

SEPTEMBER 2017

Small Satellites, Big Missions

The Implications of the Growing
Small Satellite Market for Launch
and Key Applications

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CSIS | CENTER FOR STRATEGIC &
INTERNATIONAL STUDIES

A Report of the
CSIS DEFENSE-INDUSTRIAL INITIATIVES GROUP

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Small Satellites, Big Missions

The Implications of the Growing Small Satellite Market for Launch and Key Applications

Executive Summary

On June 21, 2017, the Center for Strategic and International Studies (CSIS) hosted a two-panel event on opportunities emerging from new space technologies, particularly small-scale satellites. Panelists discussed the implications of new small satellite technology and small satellite market dynamics, not only for the government space sector, but also for private-sector users of satellite technology and the growing cohort of commercial space systems suppliers. That small satellites will continue to grow—in use, market share, capability, and overall importance—is now widely accepted. Appreciation for the direction, pace, and implications of this growth, however, remains limited. The June CSIS event and the report that follows represent an effort to understand and describe the shape and consequences of the growth ahead. For a complete record of the session, please access the full video file at <https://www.csis.org/events/small-satellites-big-missions>.

The event was organized into two panels to ensure that the discussion would examine both the importance of the growing presence of small satellites in space and the effects of the growth of this market on the launch sector. The first panel focused on the potential impact of small satellite systems on the performance of new and traditional missions in space including a mix of military, civilian, and commercial satellite uses. The discussion highlighted potential benefits resulting from the flexibility, cost, and lifecycle advantages of small satellites. The benefits discussed included key attributes such as lower costs, responsiveness and flexibility, enhanced resiliency of space capabilities to ensure the performance of critical missions, new opportunities for space mission performance, and the potential for broader and more continuous coverage from space. A clear takeaway from both panels was that the growth of the market for small satellites and their launch has major implications for the U.S. government as a developer, user, and regulator of space capabilities that merit immediate consideration.

This first set of panelists included Colonel Steve Butow, the West Coast military lead for the U.S. Department of Defense's Defense Innovation Unit Experimental (DIUx); William Jeffery, the CEO of SRI International; Bhavya Lal, a researcher at the Institute for Defense Analyses' Science and Technology Policy Institute; and Aaron Rogers, a program manager for Disruptive Space Missions at The Johns Hopkins University Applied Physics Laboratory. The panel was moderated by Todd Harrison, the director of the Aerospace Security Project at CSIS.

We need to take action to make sure, whether its peacetime or wartime, that we are able to leverage these commercial small sat developments.—*Bhavya Lal, Research Staff, IDA*

Highlighted in the first panel were ways new and traditional missions may change with the increased use and development of small satellite systems. Tools of automation and additive manufacturing are making the

“small satellite revolution” possible and companies such as OneWeb are showcasing the potential for these technologies to create massive small satellite constellations. However, the benefits of the small satellite revolution go beyond those offered by massive constellations, and the use and deployment of small satellites in a range of applications was the focus of the discussion. Compared to larger satellites, small satellites can be put in place inexpensively and quickly, and can operate in a range of orbits that may not have operational viability for large satellites. Small satellites can provide a complementary layer for existing large satellite constellations at significantly lower costs, adding much needed resiliency for certain critical systems or provide an option for rapidly supplementing satellite constellations that have suffered damage. The presence, or even the possibility, of a backup layer of capabilities for U.S. military satellite systems can provide a measure of deterrence against attacking these systems. In addition, these complementary uses of small satellites can extend the coverage, capabilities, and persistence of existing constellations.

The second panel focused on the implications of a growing small satellite market for the space launch industry. The discussion centered on the fact that delivering on the promise of small space will require significant increases in launch capacity as well as new operational models for space launch that incorporate new trajectories and more flexible delivery of payloads into space. Included on this second panel were Marco Caceres, a senior analyst and director of space studies at the Teal Group Corporation; Richard Dalbello, the vice president of business development and government affairs at Virgin Galactic; and Steve Nixon, the vice president for strategic development at Stratolaunch. The panel was moderated by Andrew Hunter, the director of the Defense-Industrial Initiatives Group at CSIS.

