Vol. 52, July 2024

MITCHELL INSTITUTE
Policy Paper

Key Points

The U.S. Space Force (USSF) recognizes that to address Russian and Chinese offensive ambitions in space, it must gain and maintain space superiority. This is reflected in the tenets of its theory of Competitive Endurance.

Small satellites, or "SmallSats," can play a much larger role in realizing the goals of Competitive Endurance, but the USSF must be allocated the resources and authorities necessary to develop and field this new generation of capability.

Employing SmallSats affords the ability to rapidly reconstitute lost capabilities and field defensive measures such as camouflage, concealment, and deception (CCD). SmallSats can also greatly expand the fielding of sensors and host a range of defensive and offensive weapons.

The changes that SmallSats represent to satellite procurement and employment mean that the USSF must likewise shift its thinking about how it fields and operates its space architecture to establish space superiority in a future conflict in space.

The attributes of SmallSats means the USSF could scale up SmallSat procurement, continuing trends that reduce costs and increase employment flexibility as well as technology refresh rates. The Space Force should leverage these dynamics to expand SmallSat usage to meet requirments of each tenet of Competitive Endurance.

Small Satellites: Answering the Call for Space Superiority

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Abstract

Now is the time for the United States to fully leverage the unique attributes of small satellites, or "SmallSats," to achieve space superiority. Adversaries like China and Russia have developed counterspace weapons to target the fragile legacy U.S. space architecture originally designed to operate in an uncontested space domain. Likewise, adversary space-enabled kill chains pose an increasing threat to U.S. and allied air, land, and maritime forces around the world. Establishing space resiliency is not enough. The United States must have the tools to achieve space superiority and deliver on the tenets of Competitive Endurance—Avoid Operational Surprise, Deny First Mover Advantage, and Conduct Responsible Counterspace Campaigning. The combination of mature technologies, lower launch costs, and increasing threats create a fleeting window of opportunity for the United States to field an architecture with SmallSats to achieve the necessary capabilities to gain and maintain space superiority.

The Space Force, Congress, and the industrial base must adjust old paradigms built around large, legacy space systems with long and costly development timelines and move toward a hybrid approach that includes both SmallSats and large, exquisite satellite systems that balance mission requirements, resilience, and the ability to operate in a contested space domain. The Space Force must develop a supporting infrastructure of awareness and communication with the capacity to effectively command and control large numbers of SmallSats. Industry must adjust its supply chain and manufacturing capabilities to account for large-scale, modular, and rapid production. Finally, realizing this vision also demands adequate funding. Congress must resource the development and acquisition of SmallSats to meet the objectives of Competitive Endurance.

Failing to operationalize SmallSats will thwart the Space Force's mandate of achieving space superiority and undermine U.S. deterrence. Given the adversary threat and the critical role that space plays for the United States and its allies, this is a critical juncture the nation must navigate wisely.

"The need to gain and maintain space superiority over peer adversaries is the distinguishing characteristic of a transformed Space Force and it is a top priority."

-Department of the Air Force Posture Statement of Secretary Kendall, General Saltzman, and General Allvin

Introduction

Russian and Chinese offensive spacepower ambitions are making headlines and are intent on erasing the vital advantage the United States has in space. U.S. defense leadership now publicly recognizes the need to gain and maintain space superiority—an essential change given the current threat environment and the incredible pace at which our adversaries are advancing their space capabilities.

To achieve the needed level of space superiority, the Department of Defense (DOD) and Congress must empower the United States Space Force (USSF) with the resources and authorities necessary to realize the full potential of small satellites, or "SmallSats." This means looking beyond proliferating large numbers of SmallSats to increase space architecture resilience to "deny a first-mover advantage." While this objective remains valid, achieving space superiority requires harnessing the potential of SmallSats in multiple ways.

Building a new hybrid architecture with SmallSats, anchored in the tenets of Competitive Endurance, will increase operational flexibility, deliver enhanced capabilities, and increase mission capacity to ensure a continued space advantage for the United States and our allies. SmallSats can improve domain awareness to "avoid operational surprise" because they can rapidly launch and broadly proliferate a variety of sensors. These sensors can be positioned to monitor emerging situations. These systems are also ideal for "responsible counterspace campaigning," given that SmallSats can host a range of kinetic and non-kinetic capabilities to defend friendly space assets and deny an adversary the ability to use space to defeat our air, land, and maritime forces. SmallSats can create these desired effects in ways legacy systems cannot, which is why the increased adoption of SmallSats will need to be a key element in our future architecture—one that empowers the Space Force to evolve at the pace, scale, and scope necessary to maintain space superiority and achieve the objectives of Competitive Endurance. With the understanding that our adversaries are pressing hard to contest space, this is a "must-do," not a "nice-to-do."

Space superiority is the ability to operate in space to achieve strategic and operational effects while denying similar use by adversaries.

