. Likewise, government organizations are hesitant to partner on critical missions with unproven, new entrant firms because they view this as too great of a risk to national security systems. This fosters a "wait and see" approach exacerbating the timeline to NSS resilience.

New entrants are poised to transform production processes to enable deployment of large constellations. For national security applications, resilience in space telecommunication services

should seek to take advantage of the speed of that production capacity, enabling rapid reconstitution and proliferation. One of the potential risks posed by using smaller satellite buses for national security systems is that the size potentially limits the ability to integrate exquisite-quality systems or protections and defensive countermeasures into the design.

Earth Observation and Navigation

The services in this bin include EO (optical, radar, radio frequency, radio occultation, etc.) and navigation and incorporate a broad range of exquisite and basic systems operating in multiple orbits. Historically, the primary buyers of commercial EO space data have been government customers and others seeking to do static mapping applications. These customers placed a premium on high-resolution imagery, which required the use of a few, expensive, large satellites.

There is currently an influx of new investors into the commercial space EO data market, striving to produce a new type of EO product: business intelligence. Evolutions in data processing technology have complemented the ability to use huge volumes of EO data, and firms are using it to track daily business cycles on a near-persistent basis around the globe. Producing this new space data product requires the use of many, many satellites. This pushes the market to use small satellites with lower unit costs.⁴⁷

Small satellites may produce lower-resolution imagery but enable high frequency coverage since they can be placed in orbit in high numbers at reasonable costs. There is a surge of new entrants into this portion of the market. The 2016 SIA report lists 22 companies either presently competing or planning to compete in the EO space data market. Nine of these firms have operational satellites in orbit, and 13 more are raising capital, with plans to launch fleets of small satellites soon. To show the scale of interest in small satellites in this market, consider that of the 22 firms, the business plans of 16 are built around small satellites. If all the small satellite business plans come to fruition, this portion of the market could soon have more than 500 satellites in operation, compared to 19 large commercial EO satellites currently operating. It is important to note, however, that five of the nine firms already in operation use large satellites, producing high-resolution imagery and earning the majority of global revenues in this market. Some established EO data companies have started hedging, adding small satellites to their high-resolution fleets by acquiring small-satellite firms. In an attempt to scale up to better compete, some small satellite start-ups have merged.⁴⁸

Commercial firms or individuals in government could reasonably assume that resilience and persistence in EO translates into large constellations of small satellites. This is either because that is what they sense is happening in commercial SATCOM markets, because that is the direction they see nation state peers moving, or because they mistakenly transposed a viable strategy in another mission/service area to this one thinking the strategy is universally applicable. In this case, while proliferation may enable persistence – the Holy Grail of EO – operators and policy-makers will not likely settle for the capability degradation. The most viable resilience strategy in this sector would apply a hybrid architecture that strengthens large, exquisite vehicles through protection and defensive operations while pursuing proliferation of less exquisitely capable supporting systems to achieve persistence.

DoD/IC Global Surveillance

Due to classification restrictions, the DoD/IC Global Surveillance Services will not be further defined in this paper, but a general characteristic of the satellites used in these systems is that they are large, exquisite systems distributed across multiple orbits. The need for exquisite functionality and perceived reluctance to accept reduced capability provided by small satellite applications, make proliferation less likely for this service. Similarly, there are no commercial alternatives for missile

warning or other unique national security missions. “Big, fat, juicy targets” are likely a reality for military surveillance services for the foreseeable future. Alternative resilience approaches would use protection, distribution, and defensive operations.

Anticipated progress in the near-term with broadband constellations should mature small bus manufacturing processes, potentially from several firms, that could be utilized to host alternate surveillance payloads later. In the long term, technological advances could close the gaps between the art of the possible and current DIB firm capabilities. Continued investment in research and development could enable the miniaturization of surveillance payloads to a format adequate for small satellite bus integration with less capability degradation to strengthen overarching resilience in this sector.