With diminishing costs of producing small satellites, the next step in the cost equation is lowering launch costs and increasing launch capacity. While these steps alone are challenging, there are even more dynamics in play for satellites with missions that require special orbits, something that may be the

I think what the role of government right now should be to take small bets . . . rather than say the government has to rush in on a white horse and save my system, I think what I’d rather say is the government needs to be smart, take small bets, be a partner, and it needs to let things fail. The last thing we need is . . . the government saving systems that aren’t stable in the marketplace.

—*Richard Dalbello, Vice President, Business Development and Government Affairs, Virgin Galactic*

case for some small satellites. As Col. Steve Butow stated, “We have to get every small satellite into its mission-designed orbit, and that will not be a small feat. I think the success of commercial small satellites will be tied very tightly with launch.” Other ways to lower the cost of

launch include reusable launch technologies, such as SpaceX and Virgin Galactic. Furthermore, as Marco Carceres argued, with an increase in production of small satellites, the U.S. launch market would be saturated with demand and an increase in launch services will be needed, including an increase in launch sites. The panelists agreed that for the small satellite revolution to be successful, small satellites would need to become in many cases the primary payload of a launch, not the secondary payloads they are now. The market seems poised to provide additional launch options domestically, and there is also substantial competition in the launch of small satellites from international launch providers.

Small Size, Big Punch

Small satellites¹ are not merely scaled-down versions of large, conventional satellites. They are qualitatively different in kind, function, and capability. They have a distinct value proposition and, on a single-satellite basis, a more limited range of capabilities on standalone basis. Their advantage comes from both greater flexibility and lower cost; lower cost includes cost to design, to develop, to produce, and, on a per unit basis, to launch. Large, conventional satellites are, and will remain, essential to the U.S. government and the commercial sector, and no serious proposal to date has suggested replacing all large satellite constellations with small satellites.

What small satellites are being proposed and used for are a growing number of missions that either complement and enhance conventional satellite fleets, or function independently to fully meet satellite needs. Communications, sensing, and imaging are currently the primary applications for small satellites. Several advanced applications are in development, including rendezvous and proximity operations (RPO), synthetic aperture radar (SAR), and spaced-based positional awareness, among others.

A Period of Great Expectation

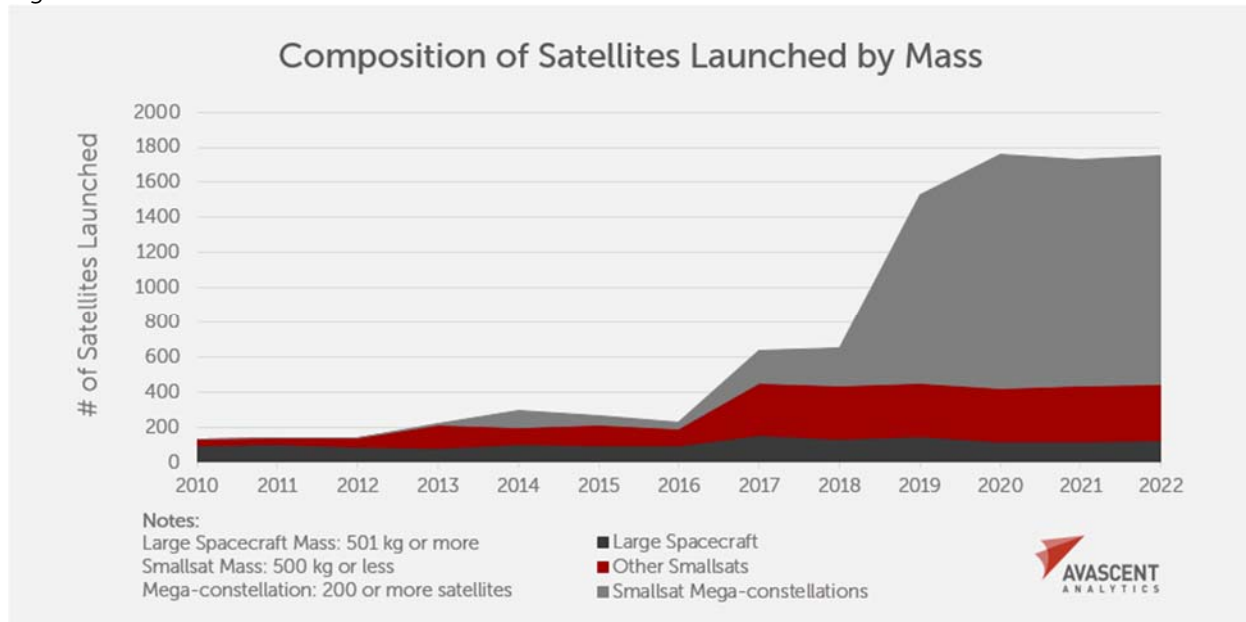
Growth in demand for satellites is being driven by growth in a host of space-related data services used by governments and, increasingly, private-sector entities. Demand for capabilities such as remote sensing, geospatial intelligence, satellite-based navigation, and atmospheric navigation, to name a few, continues to be met by the launch of traditional large-scale satellites. The market forecast shown in Figure 1 suggests that small satellites that will capture an increasing share of this growing demand.