Competitive Endurance is the USSF's theory of success to protect U.S. interests in space in "a manner that preserves the safety, security, stability, and long-term sustainability of the domain." It has three tenets:

- avoid operational surprise
- deny first-mover advantage
- undertake responsible counterspace campaigning

Source: White Paper on Competitive Endurance

Small Satellites, or SmallSats, are classes of spacecraft of 1,200 kg or less and a foundational element the USSF needs for space superiority.

A Necessary Response to the Growing Threat

The United States now finds itself in an era of sustained competition facing determined adversaries, especially China and Russia. These adversaries are developing new weapons to exploit the vulnerability of the legacy U.S. space architecture The U.S. architecture was simply not designed for warfighting in space, with satellites and associated systems optimized for performance and longevity in an uncontested domain. As former Vice Chairman of the Joint Chiefs General John Hyten famously articulated, the United States needs to stop buying "big, fat, juicy targets."[1] More recently, the Chief of Space Operations (CSO), General Saltzman, compared legacy capabilities to unarmed merchant marine vessels now being asked to become battleships.[2] The point is clear: the Space Force must field defensive capabilities to defend exquisite satellites and improve the overall architectural resilience. However, these changes take time, especially if the Space Force is constrained to old processes and has inadequate funding.

Part of this evolution demands a modernized set of capabilities that deliver essential mission effects, but they must also be combat-ready to better deter future conflicts, control escalation, and prevail if overt hostilities erupt in space. The recent revelation that Russia is pursuing a new anti-satellite (ASAT) system is just the latest in an increasing list of weapons targeting U.S. space systems. The proliferation of these threats in the past two decades highlights the efforts adversaries like Russia and China are taking to counter the U.S. advantage in space.[3] The risk of the growing number of systems extends to how these nations could use space to target our fielded forces in the air, at sea, and on the ground to disrupt joint and coalition operations. In the past two years, China has placed over 200 surveillance and reconnaissance satellites in orbit. As Maj Gen Gregory Gagnon, the lead Space Force intelligence officer stated, "the (PLAs) breakout pace in space is profound."[4]

The United States must not only respond directly to these threats but also develop innovative technologies and operating concepts to outpace our adversaries. The Space Force's theory of success, known as Competitive Endurance, achieves this by crystalizing a strategy to control escalation and, if needed, prevail in conflict in space. While space superiority and Competitive Endurance are not synonymous, the actions and capabilities needed to achieve each are similar—the key distinction between the two is whether the situation is considered competition or conflict. In either case, SmallSats must play an important role in the U.S. theory of victory. Deterring conflict, especially one extending to space, is central to the posture of the United States. Making clear to adversaries that the USSF can and will achieve space superiority is central to keeping competition from escalating.

The Competitive Endurance tenet to "deny first-mover advantage" centers around the need to change the legacy U.S. space architecture to one that is more resilient and, therefore, a less attractive target. The Space Force is currently making great strides to improve the resilience of its space architecture. The most discussed approach is the use of a large constellation of lower-cost SmallSats in low Earth orbit (LEO)—what the Space Development Agency has coined the Proliferated Warfighting Space Architecture (PWSA).[5] By increasing the number of satellites, the impact of losing one or two to attack is greatly diminished.

In this way, SmallSats are already driving a change in thinking about the U.S. space architecture and have significantly advanced related technologies and operations. As the technology continues to mature, these small platforms will be increasingly capable of an even wider variety of missions and at cost points once unimaginable. Additional adoption of SmallSats will enable:

- Advanced mission assurance measures, such as the ability to rapidly reconstitute lost capabilities, and the inclusion of defensive measures, such as camouflage, concealment, and deception (CCD).

- Expanded sensor fielding to widely dispersed or critical locations to improve domain awareness and thereby help to "avoid operational surprise."

- Hosting a range of defensive and offensive weapons aboard SmallSats to "conduct responsible counterspace campaigning."

Cultivating Future SmallSats

While the potential for SmallSats is robust, fully realizing this vision demands elements of change within the Space Force, Congress, and the industrial base. Some of these changes are already underway, such as improving space domain awareness and satellite command and control. Others represent a seismic shift in thinking about space acquisitions and operations from decades-old norms. For example, production rates for SmallSats can be on the scale of hundreds or thousands of space vehicles rather than increments of less than a dozen. This will drive new requirements for how Congress must fund and maintain oversight of space programs, as well as how the Space Force will manage them. The mass production of SmallSats will similarly force changes in how the defense industry manages supply chains and production.

Additionally, the lower cost of SmallSats compared to large, legacy monolithic systems means that a whole family of satellites and associated capabilities is possible within a single program line. This increases acquisition and operational flexibility over traditional approaches and limits disruptions caused by delayed Congressional Budget approvals. Rapid development timelines also mean greater requirements stability because new requirements can be addressed in future iterations that are being fielded in months, not years.