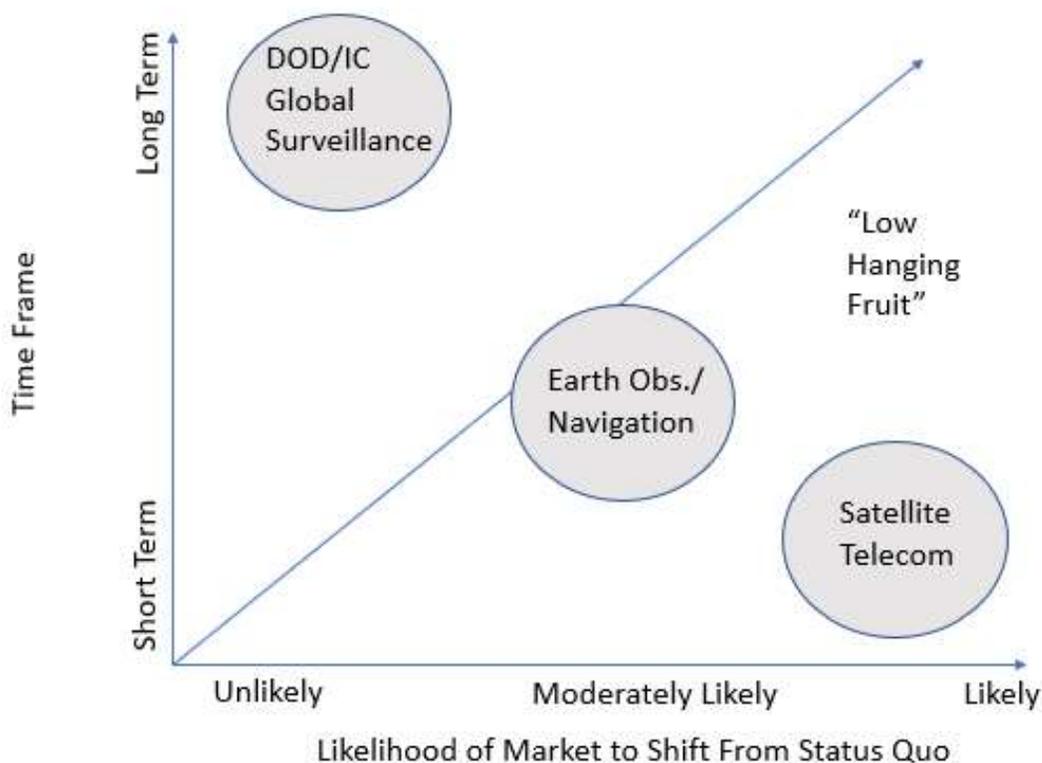


Figure 2 - Identifying Mission Capability Focus Areas

When looking to develop the ability to establish a diverse and disaggregated architecture capable of resilience and reconstitution, it is clear that the commercial satellite services market provides an opportunity to meet two mission area requirements, SATCOM and EO/navigation, in ways that could fit into the less exquisite and more distributed portion of the architecture.

Considering the likelihood of individual service markets to enable a constellation market and the associated timeframes of such, Figure 2 illustrates where government should focus to achieve elements of resilience. In the short- to mid-term, the likelihood of the commercial SATCOM and EO/navigation segments to pivot to constellation models will allow government to leverage those markets more rapidly to advance resilience objectives with less degree of government/commercial interaction than with the DoD/IC global surveillance markets.

MARKET POTENTIAL OF EMERGING SMALL SATELLITE CONSTELLATION MARKET TO ENHANCE SPACE RESILIENCE

Can the government rely on the emerging commercial constellation market to develop capabilities for resilience? The government previously studied and hoped to take advantage of this market potential—expecting cheap and prevalent launch and SATCOM capabilities—but that market did not fully materialize. In the 1990s, many commercial business plans were publicized promising to darken the skies with large constellations of small satellites. Can the government have confidence that this time is different? As discussed previously, in the long term the U.S. Government may not be able to rely on that market growing to meet a commercial demand signal. In the short term, the commercial small satellite market may not grow at a rapid enough pace to meet urgent security demands. It may mature in some mission areas but not in others critical to resilience. There is a definite possibility the U.S. DoD/IC community may need to leverage the traditional DIB prime contractors to develop the full spectrum of capabilities needed to rapidly achieve space resilience. Understanding the commercial interests driving the potential rise of the constellation market will help determine the ability of the commercial constellation market to meet the small satellite portion of the architecture.

Emerging Constellation Market Drivers and Enablers

The first mission areas where the emerging small constellation market may be able to contribute to resilience requirements are SATCOM and EO. Later, the government may have the opportunity in these markets to tap capacity to manufacture small satellites, and their supporting ground infrastructure, for other mission requirements. There are three primary underlying commercial business interests driving the current rise of a small satellite constellation market. First, for SATCOM, the continuous increase in global demand for telecommunications provides strong confidence that at least one constellation will be delivered for this market. Second, the emerging global demand for EO satellite imaging for business analytics provides a commercial incentive for new firms to develop constellations. Firms increasingly use the products from EO capabilities for disaster management, geological research, and to meet varying business objectives for a variety of users.⁴⁹ EO data is also required to determine optimal placement of radio towers to ensure terrestrial lines-of-sight transmission to enable 5G. Lastly, advancements in computing power and big data analytics enable processing EO data provided from space and create a demand for space services not previously provided, as noted above in the section on complementary markets.

The desire to capture even a fraction of market share from the ICT industry is one of the driving factors for new entrants in the space industry. The constellation market is characterized by a hope for faster, cheaper, more capable systems from smaller players, often financed by venture capital or private investors. According to the Aerospace Corporation, ‘new space’ technology allows shorter development cycles and increased affordability, focuses on providing services and information instead of infrastructure, and features business plans which target “gaps in demand for launch, communications, and EO with flexible business plans.”⁵⁰ Morgan Stanley Research highlighted potential growth to over \$1 trillion in global space economy impacts by 2040.⁵¹ While attractive from an investor’s perspective, this outlook for growth may not meet the nation’s requirement for space resilience in the required timeframe.

