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Balancing Operational Utility and Repeatability for Defense Space Systems

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Abstract

The Department of Defense and the U.S. Space Force seek to develop and field a more proliferated space architecture based on greater numbers of smaller satellites in lower orbits to counter space threats and deliver warfighting capabilities more quickly. This shift is forcing a reexamination of acquisition practices and approaches. Prototypes will need to demonstrate operational utility at the system-of-systems level. Similarly, acquisition programs will need to be designed for repeatability, since successful follow-on efforts will be critical for sustaining the system's capabilities. This paper explores some of the tensions within these different goals, offering strategies for how decision makers and acquisition program offices can design and execute space acquisition programs to deliver positive outcomes.

Introduction

The United States faces a dynamic environment for national security space. Government budgetary pressures are forcing difficult funding choices just as an increasingly contested space environment are exposing the lack of innovation, speed, and resilience within both the defense acquisition system and the industrial base. The U.S. Space Force (Space Force) is still evolving as an organization as it seeks to "transform into a warfighting service" (Secretary of the Air Force Public Affairs, 2025). On the commercial side, the space sector has experienced rapid technological and financial growth yet still faces challenges as it matures.

The Space Force seeks to field a resilient and capable space architecture both by transitioning to a more proliferated constellation of smaller satellites in diverse orbits and by leveraging commercial innovation and new suppliers. This effort represents a departure from the large, multipurpose, custom-built, and expensive satellites that were developed and produced by defense contractors with long-established ties to the Department of Defense (DoD). While the DoD's total demand for smaller satellites in low Earth orbit (LEO) is not yet fully known, its future space architecture could require a sustained pace of several hundred units per year. The DoD and the Space Force will need to 1) foster and maintain some level of competitiveness amongst its vendors, 2) routinely incorporate technological innovations that respond to new threats and requirements, and 3) ensure that its selected vendors are able to repeatedly deliver quality at scale.

The Space Force's long-term success in transitioning to and then sustaining a more proliferated space architecture depends on achieving balance between two overarching goals: operational utility and repeatability. The paper will explore some of the natural tension between these goals, describe some of the ways that acquisition programs are navigating these tensions, and offer suggestions for how decision makers and acquisition program officials should consider and make trade-offs. Although proliferation is an approach that can be applied to any orbit, the focus in this paper is large LEO constellations (LLC) for national security space missions. Employing hundreds or even thousands of satellites, LLCs represent significant departure from

legacy space systems and carry important and distinct implications for the defense acquisition community and the space industrial base.[1]

LLCs Proving Value for Commercial and Government Customers

In 2019, SpaceX and OneWeb (now Eutelsat OneWeb) each launched their first operational satellites in LEO. Although these were not the first commercial space-based broadband services, they helped raise aspirations for what commercial space companies could achieve, particularly with large constellations of small satellites enabled by falling launch costs. Both these and other LEO constellations have demonstrated commercial success. SpaceX's Starlink, in particular, has exceeded expectations for subscribers, revenue, and number of operational satellites (Erwin, 2024). Anticipating significant increases in demand for these types of space-based services, a growing number of both U.S. and foreign companies have announced plans to launch their own large LEO constellations.

Although revenue from commercial companies now exceeds global government space spending, the U.S. government, and the DoD in particular, play an important role in shaping and supporting the commercial space sector (Reber, 2024). A clear demand signal from government about its future capability needs can help drive commercial investment, and companies that secure defense contracts can show investors a diversified revenue forecast. For its part, the DoD increasingly recognizes the value of commercial innovations. For example, in addition to citing direct economic benefits to the United States, the Space Force's 2024 Commercial Space Strategy states that "[the] Space Force and the Nation become stronger through the effective integration of commercial space solutions during times of peace, competition, crisis, conflict, and post-conflict" (U.S. Space Force, 2024).

Commercial space companies that have not historically pursued defense space acquisitions have recently shown that they can compete effectively with traditional defense contractors on price and schedule. Many of these non-traditional vendors design and build satellite buses and other systems or components that can be readily modified for government or commercial applications. These dual-use technologies have been championed by industry as a way to break down barriers between commercial and government technologies and systems, reversing the trend of defense industry consolidation that started in the 1990s (Palantir, 2023).