Arguably more important than the specific numbers in Figure 1, which are necessarily uncertain, are the reasons for the projection. The growth portrayed in the figure is based on evidence showing that small satellites show tremendous promise in a wide range of applications and offer

¹ Definitions regarding what qualifies as a *small* satellite vary, though the usual cutoff is 500 kilograms or less in mass. Below this threshold there is considerable variation. Terms such as mini satellites, micro satellites, cubesats, and others imply a lot of development and experimentation at the low end of the scale. Panelists discussed satellites as small as one unit (U), or 10 centimeters cubed. In this report, we use the umbrella term “small satellites” to include all of these varieties. Small satellites are just part of the broader satellite industry ecosystem, and much of this document discusses issues relevant to the entire ecosystem, including both small satellites and their conventional, larger cousins.

several advantages to government and commercial users. Because they can be designed, built, and launched quickly, and because of their relative low cost, they can be used singly, as part of a larger constellation of small satellites, and as complements to traditional large satellite systems, providing the latter with surge capacity, resilience, and even deterrence against attack from hostile nation states.

Figure 1: Forecasted Growth in Satellites Launched



Source: Avascent Analytics.

The high expectations for small satellites are reflected not only in forecasts for launch growth like those of Figure 1, but also in investor excitement. Rocket Lab, a startup developing a new small launch vehicle, has a valuation of \$1 billion despite having only conducted a single launch that fell short of achieving complete success.

Achieving the type of steep growth portrayed in Figure 1, and consequently long-term investor returns, will require continued technology development. Small satellites' technical capabilities need to be pushed further and cost curves must continue to decline on the basis of cost per unit of functionality. Earlier periods in the industry witnessed similar expectations for explosive growth that ultimately went unfulfilled because cost reductions were never sufficiently realized.

Scale, the single greatest driver of lower unit cost in virtually any manufacturing process, will be important to small satellites. The sooner the industry gets to scale, the more quickly cost reductions will be realized. Panelist Aaron Rogers spoke to the impacts that building small satellites at scale will have throughout the supply chain, saying, "Look at OneWeb, who are trying to launch 1,000-plus satellites—how will they achieve a price point that makes that profitable and economical? There is a trickle-down effect of trying to build a \$500,000 satellite delivered to launch vehicles that goes down to the supplier chain. We see suppliers that would traditionally make star trackers that might have been \$500,000, now selling them for \$5,000." Tools like automation and additive manufacturing are also likely to contribute to lower costs for small satellite production, as panelist Richard Dalbello described. "We [Virgin Galactic] and a lot

of people in the industry are looking at additive manufacturing for actually building whole engine parts. Building an engine is still an expensive, time-consuming process. We need to introduce automation to drive the cost down dramatically—not a couple of percentage points, but rather we need 30, 40, 60 percent improvement.”