The combination of these market drivers provides increased confidence for the government to use the constellation market. The ability of a constellation of satellites to provide EO data at the resolution and frequency required to establish and maintain the 5G network infrastructure and for emerging market requirements provides a new, compelling, and enduring business incentive for small satellites that did not exist in the 1990s. As an indication of commercial profit potential, venture capitalists invested more than \$400M in ‘new space’ from 2011-2015.⁵² While the influx of venture capital into ‘new space’ is a good sign, acceptance of risk reinforces the need for expedient analysis. The EO data produced by such satellites would not be as exquisite as that produced by DoD/IC spacecraft, but it could play a critical role in resilience within a diversified architecture.

The launch market segment is responding to these constellation market drivers and developing rapid launch to enable the market even further. The promise of constellations of small satellites in LEO is encouraging investment in both large launch vehicles and smaller rocket options. Operators emerging in the constellation market are demanding launch services centered on speed, to be first to market with a full constellation, to make fast progress due to pressures from venture capital funding sources, and deployment capabilities for multiple small spacecraft to constitute a viable constellation. The current commercial launch providers are adjusting their solutions to meet the launch demands of these large constellation operators, whose business plans call for the launch of one hundred or more spacecraft.

There is also discussion about growing demand for smaller rockets geared to the LEO constellation market. Smaller launch vehicles may be useful to provide responsive timelines from contract to launch. While launch is a critical enabling section of the space market, the true value within the supply chain is the services produced, as evidenced by their dominant share of revenue in the market. It seems likely that demand for small launch services will only support the viable entrant of two or three new providers especially as the larger providers adjust their offerings to support the new market.⁵³

Current Capability of Firms in Emerging Small Satellite Constellation Market

Beyond understanding the market drivers, senior leaders need to understand the current maturity of the firms in or aiming to enter the constellation market. The Space Industry Study Group visited several firms to evaluate their maturity for delivering satellite constellations. The assessment evaluates the firms’ business plans, Concept of Operations (CONOPS) for the constellation, satellite design, and manufacturing design. The group’s assessment is qualitative and subjective based on conversations and observations with industry leaders, the firms’ leadership, and Eisenhower faculty. Table 2 shows that while firms have the ability to develop satellite constellations, prime contractors do not see a viable commercial business case yet.

Table 2 - Assessment of Firms' Maturity

FIRM MATURITY FOR SMALL SATELLITES				
Firm	Business Plan	CONOPS	Satellite Design	Manufacturing Design
<i>Foreign</i>				
Airbus / OneWeb	HIGH	HIGH	HIGH	HIGH
Surrey Satellite Technology Lab (SSTL)	LOW	LOW-MEDIUM	MEDIUM-HIGH	LOW-MEDIUM
<i>U.S. Commercial</i>				
SpaceX / Starlink	LOW	MEDIUM	LOW	LOW
SES O3b	HIGH	MEDIUM	HIGH	HIGH
SSL	HIGH	HIGH	HIGH	HIGH
<i>U.S. Prime Contractors</i>				
Lockheed-Martin	LOW	HIGH	HIGH	MEDIUM
Boeing	LOW	HIGH	HIGH	MEDIUM
Northrop-Grumman	LOW	HIGH	HIGH	MEDIUM

Foreign Firms

For SATCOM, OneWeb is furthest along in meeting their goal of a constellation of 900 spacecraft in LEO. OneWeb's mission is to bridge the digital divide by 2027 giving the half of the world with no broadband access a way to connect.⁵⁴ OneWeb and Airbus created a joint venture for satellite manufacturing and they have partnered with Hughes Network Systems to design and manufacture their gateway sites and terrestrial infrastructure, Qualcomm for their chipsets, and Arianespace, Virgin, and Blue Origin for launch. Investors in OneWeb include SoftBank, Intelsat, Coca-Cola, and Hughes. While the planned launch date of the first 10 spacecraft has moved to fourth quarter of 2018, their first gateways for the ground network were shipped by Hughes in March 2018.⁵⁵ OneWeb has attracted such a high level of investment and partnership due to the commercial market potential.

Surrey Satellite Technology Lab (SSTL) is a spin-off company of the University of Surrey in the UK with a heritage in building and operating market leading EO small satellites, with the potential to serve as intelligence, surveillance, and reconnaissance (ISR) platforms. The company is now nearly wholly owned by Airbus but functions as an independent business unit. SSTL created a concept for an EO-ISR rapid revisit constellation in LEO. The constellation would contain dozens of small satellites, with the ability for high resolution collection, with nearly the entire coverage area having a gap time of only a few minutes, and target dwell times moving towards persistent coverage. The unit cost per satellite is nearly two orders of magnitude below that of large EO spacecraft. SSTL currently has a design to launch twelve of the spacecraft at a time using the Indian Polar Satellite Launch Vehicle (PSLV). SSTL is also developing a radar spacecraft in the 450-kilogram class, with Airbus building the payload.

U.S. Commercial Firms

In the growing push to provide cheap broadband service across the globe, SpaceX's new constellation, dubbed "Starlink," is a potential game-changer. SpaceX's plan, as outlined in their Federal Communications Commission (FCC) application, is to launch 4,425 satellites with frequencies in the Ka and Ku bands that, when complete, will "provide a wide range of broadband and communications services for residential, commercial, institutional, governmental, and professional users worldwide."⁵⁶ The FCC proposal also calls for a second, larger constellation in very low Earth orbit, which consists of 7,518 satellites.⁵⁷ Using a tiered approach, SpaceX intends to launch the first 800 satellites before bringing the system online.⁵⁸ Chief among SpaceX's competitive advantages is its position as one of the world's most advanced launch service providers. Using its

growing fleet of Falcon rockets, its satellites can readily serve as secondary payloads on launches, which should help reduce the cost of the constellation.