Despite impressive growth over a short period, many commercial space companies are still searching to prove out their business models with consistent revenue. Compounding this challenge, venture capital investment in commercial space has fallen from its peak in 2021, in part due to inflation and higher interest rates (Chen et al., 2024). Venture capital investment remains a critical source of support for the commercial space sector, but this recent decline highlights the fact that venture capital is often seeking a shorter timeline for financial returns than even promising commercial space technology is likely to deliver. Overall, there is not yet a broad, established, and competitive market of companies that have proven both the utility of their technology for consumers and their ability to manufacture at scale. Government spending on commercial space products and services remains a vital part of the sector's growth plan.

DoD's Future Space Architecture Driving Changes to Acquisition

The DoD's shift to LLCs is forcing rapid changes to the defense acquisition system. Decades after abandoning earlier attempts like the Strategic Defense Initiative and the Space-

[1] As a point of comparison, the Global Positioning System operates in medium Earth orbit (MEO) and has historically been the DoD's largest military satellite constellation. At that altitude—approximately 20,000 km—a minimum of 24 satellites are required to meet operational requirements. The GPS satellite constellation, and subsequent replenishment efforts, were largely completed under traditional acquisition processes.

Based Infrared System-low (SBIRS-Low), the DoD is again pushing to employ LLCs for national security missions.[2] Since 2023, The Space Development Agency (SDA), an independent acquisition unit within the U.S. Space Force, has launched 27 prototype satellites built and operated by several different vendors. SDA plans to launch hundreds more in the coming years as part of LEO architecture to support missile warning and tracking, data transport, and other missions (Berglund, 2024a). While this is the DoD's most visible and advanced LLC acquisition effort, there is a growing interest in expanding this approach to serve other missions, potentially including navigation, space situational awareness, and communications. The shift to LLCs is also occurring amidst a renewed interest in defense acquisition reform. Acquisition cycle time—roughly the period between program initiation and capability deliver—has been a primary target of reform efforts for decades, and traditional space system acquisitions have often struggled to meet cost and schedule targets (GAO, 2017).

Space systems have long faced unique acquisition challenges. They rely on specialized components, operate in a challenging environment, and cannot be readily retrieved for upgrades and repairs. In the years after Congress established the middle tier of acquisition (MTA) approach, the DoD explored the creation of a "alternative acquisition system" for space acquisitions. This alternative system was meant to tailor standard practices and processes to better account for space systems' acquisition needs (Department of the Air Force, 2020). In particular, the pathway was intended to account for the differences in how space systems were typically developed and fielded, which was through a long development phase followed by a production of just a few satellites. The space acquisition pathway effort was abandoned before it could be implemented, though elements of the proposal have been incorporated by the DoD (Defense Business Board, 2023). Among other things, the "typical" process for space system acquisitions was being upended by a new model, championed by SDA, that upended the typical approach by creating acquisition programs with short developmental phases followed by production of many satellites.

The shift to a more proliferated space architecture carries long-term acquisition and funding implications. An LLC requires more satellites to provide equivalent Earth coverage compared to more distant constellation, making it imperative to control the cost of each satellite to manage total system cost. Because of this emphasis on unit cost, each satellite is designed and built to have a shorter operational life, lacking many of the redundancies and protections that increase costs but also allowing a larger, more expensive satellite to operate for a decade or more. At the same time, the shift to a proliferated system implies a long-term commitment. Satellites in the constellation must be regularly decommissioned and replenished to sustain operations. Abandoning the LLC and shifting the architecture back to using fewer, larger satellites could be both costly and operationally risky. Therefore, in approving the development of a proliferated space acquisition program, decision makers, including Congress, are committing resources beyond the 5-year projection that makes up the annual budget request. This provides a level of stability far greater than other acquisition programs where the hardware's projected end-of-life is known from the beginning.

Achieving and Sustaining Success

To be successful, an LLC acquisition program must strike an appropriate balance between two broad goals: operational utility and repeatability. Because an LLC operates as a system-of-systems, in that each satellite node is only as effective as its integration in the

[2] Proponents of the DoD's increased use of LLCs, and proliferated systems generally, argue that in addition to other benefits, these systems are more resilient against certain types of threats. For example, a recent report found that proliferated constellations "directly and significantly undermine the (People's Liberation Army's) preferred method of conducting operations" by reducing the number of critical nodes that can be targeted in a precision strike (Wang et al., 2025).

broader network, it must measure its performance differently than other space acquisition programs. An LLC acquisition program demonstrates operational utility by proving that its technologies work individually and collectively as intended to provide capabilities that support warfighting missions. An LLC acquisition program demonstrates that it is repeatable by, among other things, effectively controlling cost, accessing or supporting a robust and resilient industrial base, and allowing for technology insertion.