From a technical perspective, there are no obvious technology gaps to stifle industry growth, though countless technical improvements and innovations remain to be developed. Launch capacity, however, has been and may continue to be a bottleneck. Rideshare launch arrangements, a popular and inexpensive method for getting small satellites into orbit, cannot always get satellites into the correct orbits for their intended use. Panelist Col. Steve Butow noted, “Small sats really only become interesting at scale, but they also need to be in the right orbits. In my opinion, rideshare is incompatible with commercial small satellite constellation deployment—you can’t just randomly throw stuff out there. It is imperative that we get small launch, where every payload can be a primary payload. We have to get every small satellite into its mission-designed orbit, and that will not be a small feat. I think the success of commercial small satellites will be tied very tightly with launch.”

At the moment, there simply isn’t enough launch capacity for the traffic expected in Figure 1, especially given the targeted orbits. This constraint, though material, is more amenable to mitigation than in the past.

Mission Implications: Resilience, Surge, and Innovation

A variety of mission implications are likely to arise from the expected growth of the small satellite market, including significant implications for the national security space architecture. While some of these relate to ways in which small satellites differ from their larger brethren, there is also a significant element of overlap and complementarity to the missions that small satellites perform. As complements to existing conventional systems, especially those in the national security space architecture, small satellites have great potential as a means for enhancing resilience. Much of the current U.S. government space infrastructure was conceived, designed, developed, and launched in an uncontested environment. Further, much of this infrastructure is made up of a small number of very large satellites. Destroying or disabling just a few of these satellites could significantly disrupt critical systems. Small satellites can be put in place as an inexpensive complementary layer for existing large satellite constellations at a cost estimated to be a small share of the U.S. government’s current budget for space. The presence—indeed, the mere possibility—of backup capability provides a measure of deterrence. Panelist Steve Nixon spoke to this, saying, “Now, an adversary may only need to take out one satellite to cause huge problems for you. When you have a lot of small satellites in low earth orbit, that changes their deterrence calculus, because they will not derive the same benefit from an attack.” The fact that small satellite backup layers can be reconstituted quickly makes them even more effective as deterrents.

The relative low cost of small satellites offers several additional benefits. It allows surge capacity—the ability to stockpile satellites and launch many in a short period of time. Whereas small satellites can be produced quickly and inexpensively, a single conventional satellite

represents a huge investment in time and money. Producing and storing (or launching) one as a “spare” would be far too expensive for most missions.

I think an important role for the government is to help not create wealth, but to create the environment in which industry can create wealth and capability.
—William Jeffery, CEO, SRI International

Low production costs and shorter production timeframes for small satellites also allow developers to take more risks in development. They can experiment with new designs, configurations, and systems. The risk of incorporating experimental components is also lower. Lower levels of cost and of risk mean lower barriers to entry for new firms and aspiring

space entrepreneurs. Interest by entrepreneurs and investors is helping to drive innovation in the small satellite space. It is also providing new career paths and entry points into the industry for the next generation of aerospace engineers, and increasing the variety of projects these highly skilled workers engage with over the course of their careers.

Large space systems, be they satellites or launch vehicles, typically have designs that are frozen years before they are launched and put into use. For example, despite beginning its operational mission less than five years ago, in August of 2012, NASA’s Curiosity rover on Mars is only equipped with a one-megapixel camera (less resolution than the original iPhone camera) because its design was set many years prior to launch. The much shorter design-to-launch times of small satellites means that they can be put into orbit with much more recent technology than large satellites. Thus, their cameras, microprocessors, power systems, and other components can potentially be multiple generations newer. While this ability to introduce new designs with experimental capabilities quickly is critical for small commercial startups, it can be no less significant for the national security space architecture in an era where utilization of the space domain is changing rapidly.