Equidate recently set valuation of SpaceX at \$27.5 billion, including \$500 million raised for the satellite constellation.⁵⁹ Although details surrounding SpaceX's price for subscriptions are not public, The Wall Street Journal disclosed last year that SpaceX "projected the satellite-internet business would have over 40 million subscribers and bring in more than \$30 billion in revenue by 2025."⁶⁰ In line with the company mission, "to revolutionize space technology, with the ultimate goal of enabling people to live on other planets,"⁶¹ SpaceX hopes "Starlink may become a big revenue generator that can help offset R&D and operations costs for the rocket company."⁶² The FCC's approval of the proposal is subject to a few conditions, including an updated orbital debris mitigation plan.⁶³ The FCC directed SpaceX to launch 50 percent of its satellites before March 2024, with a project completion date of March 2027.⁶⁴ SpaceX launched the first two test satellites it manufactured in February 2018, but it has not publicly provided an update on the two test satellites nor has it announced a capability or facility to manufacture the number of spacecraft required for the constellation.⁶⁵

O3b Networks was founded by Greg Wyler in 2007. The company was financially backed by Société Européenne des Satellites (SES), Google, Hongkong and Shanghai Banking Corporation (HSBC), Liberty Global, Allen & Company, Northbridge Venture Partners, Soroor International, Development Bank of Southern Africa, and Sofina and Satya Capital.⁶⁶ O3b launched its first four MEO satellites in June 2013 with pre-booked capacity for operators in the Cook Islands, Pakistan, and Nigeria. In 2014 O3b began providing broadband to a growing catalog of cruise ships and marine applications. The U.S. Government, through National Oceanic and Atmospheric Administration (NOAA) and DoD, entered contracts with O3b in 2015 and 2016 to provide high throughput, low latency SATCOM. O3b has a proven supply chain and expanding customer base using its existing satellites in orbit to provide broadband service to areas not covered by fiber or cellular service. Additionally, O3b has established its ability provide managed services to its current customers in Latin America, Africa, Middle East, and Asia Pacific. Since being acquired by SES in 2016, O3b has access to capital and is working to expand its operations by expanding its constellation. In 2018, O3b added four satellites to its constellation which now totals sixteen and is expected to expand to twenty by 2019.⁶⁷

Space Systems Loral (SSL) is a global leader in integrated space technologies, delivering advanced systems for communications, exploration, data gathering, and next-generation services. Maxar vertically integrated MacDonald, Dettwiler and Associates, Limited (MDA) Technologies, SSL, Digital Globe, and Radiant Solutions to provide SATCOM (building and operating), ground infrastructure, EO, and advanced analytics. This was part of a larger effort to integrate companies to cover a broad range of space related markets, increase its access to U.S. markets, especially defense, and provide end-to-end solutions in satellites, robotics, ground stations, imagery, and analytics for commercial and government customers worldwide. Providing end-to-end solutions to the DoD market positions Maxar to compete against traditional large competitors.

SSL solutions provide GEO communications, LEO communications, EO, space infrastructure services, robotics, exploration, and U.S. Government systems. SSL's products include high-power geostationary satellites, state-of-the-art small satellites, and sophisticated robotics and automation solutions for remote operations. SSL has built more geostationary communications satellites on orbit today than any other manufacturer. SSL has decades of hosted payload experience, more than 2,200 on-orbit years of experience, launched over 270 satellites, has more than 80 GEO satellites currently on-orbit, innovative LEO satellites, and cost-effective manufacturing. SSL has a

dedicated small satellite manufacturing facility and the experience to rapidly manufacture small satellites.

U.S. Prime Contractors

Lockheed Martin Space is one of the five major business divisions of Lockheed Martin. The division currently employs about 16,000 people, and its most notable products are commercial and military satellites, launch through its ULA joint venture with Boeing, space exploration probes, missile defense systems, NASA's Orion Multi-Purpose Crew Vehicle, and the Space Shuttle External Tank. The Space program is heavily linked to government contracts and partners with a variety of other companies to address space requirements. They are an established provider of space services and equipment to DoD. They are very well positioned in the market and can compete on new contracts as well as service existing DoD contracts.