Achieving this SmallSat vision requires the Space Force, Congress, and the industrial base to adjust old paradigms tied to legacy space capabilities and evolve their processes to better meet today's requirements through the following steps:

- Grow funding related to Competitive Endurance to meet requirements in alignment with growing threats.

- Support the industrial base in ramping up SmallSat production, with special attention paid to supply chain investment and production streamlining required for large-scale procurement.

- Continue to develop and scale space launch options to improve affordability and frequency.

- Develop and adopt tactics, techniques, and procedures (TTPs) for SmallSats associated with their operating requirements. These are unique and distinct from operations optimized for legacy systems that accomplished fewer missions with less risk. These TTPs may include new technologies, such as artificial intelligence and machine learning (AI/ML), to support pattern recognition and rapid response options.

- Increase cyber security and sensing capabilities for greater resiliency and situational awareness.

- Prioritize architecture sustainability and make management, disposal, and reconstitution part of the strategy for the U.S. space architecture.

SmallSats can continue to transform how the United States looks at space, and the revolutionary changes they represent are exactly what the Space Force needs to stay ahead of rapidly evolving threats and achieve space superiority. Failing to implement these reforms will see the Space Force, Congress, and the industrial base struggle to match what our Guardians and the broader joint force require to achieve their mission results in an era where the adversaries are rapidly changing what it takes to deter and, if necessary, fight and win in space.

Figure 1: The first United States satellite, Explorer 1, being mated to the launch vehicle in 1958.

Source: NASA/JPL-Caltech

Before Great Power Competition: Cold War to Regional Conflicts

From the birth of the Space Age, SmallSats have played a critical role. The very first satellites were SmallSats.[6] Over the past 65 years, SmallSats remained the platform of choice for scientific payloads, experiments, and even some demonstrations and prototypes. Still, few SmallSats transitioned to become fielded operational capabilities. Instead, much larger satellites with increased capabilities and higher levels of redundancy and reliability performed operational missions.

Until recently, space was primarily populated by these large satellites operating in a relatively uncontested domain. The Cold War context of the First Space Age (1957–1989) placed an emphasis on space assets to support strategic nuclear weapons decision-making. This involved missions like nuclear command, control, and communications (NC3) and the ability to monitor Soviet nuclear activities through intelligence and missile warning satellites. Given that global stability hinged on the ability to maintain these systems in the event of an adversary nuclear attack, many of these satellites were hardened against nuclear radiation effects.

During this period, low-risk tolerance drove requirements for high reliability, which, in turn, drove up costs and development timelines. Compounding the condition was the cost of launch, which itself required a high level of reliability to assure the successful delivery of a few exquisite satellites to their orbits. Each major satellite was a massive systems-of-systems enterprise that could tolerate little-to-no risk. Schedules and budgets reflected this. Consider the Milstar 2 NC3 communications satellite, which weighed 10,000 lbs and cost $800 million. The size of this satellite required a $433 million Titan IV rocket to get it into orbit.[7]

The self-compounding cycle of cost and development time growth resulted in slow technology refresh for systems and