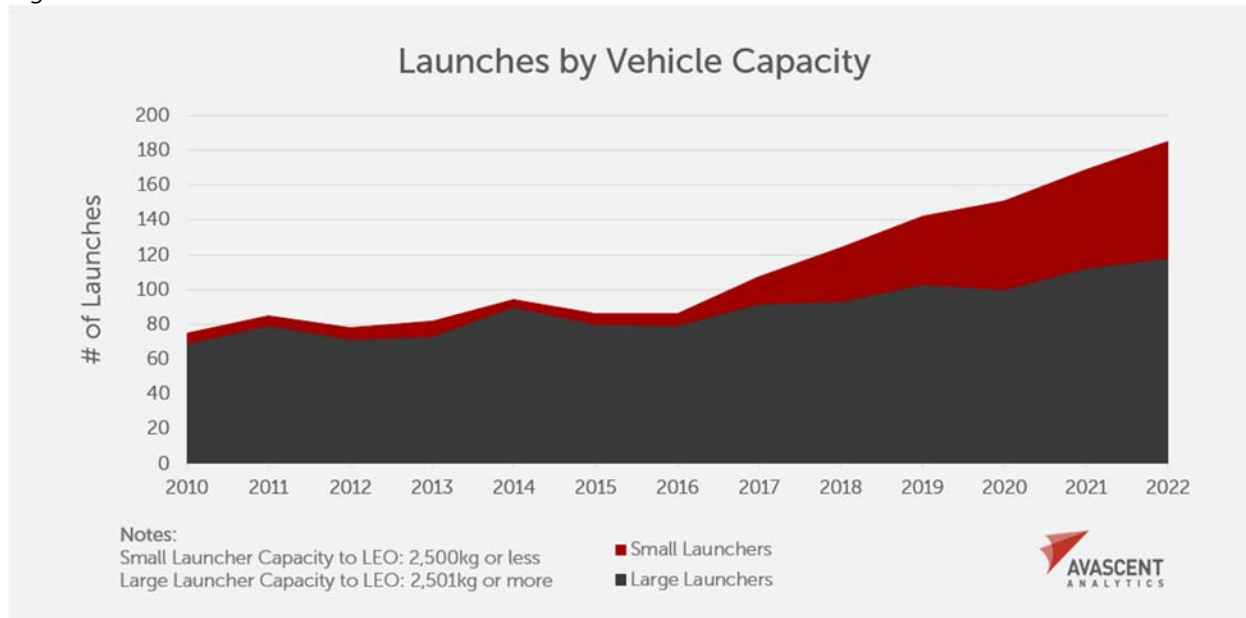
Finally, small satellites hold tremendous promise for new applications in the military, commercial, scientific, and humanitarian sectors. Panelist William Jeffrey described some potential scientific applications, saying, “There are a number of phenomena in the space environment that are highly dynamic, where you need a lot of temporal and spatial coverage—space weather, radiation environment, subtle changes in the Earth’s magnetic field, and the 3D-structure of the Earth’s atmosphere. I’m very bullish that as small sats continue to develop, particularly if we can get low-cost launch access, that we will be able to rewrite some of our scientific knowledge of the Earth’s atmosphere and the planetary systems around us.” Panelist Bhavya Lal added that their low cost allows small satellites to act as expendable platforms, opening up a range of new applications, saying, “You could do research in very low Earth orbit—we could not put spacecraft there before because they degrade too quickly.”

More Satellites, More Launches

Any significant growth in small satellite use will depend on commensurate growth in launch services. The forecasted growth in launches shown in Figure 2 mimics that of the number of

satellites launches predicted in Figure 1. Any delay in making available new launch capacity will slow the growth shown in Figure 1. At present, launch may be the most significant potential roadblock to small satellite growth. Panelist Marco Caceres explained, “We’re talking about launching potentially thousands of satellites per year. We’ve never seen this before. If this is going to happen, we will need more launch vehicles, and those launch vehicles will need to reduce their turnaround times . . . We also need more launch sites, because you can’t launch that many times from the sites we currently have.”

Figure 2: Forecasted Growth in Satellite Launches



Source: Avascent Analytics.