Operational Utility

Prototyping is central to the DoD's plan for demonstrating progress toward and achieving operational utility for LLCs. The DoD's 2022 *Prototyping Guidebook* defines a prototype as "a model (e.g., physical, digital, conceptual, and analytical) build to evaluate and inform its feasibility or usefulness." Because of the limited utility of a single satellite within an LLC, the measurement of operational utility must primarily occur at the network, or system-of-systems, level. Therefore, a prototype system must field a sufficient number and diversity of satellites to "evaluate and inform" options about the future operational constellation. This adds complexity to prototyping efforts, since acquisition program offices will need to establish system-level performance goals to evaluate the prototype's success. This is also consistent with prior research showing that identifying and resolving conflicting definitions of success is a key challenge for prototyping efforts (Seraphin et al., 2025).

For its primary acquisitions, the SDA has utilized the MTA rapid prototyping pathway to streamline acquisition processes and help deliver capabilities more quickly. As of March 2025, SDA has 27 prototype satellites on orbit made by several different vendors. Together, these satellites composing the agency's Tranche 0 efforts, which are intended to "demonstrate the feasibility of a proliferated architecture in cost, schedule, and scalability toward necessary performance" (Space Development Agency, n.d.). SDA leadership recently stated that they continue to test and learn from Tranche 0 as they prepare to launch the next round of satellite, Tranche 1, later this year (Hadley, 2025).

Although system-level performance is the key metric, testing and verifying an individual satellite's functionality remains a vital part of the acquisition process for LLCs. While proliferated satellites require many of the same kinds of components as traditional satellites, there are important differences, mainly due to the need for LLCs to rapidly, flexibly, and efficiently pass large volumes of data across different nodes. For example, optical communications terminals (OCT) are a key component for many LLCs that enable rapid, secure space-to-space and space-to-ground communications. Instead of using radiofrequency communications, OCTs transmit and receive in the infrared spectrum and are a low size, weight, and power option capable of much higher data rates. However, because the DoD has not previously deployed this technology at scale, it has been a challenge for SDA and its vendors to obtain a sufficient number of reliable OCTs, demonstrate technology interoperability through ground testing, and verify the full range of required capabilities (GAO, 2025). Other important technologies include software algorithms and on-board computer processing so that the constellation is able to perform more of its tasking without sending data back to a ground station.

While SDA is likely to use the MTA rapid prototyping pathway for future acquisition programs, recent legislative changes have granted increased flexibility for how MTAs are executed. Specifically, the National Defense Authorization Act for Fiscal Year 2025 included a provision that allows for "continuous iterative prototyping and fielding under the same program or project for an unlimited number of subsequent periods, where each period is intended to be five years" (National Defense Authorization Act, 2024). Prior to this change, each rapid prototyping or fielding effort had to be executed as a standalone acquisition program. It remains to be seen whether and how acquisition programs will use this new authority for national

security space acquisitions, including LLCs; however, it could greatly help reduce administrative burden when transitioning from one effort to the next.

Repeatability

Whereas most acquisition programs are evaluated primarily by the degree to which they meet cost, schedule, and performance goals, repeatability is another valuable metric for evaluating LLC's success. The initial acquisition program or programs that deliver the operational system must be followed by future rounds of development, production, and fielding to sustain the constellation and its capabilities. Here again, the overall system is the appropriate unit of measurement, and assessments of an acquisition program's repeatability provide insight as to whether the system's operational utility can be sustained.

There are several different ways to evaluate whether an acquisition program is repeatable, but three specific ways deserve special attention: affordability, industrial base capacity and capability, and mechanisms for technology insertion.

Affordability. Controlling LLC's unit cost is critical for acquisition success. Because of the large satellite quantities involved and the need to periodically replenish the constellation, unit cost increases can quickly add up to a significant amount. In addition to increasing budgetary pressures, these cost increases could also erode the program's support within the DoD and Congress. Program offices can help control costs by leveraging commercial capabilities that require little to no additional development work or modifications to meet government requirements. They may also use fixed price contracts to limit the government's financial risk on any cost overruns, as the Space Force has increasingly prioritized over the past several years.