Lockheed Martin's small satellite manufacturing capacity has been demonstrated through the manufacture and launch of 150 satellites weighing less than 1,000 kilograms, including the manufacture and launch of four micro satellites weighing less than 100 kilograms since 2005.⁶⁸ The company is investing in innovations to make small satellites capable of meaningful missions. In May 2018, it was awarded a sole-source contract for the majority of the next generation overhead persistent IR program missile warning satellites, predicated on an expectation of rapid development.⁶⁹

Boeing is the world's largest aerospace corporation, supporting commercial, military, and civil customers. The Defense, Space, and Security segment of the company earned 22% of the company's revenue in 2017.⁷⁰ Boeing has a long history supporting U.S. space endeavors with involvement in spacecraft manufacturing, launch through its ULA joint venture with Lockheed Martin, the return to launching humans into space through the Starliner, and building and integrating many parts of the ISS.⁷¹ Through a collaboration with Defense Advanced Research Projects Agency (DARPA), Boeing is designing, building, and testing a technology demonstration vehicle, Phantom Express, to provide rapid, aircraft-like access to space to deploy small satellites into LEO.⁷² The company is focused on providing flexible designs for any mission and finding ways to drive down the cost of spacecraft. Boeing has manufactured cube and nanosatellites for government customers, but their smallest advertised spacecraft is the 502 series, which is 1,000 kg.

Northrop Grumman is a large defense prime contractor with long expertise in government satellite manufacturing for both NSS and civil space, but with low revenue and little focus in the commercial satellite manufacturing market. Their expertise has been built on participation (payload system development or large satellite integration) in classic large "exquisite" systems including the complex, and delayed, James Webb Space Telescope. In May 2018, it was awarded a sole-source contract for two polar-orbit missile warning satellites (part of the next generation overhead persistent IR program) with expectation of rapid development.⁷³ Interestingly, as early as 2014 Northrop Grumman offered a small-sized flexible modular spacecraft to the Air Force⁷⁴ and continues to offer concepts for small modular multi-mission satellites in its Eagle spacecraft line. During field studies, Northrop Grumman highlighted the "Knight Eagle" satellite as a capable plug-and-play resilience spacecraft for constellation use.

Northrop Grumman expects to close a \$9 billion acquisition of Orbital ATK by mid-2018. This acquisition offers a means for Northrop Grumman to vertically integrate its space units and expand its market reach in multiple segments: enhancing small and commercial satellite manufacturing capability, providing organic launch capability (Pegasus, Minotaur, Antares, and Next Generation Launcher), and acquiring a major stake in solid rocket motor production for both space launch and ballistic missiles. Orbital ATK's long experience in building innovative mid- to small-

sized commercial and government satellites will complement Northrop Grumman's capabilities and makes it a strong competitor across nearly all satellite and launch manufacturing opportunities for commercial, military, IC, and civil space efforts.

Lockheed Martin, Boeing, and Northrop Grumman are established firms in the space industry, have a deep understanding of DoD, IC, and civil missions and business processes, and the ability to meet its needs through existing capacity, growth, or partnership. Overall, the U.S. prime contractors have the capabilities and infrastructure to flexibly respond to U.S. Government demand signals for resiliency across a wide spectrum of requirements. Lacking a strong or coherent demand signal from U.S. Government entities, they do not have an active business plan for a constellation system.

Timing for Market to Mature

To estimate the timing for this constellation market to mature, this Industry Study examined the estimated timeframe for such a constellation to be built, launched, and made operational to include ground station and functional capability. Beyond this functional timeline, the commercial business case would also need to become viable.

Based on the current stage of several new small satellite companies planning for LEO constellations of sizes varying from 100 to 4,000 small satellites, this Industry Study estimate that the constellations could be launched and operational in the next five years. Based on conversations during field studies with industry, it is estimated that it will take at least ten years for a business case to become profitable in these 'new space' ventures.⁷⁵ Can the U.S. Government wait ten years to leverage the market? Is this timeline for commercially-incentivized growth in the small satellite manufacturing market rapid enough to meet DoD resilience needs? If the DoD cannot wait this long, then the nation needs alternate options to enhance its space resiliency.

Given the maturity of the firms, the government has a number of options within "the art of the possible" across the spectrum of the NSIB to develop and/or procure mission capability to enhance space resilience. The government has three general options detailed in the following sections.

Market Option 1: Buy Mission Needs as a Service

While commercial satellite service providers do not typically launch spacecraft with substantial spare capacity, some spare SATCOM capacity exists, and SATCOM operators sign agreements with users/providers on the basis of flexible demand. Understanding these two factors provides a potential basis for the DoD to source these services in the event of a need for surge capacity, if coupled with existing federal authorities.

Mature commercial markets exist in GEO and MEO for telecommunications and ISR. EO and telecommunications is expected to be widely available commercially from LEO in the next five years. For ground stations, the commercial market is maturing and represents an opportunity to enhance resiliency. The current satellite service providers have their ground stations integrated for multiple satellites in multiple orbits and through automation can control their constellations with limited number of staff compared to the military control stations.

In the EO data market, the government has exiting contracts through NGA to obtain commercial data. However, the number of commercial spacecraft supplying the EO market is much smaller than the commercial SATCOM market. In addition, the developing requirements for space resilience architecture will likely include the ability for EO assets to tip and cue other satellites based on observations, as well as requirements for more frequent revisit rates. Thus, a resilient EO space architecture may require a reserve fleet of spacecraft in orbit that can be called upon when other

mission assets are at risk. This would require direct discussions and procurement with the EO operators to determine their willingness to step outside their normal business models.