Anticipating this potential gap in capacity, several new private-sector firms have been created to close the shortfall. As a group, these new entrants—which include companies such as SpaceX, Stratolaunch Systems, Virgin Galactic, Rocket Labs, Masten, ORBITEC, Generation Orbit, Vector Space, Zero Point, and others—are developing new and innovative approaches for satellite launch. Stratolaunch is using the world’s largest airplane, with a wingspan of 385 feet, for use with the Pegasus launch vehicle. Virgin Galactic is working on a similar system with its LauncherOne vehicle, which will be air launched from Virgin’s Cosmic Girl aircraft.

Both systems aim to provide launch flexibility and responsiveness in terms of where and when launches take place. Because launch vehicles are air launched from carrier planes in flight, they are freed from many of the restrictions and hindrances of physical launch sites—wait times, weather delays, etc. Using carrier planes will also enable companies to launch in multiple directions and trajectories from a single takeoff location, allowing launch customers put satellites into a variety of orbits.

In addition to location and orbit flexibility, new entrants hope to reduce the wait times for launch, which are typically measured in years. New entrants to the launch service business hope to eventually provide responsive launch on demand (LOD), that is, the ability to schedule and launch a satellite almost immediately. Steve Nixon described the need for LOD: “If something

were to happen in the commercial world, if there was some hole in a constellation, can you rapidly fill that hole? To do that, you need to already have a launcher procured and ready to go.” Richard Dalbello added, “If you look at the way the industry works today, you have companies building satellites that are always two to three years away from launch. What we’re offering is the ability to rapidly accelerate that pace. We think this will have direct implications on both DoD and the commercial sector.”

New launch services are not just being developed by U.S. and European companies. China and India will provide plenty of competition in the launch service marketplace. Indeed, India’s Polar Satellite Launch Vehicle (PSLV), which can place small satellites into Sun-synchronous orbits, had its 40th launch in July of this year, so international competition is already here. All new launch companies, regardless of where they are headquartered, will need to push technology development aggressively in order to remain competitive on schedule, flexibility, and cost. Launch schedule—that is, quickness to launch—will increasingly become the basis for competition among launch providers. This will be increasingly true as the capability to launch small satellites separate from the launch of larger satellites grows.

The Expanding Ecosystem

Launch services, despite their crucial role in the industry, represent less than 1 percent of the satellite value chain. Euroconsult’s report, *Satellite Value Chain: Snapshot 2016*, estimates launch services at just \$1.3 billion in annual revenue for all satellite configurations. This compares to satellite manufacturing at \$4 billion, operations at \$14 billion, and downstream satellite services at \$217 billion.

These industry segments do not work in isolation, but are dependent on each other and on large networks of suppliers (companies that make parts and components of satellites, launch vehicles, monitoring systems, and downstream analysis platforms), investors, customers, research institutions, and government agencies and regulators. This interdependency is true in both the commercial and national security space sectors. Currently, there is a good deal of partnering between established satellite companies and newer startups. Companies that make conventional large satellites have not historically manufactured in large numbers. If they are to be successful in small satellite manufacturing, they will need to rely on scale. For this reason and others, established firms are partnering with newer entrants and smaller startups to experiment with new technologies, systems, and configurations. Partnerships and other commercial connections will continue to multiply and evolve as the ecosystem for satellites matures.

As more startups form and enter the industry, venture capital will play an increasingly important role in the satellite ecosystem. Because risk capital is provided for entrepreneurial satellite activity, it focuses disproportionately on small satellites and downstream services. To date, several satellite startups have succeeded in getting early round funding. They’ve secured these early investments mostly on promise, and on the potential of their novel ideas. Their ability to attract later-round funding will be tied much more closely to success in the commercial marketplace.

Many satellite startups are being formed in the downstream services portion of the satellite value chain. General growth in the industry and coincident trends related to big data have

spawned a huge potential market for satellite data services and analytics. Data that can only be collected by satellite is vital for a growing range of applications and sectors, including navigation, communication, meteorology, agriculture, and many others. The amount of satellite data and the range of applications for that data will continue to grow in the future as new technologies develop and more satellites come online.