Industrial base capacity and capability. The capacity and capability of the space industrial base are vital to the long-term success of LLC acquisitions. Vendors must be both willing to pursue and able to execute government contracts. SDA has been successful in developing a diverse and large number of vendors that are competing for and winning its contracts. However, the rapid transition to LLCs has revealed some signs of stress within the space industrial base, including delays, missed deliveries, and quality issues (Berglund, 2024b). Some of these challenges are likely to be resolved as the government's LLC efforts mature and more satellites are successfully fielded, but continued assessments of the space industrial base and supply chains are needed. On short acquisition timelines, even small delays can have a significant operational impact.

Mechanisms for technology insertion. An LLC that fails to provide opportunities for technology insertion and refresh will fail to keep pace with innovation and threats. In the context of weapon system acquisitions and repeatability, this idea is somewhat counterintuitive. Technology development is typically the highest risk component of any acquisition program, and keeping requirements stable has long been identified as important to successful acquisition outcomes (Anton et al., 2020). However, an LLC cannot be successful over the long-term if it fails to take advantage of the predictable cycle of satellite replenishment with improved hardware. This process can and should be done incrementally, avoiding the temptation to take large technology leaps between satellite generations. Recognizing this, the SDA has outlined some of its capability goals as part of a "technology roadmap," providing an important signal of the agency's long-term plans to drive technology development within industry (Berglund, 2024a, p. 10).

Scaling Manufacturing and Building Resilient Supply Chains

There is a critical scaling challenge for the space industrial base to overcome in meeting the DoD's needs for LLCs. The shift from low- to high-volume production of satellites not only

increases the number of components, subcomponents, and parts required, it also necessitates a fundamentally different approach to manufacturing. For national security space acquisitions, low-volume satellite production—often 0–10 units—utilizes customized, labor-intensive manufacturing techniques often performed by specialized personnel. In contrast, high-volume satellite production—50–100 units or more—borrows principles from the automobile, commercial airplane, and consumer electronics industries to rapidly and efficiently manufacture satellites that relies more on processes than personnel to achieve quality and consistency.[3]

Companies that are able to reach and sustain high-volume production will have a sizeable advantage over companies that are unable to do so. This advantage may be particularly important for LLCs, in that vendors that are able to secure a significant portion of the early acquisition efforts will be able to reinvest their profits into capital improvements. These improvements will further reduce manufacturing costs and increase efficiencies, strengthening their competitiveness for future awards, either for a comparable government or commercial LLC.

The size and composition of the DoD's future space architecture will help shape the number and diversity of satellite manufacturers that are able to compete for future LLC acquisition programs. To promote efficiency, rapid delivery, and lower costs, the government can encourage companies to design and implement high-volume production by designing LLC acquisition programs have include production quantities greater than 50 satellites. This is still applicable if the acquisition program's total quantities are divided amongst several vendors, as the SDA has typically done. For example, a total quantity demand of 250 satellites could be split among two to five high-volume satellite manufacturers.

While high-volume production promotes efficiency and cost savings, there are other factors acquisition decision makers should consider. Most notably, promoting innovation and competition may require creating opportunities for vendors that have not yet fully developed or institutionalized high-volume production. When it was created, part of the SDA's initial tasking was to foster growth within the U.S. space industrial base, and the agency has consistently divided its contract awards amongst a diverse range of contractors is consistent goal. For the Space Force overall, balancing its commitment to fostering the growth of the space industrial base against greater efficiencies from more winner-take-all contract awards may become increasingly difficult. However, if this balance can be achieved, LLCs can be an important mechanism for the DoD to both deliver its operational capabilities and support the continued maturation of the space industrial base.

Strategies for Building Resilience Throughout the Space Industrial Base

There are several strategies the DoD and Space Force could pursue for LLC acquisition programs to balance high-volume production, and the benefits it provides, with innovation, including competition and opportunities for diverse vendors. Employing a mix of these strategies will help promote the overall resilience and dynamism of the space industrial base.

Create tiers of competition for potential vendors. Acquisition programs could intentionally carve out a portion of their production awards for newer, smaller vendors. This would provide access to companies that have demonstrated promising technologies but have not had access to prior contract awards, commercial opportunities, or private capital to scale their manufacturing processes. Vendors performing these awards would then be able to demonstrate increasing levels of manufacturing maturity as their production units increase.

[3] Prior research has identified roughly 100 units as the quantity that separates low- and high-volume production. Discussions with the authors of this research suggest that this is an estimate. Flow processing can be achieved with fewer units, roughly 50, but production benefits increase as quantities increase (Eccles et al., 2020).