Unfortunately, there are no commercial demands or capabilities for Infrared (IR) missile warning. There is a small and emerging commercial market for Synthetic Aperture Radar (SAR).⁷⁶ The capabilities and capacity for these mission needs are primarily unique government activities; therefore, the government will not be able to procure these mission sets as a service from the commercial market yet. There is a possibility in the long-term that the commercial demand for EO data will grow to demand the data regardless of weather or time of day. If that is the case, there is a possibility in the longer term that SAR capabilities from a constellation model will become a robust commercial market capability.

Airbus/OneWeb and SSTL are foreign firms, so senior leaders must balance the desire for U.S.-based capabilities with the timeliness required for buying the service. Once OneWeb demonstrates the viability of a small satellite architecture, the nation could leverage that architecture with other payloads to support the required missions. However, the nation would need to accept the risk to procure this service from a foreign firm, and senior leaders would need to provide authorities for space operators and acquirers to partner with OneWeb to develop and field the additional payloads into the small satellite architecture.

Market Option 2: Incentivize Firms to Accelerate Market Maturity

Broadly speaking, the U.S. Government can do several things to set the conditions for market growth to support the constellation model. The United States needs to ensure it has regulations that encourage and incentivize the creation and continued business operations of ‘new space’ companies. FCC International Bureau (IB) opened docket number 18-86 on March 27, 2018 to request industry input on whether a new authorization process is required to streamline licensing procedures for small satellite operations in NGE0 orbit, the spectrum needs, and application and regulatory fee issues.⁷⁷ It is a clear indication that the FCC is taking the growing potential of the small satellite market seriously and is looking to foster its growth in the U.S.

In addition, the U.S. regulatory regime needs to lead the way for regulations that consider the technology and business operations of ‘new space’. This would include changing FCC licensing and fees to account for the large number of satellites in small space constellations. The FCC could also facilitate communication between U.S. firms to ensure understanding of their need for spectrum licenses, the status of their constellations, and the user’s voice to explain the mission criticality of their use of space.

The added benefit of this approach is contending with the growth of Chinese space industry and capabilities. Because China provides considerable investment in support of their domestic small satellite industry, U.S. Government regulation reform will have the additional benefit of making U.S. companies more competitive in a key growth market emerging in global economic competition. “In the short-term, global commercial firms will tussle in the market to gain ascendancy/market share, including vs the USG. USG can help US space industry by incentivizing their global competitiveness (tax, licensing, clarity of regulations/policy, purchasing of capabilities, transfer of technology, pressing forward with big science/manned missions, etc.)”⁷⁸ This will allow the nation to be competitive within the international environment so that start-ups decide to remain in the U.S. because of its more attractive regulations for their business model.

As discussed in the prior section on market timing, this option may not incentivize the market to mature in a timely fashion to support U.S. space resilience. Regulatory reform creates a long-term environment for a stable small satellite market, yet market demand drives the speed of its maturity. If

the government wants to accelerate capabilities for space resilience, then the nation will need to provide clear direction and capital investment.

Market Option 3: Provide a Clear Demand Signal to U.S. Industrial Base for Constellations

The commercial constellation market firms will deliver telecommunications capabilities on their own, and this Industry Study expects there will be two to three competitors the government can take advantage of for space resiliency. The EO market is almost there, and there will be strong potential for partnerships and hosted payloads for space resilience requirements. However, the remaining mission requirements will need capital investment from the U.S. Government. For IR, Airbus will have capabilities, but U.S. leadership will be reticent to rely on a foreign firm for this mission. The same conclusion applies to OneWeb for follow-on EO capabilities derived from their small satellite architecture. The U.S. space industry cannot currently perform rapid reconstitution of satellite constellations. Airbus and OneWeb are building a manufacturing facility in Florida, which may be a viable option. The nation could buy services from SES O3b Networks, SpaceX/Starlink, or SSL, but, as displayed in Figure 2, these firms are not yet mature enough to provide space resilience on desired timelines.

There is no U.S.-based commercial market for missile warning or unique IC national security missions. The draft FY19 National Defense Authorization Act (NDAA) proposal notes the need for the nation to develop these payloads. It discusses the use of small- and medium-size buses for strategic and tactical satellite payloads and directs the Secretary of Defense, in coordination with the Director of National Intelligence, to provide “a briefing on the risks, benefits, and cost savings with respect to using small- and medium-size buses for strategic and tactical satellite payloads for protected satellite communications programs and next-generation overhead persistent infrared systems.”⁷⁹ Actually, Congress goes even further when it discusses the concept of a Persistent Space-Based Sensor Architecture and directs the DoD (e.g. Missile Defense Agency) to “complete a plan and initiate development in fiscal year 2019 for a space-based missile defense sensor architecture.”⁸⁰

This Industry Study group is concerned about Congress specifically calling out the potential for Other Transactional Authority (OTA) to be used for the space-based missile defense sensor architecture. OTA is best used for rapid prototyping and delivering tactical solutions. OTA vehicles are not ideal for Major Defense Acquisition Programs requiring significant capital investment. The nation will need to leverage traditional DIB prime contractors to provide resilience in mission segments that are unique for national security requirements. The DIB has defense-specific technical understanding, DoD-unique contracting expertise, modeling capability to help define the required hybrid architecture, the required clearances for a nuanced understanding of the threat, and a holistic understanding of the military and intelligence mission requirements.