The Role of Government

Historically, the government role in the satellite industry was near absolute. As the primary buyer of space equipment of any kind and as the primary buyer/provider of launch, government dictated what was built, when, and by whom. Several decades of growth in commercial satellite use has changed that landscape, but the role of government is still central as both regulator and customer.²

As a buyer of satellite technology, the government has an interest in a technically strong and competitive private-sector technology base. As a disproportionately large “anchor” customer, the government can and should use its buying power to help shape technology development. This does not mean picking winners, but rather implies a government investment portfolio that is as diverse as possible while maintaining mission performance. Small satellites and accompanying launch services represent a domain in which small bets can be made with low risk and low cost, as Richard Dalbello described, indicating, “NASA created a very small program with a budget of about \$15 million called VCLS [the Venture Class Launch Services program]. They contracted with three separate launch companies that hadn’t flown yet. These were small bets. If they all fail, the loss isn’t that significant, but it could be that NASA’s participation on the front end has a profound effect on those companies.” The upside benefit of these bets is not merely lower cost, but potentially significant improvements in performance and resilience. As Bhavya Lal explained, these benefits could also be important for DoD, stating, “We need to take action to make sure, whether its peacetime or wartime, that we are able to leverage these commercial small sat developments.” There are a number of ways that the government, including the Department of Defense, could undertake efforts similar to those of NASA to spur the development of small satellite capabilities through small satellite demonstration projects or through the purchase of services from, hosting payloads on, or undertaking the deployment of satellites within, small satellite constellations to supplement or support government needs.

Government use of technology and services from new entrants in the satellite sector will require greater flexibility in procurement. This includes policy changes that make it easier to engage with smaller startup companies with little to no experience with, or appetite for, typical government procurement processes. Col. Butow described DIUx’s efforts to engage with the tech community, saying, “Normally, when DoD does business with the commercial sector, we go through something called FedBizOpps, which, if you’re a high-tech company in Silicon Valley, San Francisco, Boston, or any of our other ecosystems, they don’t even know what that is. We have to have boots on the ground out in these technology hotspots and rely on our

² For a detailed discussion of the potential evolution of the government’s role in space as the commercial space market grows, see Todd Harrison et al., *Implications of Ultra-Low-Cost Access to Space* (Washington, DC: CSIS, March 2017), <https://www.csis.org/analysis/implications-ultra-low-cost-access-space>.

relationships to find out who these people are and what they are doing.” Changes are also needed that make it easier for the government to procure equipment and services outside of its usual, often “closed,” supplier base. SpaceX’s recent success in winning launch work for the U.S. military and DIUx’s 2016 prototyping contracts for small satellites suggest progress in this area is being made.

Something the government can think about is subsidizing launch, especially if there are emerging new launch technologies that would not otherwise get funding from other sources.

—Bhavya Lal, Research Staff, IDA

While the U.S. government may be losing share as satellite buyer—roughly 80 percent of upcoming launches are commercial—it remains the sole regulator of space. Much can be done at the policy and regulatory level to support small satellite technology and market development. Not surprisingly, many U.S. government space policies and regulations are decades old and merit revisiting. Col. Butow noted, “We made decisions in the past that have impeded the evolution of the commercial space industry in the United States, when the Europeans, the Canadians and the Japanese did not. We need to be competitive as an industrial nation.” Several pieces of legislation have been introduced in the U.S. Congress toward this objective, and H.R. 2809, *The American Space Commerce Free Enterprise Act of 2017*, was recently considered and moved forward by the U.S. House Committee on Science, Space, and Technology. The bill is intended to streamline the process for government authorization and supervision of nongovernmental space activities.³ In addition, many issues of space regulation, such as standards for space traffic management and orbital disposal (deorbit), legal definitions and standards for issues such as property rights, salvage, and space piracy, and trade considerations pertaining to domestic company subsidization, will require international cooperation.