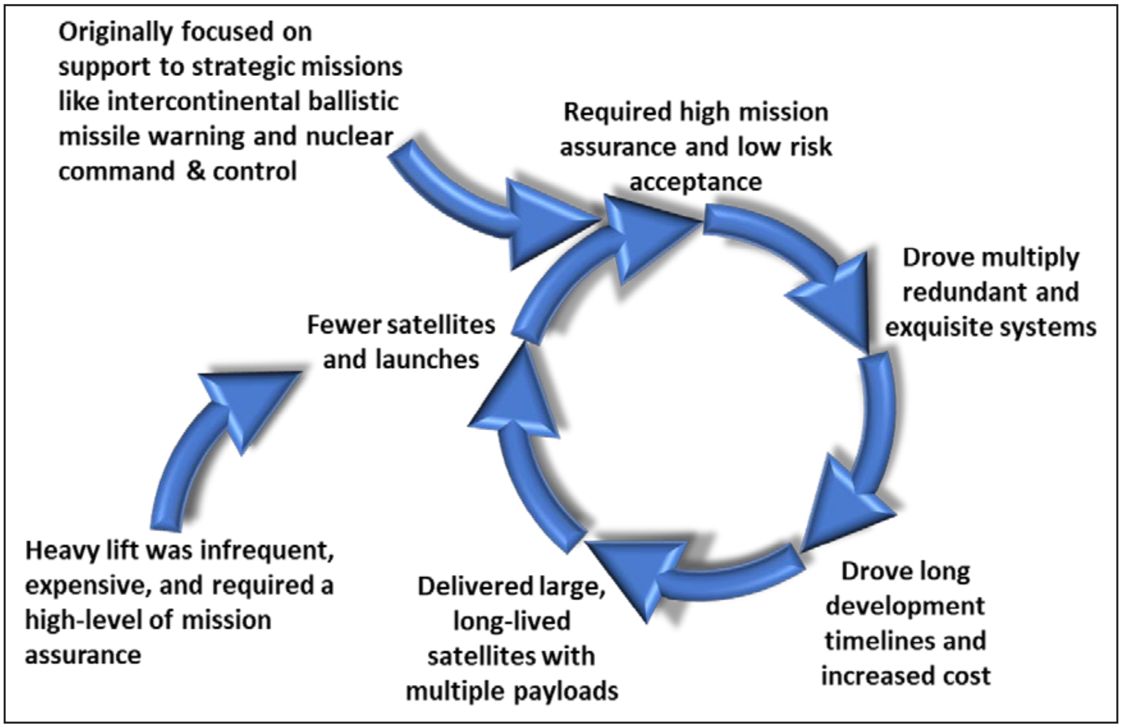

Figure 2: Cycle of factors common in legacy National Security Space Satellite Development.

Source: Mitchell Institute

missions. The integration of capabilities into the final satellite could take years, meaning that by the time a satellite launched, some of its payloads were no longer at the cutting edge of technology. The high level of built-in assurance also meant a satellite would survive well past its design life, which is useful in some regards and has frankly helped bridge capability and capacity gaps in key areas. But, it has also yielded a paradigm where outdated technology shaped the scale and scope of operations much longer than envisioned.

These trends generally continued during the Second Space Age (1990–2017), when the U.S. military emphasized using space to integrate and enhance joint operations.[8] After the end of the Cold War, the use of space capabilities to enhance conventional warfighting, exemplified during Operation Desert Storm, led to an undeniable asymmetric advantage that continues to shape modern warfare. This conventional employment of space systems marked the start of the second space age. The Global Positioning System (GPS) enabled navigation across featureless terrain, and satellites provided theater missile warning, weather forecasting advantages to aid mission planning, and satellite communications connecting joint operations. Further conventional mission growth continued to expand in subsequent years.

It is important to highlight that these highly engineered, very capable, and extremely reliable satellites proved indispensable in the Cold War and across multiple operations in the following decades, with many still in service today. They fostered a revolution in military thinking. Consider the game-changing factors tied to precision strike, enabled by laser and GPS guided munitions, which enabled U.S. and allied combat aircraft to attack multiple targets per sortie rather than needing to generate multiple sorties to attack a single target. This put fewer Airmen in harm's way and decreased the time to achieve the desired effect.

The Defense Meteorological Satellite Program (DMSP)

The Defense Meteorological Satellite Program (DMSP) is an example of a single satellite hosting multiple payloads to support a single mission. The final satellite, DMSP-20, cost over $500M, including storage and refurbishment. Congress canceled it and its $120M launch system in 2016. Efforts to establish a consolidated weather follow-on program failed. The Space Force is now pursuing a disaggregated approach to the weather mission using SmallSats, including Electro-Optical/Infrared Weather System (EWS) and Weather System Follow-on—Microwave (WSF-M). The unlaunched DMSP-20 now resides at the Space Systems Command Headquarters in Los Angeles, CA.

Sources: "New U.S. Military Weather Satellites Could Launch on Minotaur Rockets"; and *Winds of Change: Environmental Monitoring for an Era of Peer Competition*.

Image: Then-Secretary of the Air Force Heather Wilson and Lt Gen John Thompson, then-commander of the Space and Missile Systems Center and Program Executive Officer for Space in front of a decommissioned DMSP 20 satellite in 2017. U.S. Air Force photo/Sarah Corrice

Unfortunately, while U.S. military reliance on the space enterprise grew, leaders largely disregarded warning indicators regarding adversary intent to contest the domain. This was compounded by the U.S. shift in its strategic priorities during the Global War on Terror. To that point, consider that the 2001 Congressionally mandated Space Commission Report warned of the growing risk of a space Pearl Harbor-type attack. Its recommendations included improving satellite survivability, organizational consolidation, and budgetary alignment, but they were largely ignored by multiple administrations. They look prescient when viewed in the present context. What cannot be regained is the two decades of time lost to adjust our architecture. This intensifies the need for concerted reforms now.

By contrast, China has spent the past three decades preparing for a potential conflict with the United States—a contest that would extend to or even start in space. Russia has also made similar moves and has employed some of these techniques in its invasion of Ukraine. Key to the Chinese and Russian plans are their efforts to counter U.S. space-enabled precision strike kill chains, which are highly reliant upon a handful of exquisite on-orbit systems.[9] This approach is a central tenet of China's concept of "informationized warfare."[10] Peoples Liberation Army (PLA) doctrine stipulates that holding U.S. assets on-orbit at risk, especially those tied to command and control.[11] The goal is to render U.S. and allied fielded forces deaf, blind, and fractured without the connectivity from U.S. space assets. That is largely what China was signaling in 2007 when they tested a direct ascent anti-satellite weapon.[12] However, U.S. policy positions did little to address the growing threats to its space dependencies. As a result, the momentum of existing space acquisition efforts continued to field large systems designed for an uncontested domain, relegating SmallSats to scientific and experimental missions.