As noted in Table 2 and the resulting discussion, the DIB prime contractors are taking a “wait and see” approach on satellite constellations and require a clear demand signal from the DoD. The unique elements of the DIB may be required to meet the initial, urgent requirements. If the commercial constellation market matures in the next five to ten years, the DoD and IC will have the opportunity to assess the state of the commercial sector to consider buying the capability from the commercial market in future updates to the small satellite portion of the hybrid architecture.

RECOMMENDATIONS

Recommendation 1 – Enhance Resilience through Diversification with Commercial SATCOM and EO Constellations

We recommend leveraging the model of mature commercial satellite service market's capability for communications and EO mission requirements. In order to facilitate the ability of the government to leverage this commercial market as a service and still provide the flexibility needed for potential national emergencies, changes need to be made to the Federal Acquisition Regulations (FAR) and the training of acquisition professionals.

For the EO mission requirements, the government must decide what objectives it needs to fulfill with a satellite constellation in order to provide resilience without severely degrading mission capability. Then it needs to meet with commercial EO operators, firms specializing in big data analytics, and satellite operators experienced in tipping and cueing between satellites to determine the capabilities in industry and the options to meet the requirement. Once informed of the capabilities available, the government will be able to assess its objectives against those capabilities and determine the best acquisition approach, which may result in the procurement of data, data analytics, or a satellite constellation. The acquisition approach must be informed by a full understanding of the market, its long-term viability, its ability to provide the capability required, and its willingness to provide it in that manner. In order to produce this nuanced assessment of the market, the government's acquisition professionals must be trained to assess the long-term viability of markets. In order to provide commercial satellite service providers a clear signal of the potential for the DoD to require them to prioritize service to DoD over commercial customers in a national emergency, solicitation and contract language should be created to indicate the option for a Defense Priorities and Allocations System (DPAS) rating to be added to their government contract vehicles. As DoD expands its military SATCOM offerings by exploring the use of commercial capabilities, it is important to ensure they analyze the potential need for similar language to provide clear indication that the government may require them to prioritize service to DoD over their commercial customers.

The purpose of the Defense Production Act is to help ensure that products, materials, and services needed for defense are expeditiously available.⁸¹ The act authorizes the President to require certain defense and energy contracts be performed on a priority basis to promote the national defense and provides a framework for rapid industrial response in a national emergency.⁸² The DoD uses the authority under the DPAS to designate industrial priority ratings of DO or DX on its applicable contracts.⁸³ A DO-rated order must be given production preference over commercial orders. DX-rated orders must be given preference over DO-rated orders and commercial orders. While DPAS is traditionally thought of for production efforts, we interpret the language as including services. There is no way for a contracting officer to indicate that a contract is provisionally rated.⁸⁴

The Complex Commercial SATCOM Solutions (CS3) contract vehicle established by GSA and executed for DoD through the Defense Information Systems Agency (DISA) has 22 different contractors, and includes all of the large commercial SATCOM firms, such as Hughes, Inmarsat Government, Intelsat, SES Government Solutions, and Trace Systems.⁸⁵ A review of the current contracts reveals no mention of DPAS rating or the possibility of a DPAS rating being included on orders under the contract.⁸⁶ We recommend modifying the contracts to include language that a DPAS rating of DO may be included on orders on the contract to require prioritization of service to DoD over commercial customers to allow industry to plan, put the appropriate terms and conditions in their contracts with commercial customers, and to ensure they flow down the requirement to subcontractors at any tier.

Recommendation 2 – Policy Changes to Incentivize Participation and Accelerate Market Maturity

In order to ensure a robust, competitive commercial space sector that is able to support the U.S. Government's need for resilience in space, the Trump Administration will need to implement a package of initiatives and policies that demonstrate long-term government support toward achieving enhanced national security through space. It is imperative that the administration consolidate and streamline the regulatory landscape, removing frictions, burdens, and fees, to enable small satellite and constellation development to continue unabated by bureaucracy. Further, for space-related manufacturing companies (as opposed to services), return on capital investments is key, so that any way to increase profit on the margins is essential to sustaining future investments.⁸⁷ A government backed, lower cost insurance program could therefore go a long way in increasing profitability and sustaining the industry.

Export financing is another tool that the U.S. Government can employ to encourage activity in commercial space. While this helps the overall market viability, the reduced demand or involvement from the government could come at a cost to resiliency if companies are not as responsive to government needs or willing to partner. In addition, outside of the U.S., other space ventures are overwhelmingly financed or controlled by foreign government interests, allowing them to posture even seemingly commercial activities in a way that directly meets the governments' strategy for the use of space. The government should be doing everything possible, including the reauthorization of the U.S. Ex-Im Bank, to support this booming industry and to solidify it as an engine of the industrial base.