Beyond its roles as a buyer and regulator, the government plays many other key roles in supporting the satellite ecosystem. Expanding U.S. launch infrastructure is necessary to help alleviate the bottleneck in launch. Bhavya Lal argued that more is needed than just infrastructure investment, but even going so far as federal subsidies for launch. This could take the form of purchasing launch services to demonstrate the capability for responsive launch or to enable the demonstration of missions that are likely to become increasingly important in the future such as the clearing of space debris. In doing so, however, the government should be mindful of the effects of its activity on commercial market dynamics. As Richard Dalbello put it with respect to the government’s role in the launch market, “I think what the role of government right now should be is to take small bets . . . rather than say the government has to rush in on a white horse and save my system, I think what I’d rather say is the government needs to be smart, take small bets, be a partner, and it needs to let things fail. The last thing we need is . . . the government saving systems that aren’t stable in the marketplace.”

Further upstream, the government funds a large share of the basic science and applied research and development (R&D) relevant to the entire satellite value chain, from production to

³ The Outer Space Treaty of 1967 imposes an obligation on the federal government to supervise and authorize the space activities of the United States: <https://history.nasa.gov/1967treaty.html>.

downstream services. The government's still significant role in the space market also has implications for the competitive structure of the industry. In an era when the space market is growing rapidly, the government must seek to both leverage new technology and launch capacity for its benefit while not becoming dependent on market growth that may or may not materialize as expected. The industry is currently in an era of great change to both the technology and business models of satellite use. It is attracting considerable investment and valuations on new companies are high—witness Rocket Lab's nine-figure valuation. While the government should invest where appropriate in the higher-risk, higher-reward approaches of select new companies, it should not become overly dependent on these investments for current mission success. In the long run the government will likely get the most out of the commercial space market when it has grown to the point that there is ample competition that allows the best solutions to emerge.⁴

DIUx, mentioned already, provides a good model for targeted government support of companies with promising satellite technologies. Col. Butow described the process, which allows DIUx to work with innovative commercial startups without effectively trying to turn them into defense contractors. "We don't put out a laundry list of requirements, we put out a problem statement. Companies respond by saying, 'Here's how our commercial solution can solve your problem.' By doing that, we're not reinventing these companies just by doing business with them." DIUx provides companies with winning pitches small amounts of funding for technology development and with technical assistance. The funding provided is not equity, and so if funded companies wish to grow as traditional startups, they must compete for venture funding like all startups. DIUx benefits by accelerating development of a useful technology for the U.S. Department of Defense.

The Path Ahead

The growth of the space market, and the emerging importance of small satellites in that market, has significant implications for both government and commercial entities. The potential benefits to critical system resilience alone make small satellites and capabilities for responsive launch an important avenue for the U.S. government to explore. Furthermore, the range of new applications available as a result of new satellite designs and new launch capabilities will have implications for both government and commercial customers. As the growth of this market continues, the government will face choices about whether and how to leverage and influence the direction of critical new technologies in small space and about the structure of the space market, not to mention the need to anticipate and address the use of these capabilities by adversaries.

Much progress remains to be made with small satellite technology itself. Integration with ground systems must be improved. For sensitive applications, both government and commercial, cybersecurity remains a challenge. Additionally, radiation hardening and other adaptations made to technology for use in space must be accommodated to very small

⁴ For a detailed discussion of how the government can address the changing market for national security launch, see Todd Harrison et al., *Beyond the RD-180* (Washington, DC: CSIS, March 2017), <https://www.csis.org/analysis/beyond-rd-180>.

geometries. Many claims of small satellite capabilities have yet to be proven beyond the lab. Most of the technological advances in this sector are being driven by commercial entities, and in many cases by small startups. One of the biggest challenges remains scale, both in producing small satellites affordably and in providing sufficient launch capacity. Nevertheless, the cost advantages and flexibility provided by small satellites appear likely to drive significant growth in the market. The U.S. government needs to continue and to deepen its engagement in this “small space” market to ensure that the potential benefits of small space are realized for both government and commercial users.

About the Authors and Editors

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