Satellites for Great Power Competition

More recent shifts, primarily the recognition that space is a warfighting domain, advancements in satellite technology, and the simultaneous reduction in launch cost and increase in launch tempo make fielding SmallSats more desirable and practical. Leaders recognize that the United States needs to ensure its edge in space against a rapidly growing threat. That is largely why it stood up the Space Force and U.S. Space Command. A driving component that underpinned this shift involved a growing understanding that space superiority was an increasingly vital condition that must be deliberately secured and maintained—just as we work to maintain access to the other domains on Earth through missions like air superiority. As former Strategic Command Commander General Kevin Chilton explained:

> *It is unimaginable that we would intentionally fail to equip and train our Air Force, Army, and naval forces with the authorities and tools necessary to gain and maintain superiority in the air, land, and maritime domains. Deterrence is built upon credible power to act offensively and defensively—to threaten an adversary with unacceptable cost or denial of objective. Our first goal should be to deter adversaries from attacking our critical space assets.*[13]

The challenges involved with this paradigm shift are distinct, especially given that China and Russia have both worked to challenge the space domain years before the United States woke up to the changing nature of the threat. The good news for the USSF is that options exist to rapidly adjust and evolve space capabilities in alignment with the threat and mission imperatives. To that end, the service must recognize and embrace the full potential of a new generation of SmallSats. Enabled by advancements in computing power and falling launch costs, which have significantly lowered the barriers to entry, SmallSats are now viable operational platforms. Many new market entrants and traditional companies are already demonstrating innovative capabilities and cost-effective employment strategies for SmallSats, delivering a broad range of services, including remote sensing, communication, navigation, terrestrial environmental monitoring, missile tracking, and domain awareness. The industry should also be unleashed, in terms of policy, to develop offensive and defensive capabilities to gain and maintain space superiority.

Increasing Threats

The imperative for action is clear. China and Russia are undeterred by a lack of U.S. space superiority capabilities and emboldened by the fragility of the legacy U.S. space architecture. Both are fielding multiple kinetic and non-kinetic ASAT weapons.[14] Kinetic weapons that can destroy satellites and cause long-lived debris are particularly problematic, posing serious risks to other satellites and spacecraft. In fact, China's 2007 ASAT missile launch test created more than 3,000 pieces of space debris, most of which persists and will remain in orbit for decades.[15] These ground-based ASAT missiles are most likely intended to strike targets in LEO, but another 2013 Chinese launch of an object to 30,000 km means that China could potentially reach satellites as far away as geosynchronous orbit (GEO). That is where many exquisite legacy U.S. satellite systems orbit—including its early warning and communication satellites.[16] China continues to pursue a kinetic ASAT weapons capability.[17]

Russia has similarly accelerated its counterspace programs and advanced both its direct ascent and co-orbital ASAT capabilities. For example, in 2019, Russia deployed a "nesting doll" satellite to shadow a sensitive U.S. national security satellite.

The concern, aside from its ability to track and monitor the U.S. asset, was that such a capability could intentionally collide with a U.S. satellite to create a kinetic kill.[18] On November 15, 2021, Russia also shot down its Cosmos 1408 satellite in LEO using a direct ascent ASAT, which created more than 1,500 pieces of space debris.[19] In February 2024, it was revealed that Russia is developing a nuclear ASAT, presumably meant to target the growing U.S. proliferated LEO satellite architecture. Furthermore, in April, Russia vetoed a U.N. resolution calling for member states to uphold the Outer Space Treaty's prohibition against orbital nuclear weapons, creating greater tension amid their ongoing war in Europe and raising concern for a nuclear ASAT.[20] As Dr. John Plumb, former Assistant Secretary of Defense for Space, testified in May 2024, a nuclear weapon in space is "an indiscriminate weapon; doesn't have national boundaries; [and] doesn't determine between military satellites, civilian satellites, or commercial satellites."[21]