Recommendation 3 – Government Priorities and Resources to Industry

If we chose to prioritize domestic manufacturing capabilities instead of time urgency, we accept risk in terms of vulnerability to attack in the short-term. We recommend directly engaging industry and providing investment now to develop constellation-based DoD/IC global surveillance capabilities. Using diverse avenues across the NSIB, including University Affiliated Research Centers (UARC) and industry days that welcome start-ups and non-traditional defense manufacturers, directly fund the art of the possible.⁸⁸

DoD cannot wait five to ten years for proof of concept from the constellation market for DoD/IC global surveillance applications. Thus, an immediate approach that uses the traditional DIB now is necessary to allow the U.S. to maintain its competitive advantage in space. The DIB has the ability move with speed, technical understanding and expertise to define the full architecture, the required clearances for a nuanced understanding of the threat, and a holistic understanding of the military and intelligence mission requirements. If the commercial small satellite market matures in the next five to ten years, the DoD and IC will have the opportunity to assess the state of the commercial sector to consider buying the capability from the commercial market firms when the small satellite portion of the architecture needs to be refreshed.

Industry does not respond via capital expenditures to words and policy proclamations alone. They will not typically take concrete actions to prepare their business for the potential new focus within the DoD market until government contracts and funding affirm that policy and its priority. The DoD and the IC are serious about exploring a new approach to buying spacecraft. Therefore, the government must communicate the requirement for a diversified architecture with Requests for Information (RFIs) and Requests for Proposals (RFPs).

While a broad array of approaches could support this concept of resilience based on constellations, there are other limiting factors. In addition to the impacts on the satellite manufacturing market, a small satellite revolution would strain supporting launch markets, which already suffer from today's short-term constrained capacity and hesitancy to transition to support smaller satellite launch capabilities. The overarching small satellite dilemma illustrates the constraints with the government's approach to tackling resilience and provides an opportunity to explore the alternative approach to communicate a more diverse set of requirements to industry to achieve SATCOM mission assurance.

Recommendation 4 – Establish a Single Authority for Space

Congress needs to push for a Director of National Security Space as the Executive Agent for Space with the sole authority, responsibility, and accountability for the planning and execution of the NSS program.⁸⁹ There are 60 different government stakeholders 'responsible' for NSS.⁹⁰ This leads to fragmented leadership for NSS strategy, budgets, requirements, and acquisition.⁹¹ With multiple offices and individuals 'in charge' of these key areas, 'no one is in charge' which leads to an "inability to resolve interagency differences in setting achievable requirements and resource priorities."⁹² In Defense Space Acquisitions, this fragmentation contributes to program delays, cancellations, cost increases, and inefficient operations.⁹³

NSS needs to be redefined to include a whole of government solution to fully address the current space challenges and ensure the U.S. maintains its competitive national security advantage in space. A separate DoD space corps or space department is not the answer, the U.S. needs a structure for space similar to that of the Director of National Intelligence that establishes a Director of National Security Space to integrate requirements, set priorities, evaluate alternatives, and align resources for NSS in order to seek the best solution across the military, intelligence, civilian, and commercial space sectors.⁹⁴ Without this realignment, the nation reduces its capability to provide a demand signal for regular business opportunities that encourage investment in research and development and business decisions focused on the long-term.

Recommendation 5 – Collaborate with Allies for Resilience

Our allies and partners provide an opportunity for the U.S. to leverage additional options for resilience. The U.S. needs to look for opportunities to evaluate opportunities for commercial and international partners to provide potential emergency backups for national security missions. This will likely require a higher cost than the commercial market demands and may require some initial investment, but the return in the event of an attack or loss of primary control stations would be immeasurable. A robust network of allied and partner space assets could make the targeting calculus for adversaries more difficult.

In addition to encouraging domestic investment and production by U.S. companies, senior administration officials involved in space have also signaled interest in encouraging friendly foreign investment on U.S. soil as a way to build up the industry and also to reinforce resilience.⁹⁵ This should incentivize allies to closely cooperate on resiliency in order to defend their country's assets and make an attack or disruption by a hostile government less likely if they face opposition from several nations with interests in U.S. space assets.

CONCLUSION

The three major segments of the space industry: manufacturing, launch, and services, are a variety of market structures and maturity levels in terms of their ability to support resilience in NSS through the constellation model. Complementary markets may provide synergistic opportunities to encourage or expedite the ability of the segment to play a role in resilience. The current regulatory environment and NSS structure inhibits the ability of the commercial sector to anticipate and respond to future requirements. The industry is not monolithic and requires novel approaches to achieve objectives. The government must identify areas to share space-based services with commercial operators as well as invigorate market segments that will lead to rapid reconstitution and surge capacity in order to address the contested NSS environment. The traditional suppliers of DoD and IC space systems, the larger prime contractors, are not getting this demand signal clearly and while poised to pivot to more innovative development and implementation models, have not engaged beyond the traditional demand for large and exquisite space-based equipment.

Several recommendations should be adopted to best achieve resilience. First, where the capacity to achieve resilience requirements already exists in the commercial sector, the government should diversify by buying services instead of infrastructure. By removing policy and commercial barriers, the government can improve the health of the space industry. In cases where the required mission needs do not yet have a viable business case, the government should incentivize both the large prime contractors and new entrants to develop capability. Within the government, creating a single authority for space would minimize barriers to success. Finally, by expanding the aperture on who provides resilience and where it resides to include allies and partners, we reduce likelihood of adversarial action and spread the burden of resilience.

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