Connect low-volume producers with scaling opportunities. Manufacturing scale is not the only challenge smaller vendors need to overcome, and the government should continue to engage with companies to promote early-stage technology development that may provide warfighting capabilities over the next 5–10 years or more. Service or department-wide opportunities exist: Small Business Innovation Research, Small Business Technology Transfer, Strategic Funding Increase, Tactical Funding Increase, the Office of Strategic Capital domestic manufacturing loans, and the Small Business Investment Company Critical Technologies Initiative. Some of these opportunities are explicitly designed to support scaling and commercialization. On the acquisition program side, SDA created the Hybrid Acquisition for Proliferated Earth Orbit to identify and support companies for prototyping and experimentation efforts that might support long-term needs (Space Development Agency, 2024). Connecting these efforts to LLCs, with sustained funding and long-term support, can help create a pipeline of innovation for warfighting capabilities.

Invest in diversity across tiers. Access to parts and components has been an acute supply chain challenge for the defense industrial base over the past decade, contributing to schedule delays for national security space acquisition programs (Berglund, 2024b). While some well-funded companies are able to take steps to insulate themselves from supply chain disruptions through vertical integration, many companies will not be able to make these investments prior to receiving customer orders. The DoD and Space Force can continue to make strategic investments in technologies and inputs, such as critical minerals, semiconductors, and solar cells. The government should also redouble its efforts to identify and take action to resolve weaknesses within its supply chain, particularly diminishing manufacturing sources and material shortages.

Facilitate hybrid space solutions. Efforts to increase the interoperability of government and commercial space systems can further enhance the DoD's capabilities as well as the resilience of the space industrial base. These hybrid solutions expand opportunities for nontraditional vendors to participate in national security missions, building trust between the vendor and the government that can facilitate future engagement. Moreover, just like LLCs overall, greater path diversity for sending and receiving information increases mission resilience. Because LLCs are structured at a system-of-systems level and many commercial companies operate assets in LEO, government LLCs are well-positioned for this kind of approach. Recent government efforts to develop hybrid solutions include the Defense Innovation Unit's Hybrid Space Architecture program to develop networking and other backend services to facilitate hybrid communications transmissions. On the hardware side, the Defense Advanced Research Projects Agency (DARPA) is developing a reconfigurable OCT that would serve as a connection point between disparate constellations that would otherwise not be able to communicate (DARPA, n.d.).

Opportunities for Commercial Services

One possibility that could further upend the future of space system acquisition is that the DoD increasingly adopts a more service-based model for national security space capabilities that have previously been considered primarily within the purview of government systems. The DoD's 2024 *Commercial Space Integration Strategy* identifies 13 mission areas for national security space, including environmental monitoring, missile warning, nuclear detonation detection, and satellite communications (p. 5). The strategy organizes each of these missions under one of three categories based on whether the responsibility for executing the mission relies primarily on the government or the commercial sector: government primary mission areas,

hybrid mission areas, and commercial primary mission areas.[4] In the coming years, as commercial space services expand, the DoD could decide to place more missions in the "commercial primary" category.

Signs of this shift are already visible, as the DoD and Space Force officials have repeatedly stated their interest in integrating commercial companies and procuring commercial space services (Erwin, 2025). This rhetoric has been matched by action. In late 2024, the DoD raised the ceiling on its proliferated LEO Satellite-Based Services program from $900 million to roughly $13 billion (Luckenbaugh, 2024). The success of this program, and the continued challenge to meet aggressive cost and schedule targets for national security space acquisition programs, could create further momentum for commercial space services. However, some government missions are likely to remain specialized enough that the government will continue to lead, particularly in areas that lack a clear commercial corollary.

Conclusion

The DoD's efforts to proliferate its space architecture and harness commercial space innovations will be two of the dominant trends in national security space over the next decade. These goals immense promise to improve space warfighting capabilities as well as improve acquisition outcomes. However, they also challenge existing processes and approaches. To be successful, the space acquisition community will need to adapt its approach to things like prototyping and manufacturing, while also finding new ways to promote competition and innovation. Finally, the extent to which the DoD demonstrates its commitment to pursuing proliferation and utilizing commercial space capabilities will help spur industry to continue developing the space warfighting capabilities that the United States needs.

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[4] Government primary mission areas are those where "a preponderance of functions must be performed by the government, which include more traditional and sensitive national security capabilities, like missile warning and command and control. Commercial primary mission areas are those where companies "have demonstrated technological maturity and met the Department's requirements and capability needs for mission assurance," which include emerging missions like in-space servicing, assembly, and manufacturing (ISAM).

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