U.S. adversaries are also rapidly fielding non-kinetic anti-satellite weapons, including lasers, jammers, and cyber-weapons, that can temporarily or permanently disable satellites without physically damaging them. Since the early 2000s, the PLA has fielded at least two ground-based lasers at two sites, Korla and Bohu, that are capable of temporarily blinding or permanently disabling satellites.[22] In 2006, the PLA deliberately lazed a U.S. National Reconnaissance Office (NRO) satellite, which U.S. officials characterized as a "test."[23] The development of a wide array of downlink and uplink satellite jamming has likewise been "tested;" Russia has conducted widespread localized downlink jamming of Starlink satellites in Ukraine, and Russia's Tirada-2 mobile EW system can reportedly conduct uplink jamming of communications satellites that could potentially cause permanent damage.[24] Cyber-attacks represent perhaps the most serious non-kinetic form of attack against space systems. For this reason, as Dr. Tournear of the Space Development Agency noted, cyber-attacks can serve as a "common mode of failure" for an entire satellite constellation, whether that constellation is proliferated or not.[25] Combined, these threats underscore the need to alter the space operations paradigm to a more resilient and flexible architecture with increased capabilities and capacity to respond.

Increasing Opportunities

As threats grow, so do the means to counter them. Advancements in manufacturing and computer processing power, lower launch costs, and a booming space industrial base now make building a resilient architecture with SmallSats technically and economically feasible.New space capabilities can now accelerate development, testing, and fielding at unprecedented rates. This allows for rapid advancements and upgrades on-orbit.

To better understand how SmallSats can support Competitive Endurance and space superiority, it is helpful to understand what a SmallSat is and what advantages it can offer. SmallSats are classes of spacecraft that are significantly smaller and lighter than traditional satellites. This seemingly simple definition belies the full spectrum of capabilities they offer. For example, most SmallSats typically weigh around 100–200 kg, though very light (less than 1 kg) and very heavy (600–1,200 kg) SmallSats do exist. SmallSats can range in size from as small as a credit card to as large as a standard refrigerator.[26] Traditional defense satellites like the Space-Based Infrared System (SBIRS) missile warning satellites or Milstar communication satellites were often the size of a school bus and could weigh 2,500 kg or more.[27] The difference in size alone has fundamental correlations to easier production and lower costs.[28]

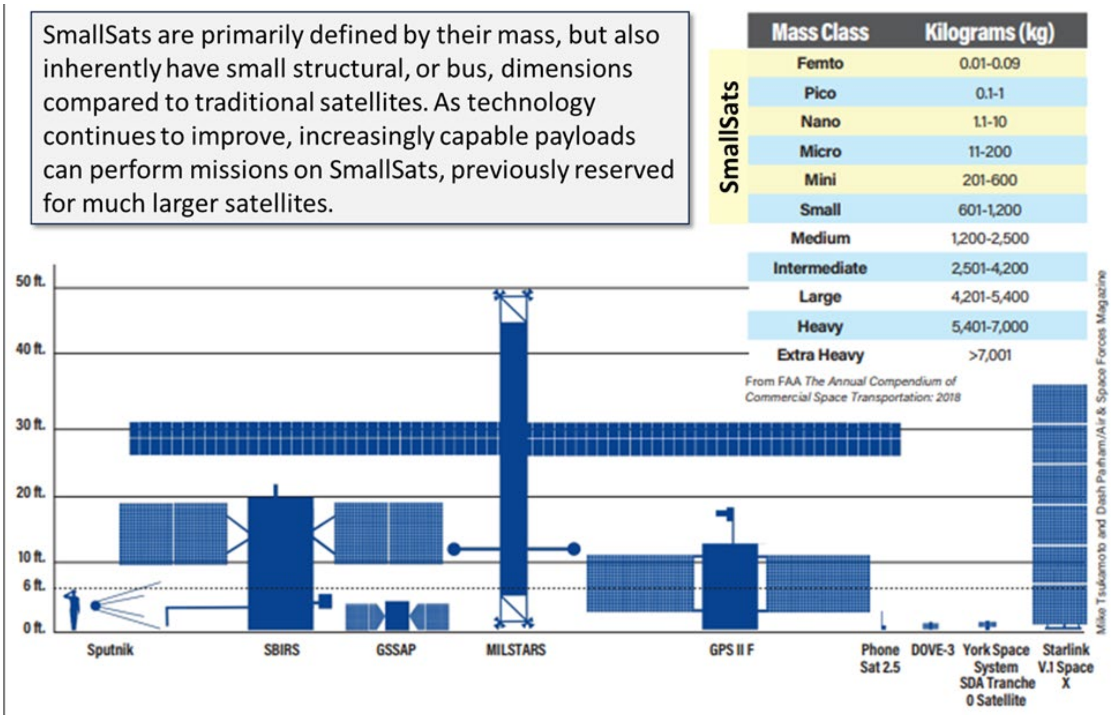

Figure 3: Relative size of SmallSats to traditional satellites.

Source: Mitchell Institute and Air & Space Forces Magazine

Standardizing SmallSats

Many SmallSats also follow standardized form factors (i.e., size and shape) that enable rapid assembly and simplify the launch and deployment process. Designing satellites to a common form factor reduces the barriers to entry, making SmallSats faster and more cost-effective to build. As SmallSat technology continues to evolve, these standardized form factors will be increasingly capable of performing critical operational missions.

The first widespread form factor enabling SmallSat mass production was CubeSats, which adhere to a standardized size and shape, using "units" that measure 10 cm on each side. A single unit, or 1U CubeSat, only weighs about 1–1.5 kg (2–2.5 lbs). This standardized form factor and the subsequent development of the Poly-Picosatellite Orbital Deployer (P-POD), which could be easily mounted to launch vehicles, enabled the widespread deployment of CubeSats aboard launchers typically used to place larger, more traditional satellites in orbit.[29] As a result, since their introduction in 1998, over 4,000 CubeSats have been launched globally.[30] Additionally, the modularity of the cube form allowed satellite builders to construct satellites quickly and cheaply in a range of flexible design options, expanding from 1U to as large as 27U.[31] This revolutionized key segments of the space economy.

The Evolved Expendable Launch Vehicle (EELV), first launched in 2002, created another form of rideshare opportunity for SmallSats known as the EELV Secondary Payload Adaptor (ESPA).[32] The initial ESPA design has six ports around its perimeter that can each host up to 180 kg (396 lbs). Smaller satellites can also share an ESPA port in a half-ESPA configuration. These ESPA class satellite

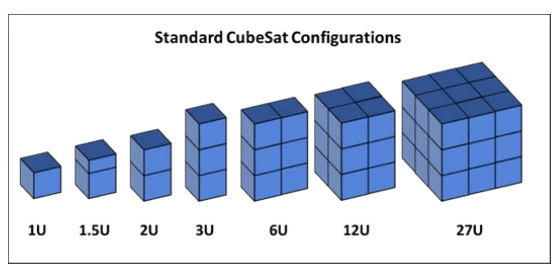

Figure 4: With several standardized CubeSat configurations a variety of users have gained access to space.

Source: Mitchell Institute and Air & Space Forces Magazine payloads have standardized specifications, which promotes easier integration and allows SmallSats to be designed and built independently from the primary satellite and the launch vehicle.[33] The first use of this approach was the Space Test Program's STP-1 mission in 2007, which placed six experimental satellites into two different orbits.[34]

The versatility of deployment and hosting options afforded by ESPA increase the flexibility of the Space Force's satellite operations. Payloads can remain attached to the ESPA receiving power, communication, and station keeping, or they can deploy from the ESPA as free-flying SmallSats. ESPA-class satellites or hosted payloads can stay in the vicinity of the primary payload or be placed in other orbits. There are also ESPA variants designed with additional propulsion capacity. Space Systems Command is continuing this approach under the Rapid On-Orbit Space Technology Evaluation Ring (ROOSTER) program at least through 2027.[35] Emerging launch providers are exploring similar approaches. Blue Origin's Blue Ring is a method of maneuvering satellites to their desired orbits, serving as a satellite bus and refueling station.[36]

The standardization enabled by a combination of CubeSats and ESPA-class satellites has expanded the adoption and launch opportunities for SmallSats. Standardized attributes and interfaces are just as critical to the rapid development and deployment of SmallSats as the lower manufacturing cost. They will also enable future integration into new mission areas as part of a hybrid architecture.

Cheaper launch & improving technology

Another key enabler that is empowering the growth of SmallSats is lower launch costs. Launch and satellite development costs began to decline significantly as the total number of launches and satellites on-orbit expanded in the early 2010s. In 2015, SpaceX achieved a game-changing milestone with its first successful vertical landing and recovery of a

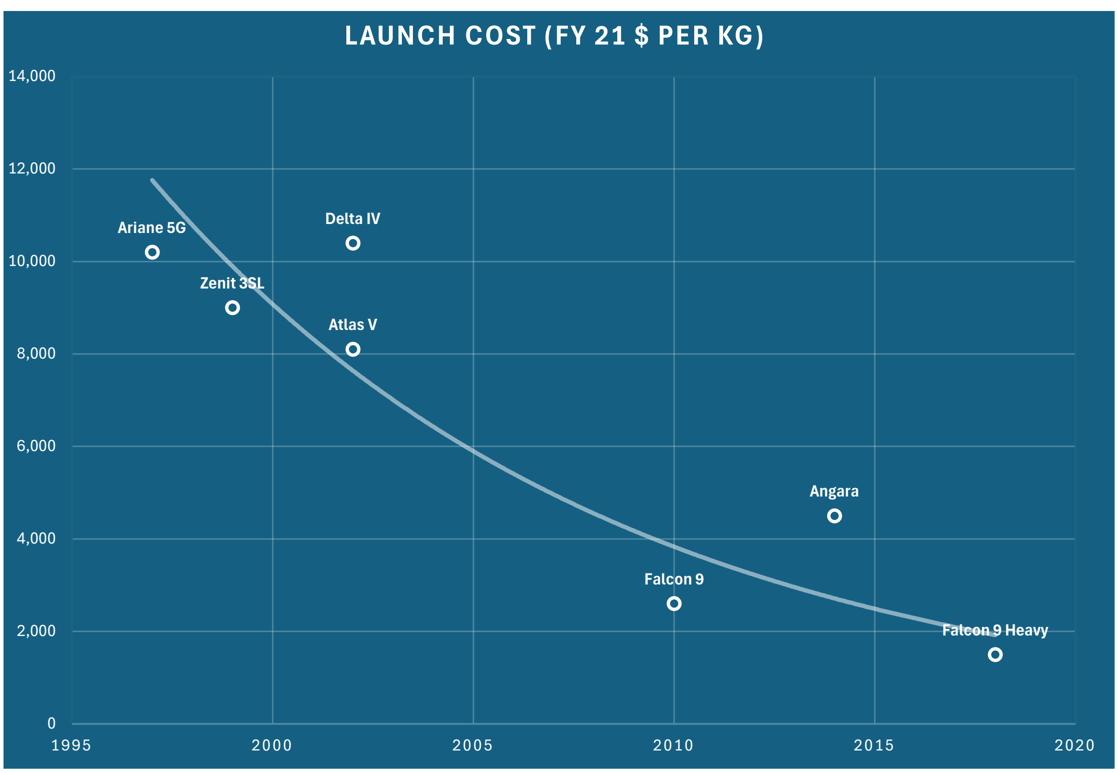

Figure 5: Decreasing Launch Costs over the past 20 years have enabled increased launch opportunity for SmallSats.

Source: Mitchell Institute

SpaceX's Starlink

By far the most common SmallSats currently in service are SpaceX's Starlink LEO communication satellites. Starlink satellites make up 56 percent of the SmallSats launched between 2014 and 2023, and have proven the feasibility of mass proliferated small satellite constellations.

However, the history of Starlink highlights the reoccurring temptation in satellite development to add increased mass and capability to satellites. The original Starlink V1.5 satellites weighed approximately 260 kg. The follow on Starlink V2 will provide 10x the bandwidth but is estimated to weigh 2,750–4,400 kg, making it so large that it cannot fit on the current generation of Falcon 9 rockets. This resulted in SpaceX developing a bridge solution, the Starlink V2 Mini satellite, until its larger Starship class rocket is operational. These "mini" satellites weigh 800 kg and boast four times the communication capacity as the earlier V1.5 model.

Sources: Bryce Tech, "Smallsats by the Numbers 2024," slide 18; and "SpaceX unveils first batch of larger upgraded Starlink satellites."

rocket's first-stage booster. As boosters make up a large percentage of launch costs, the ability to reuse the expensive engineering and manufactured product saves an enormous amount of time and resources, ultimately lowering the overall price per payload pound.[37] Today, Falcon 9 rockets can deliver payloads into LEO for approximately $1,200 a pound. By contrast, the Space Shuttle program retired in 2011 cost a staggering $30,000 per pound to launch payloads to LEO.[38] While SpaceX's Falcon Heavy and in-development super heavy rockets like SpaceX's Starship, ULA's Vulcan, and Blue Origin's New Glenn aim for massive lift at low cost, numerous other launch companies like Rocket Lab, Relativity, and Astra now compete to provide affordable, dedicated SmallSat launch on short notice. The positive impact of this development cannot be overstated—it changed what it means to access space. The fact that the United States is leading this change should be celebrated but not taken for granted. Continued stewardship is key to sustaining this advantage.

Lowering launch costs and thereby broadening access to space has spurred industry growth, enabling the development of large constellations of relatively small, affordable satellites. For instance, SpaceX has launched over 5,000 satellites for its Starlink broadband internet network, with plans for up to 42,000.[39] Planet's Earth observation constellation recently passed 200 satellites, while HawkEye 360 aims to operate a total of 60 satellites to geolocate radio frequency signals for signals intelligence.[40] These new capabilities, as part of mega-constellations providing global persistent coverage, are less complex than legacy systems due to reduced redundancy and a number of subsystems, allowing for shorter development and production timelines. Along with more frequent launches, this equates to an ability to rapidly integrate new technological advancements that were previously inconceivable and unobtainable. Lower launch and satellite manufacturing costs and faster development timelines mean SmallSats are practical and available.

The continued miniaturization and commercialization of enabling technology—ranging from satellite buses to microprocessors and sensors—are also delivering SmallSats that are more capable than ever before. As a result, the NRO has recently built entire payloads that weigh roughly the same as some legacy satellite components did only 10 to 15 years ago.[41] The significance for the U.S. national security space architecture is that SmallSats, either individually or as a constellation, can now match capabilities that required a bus-sized satellite a decade ago.

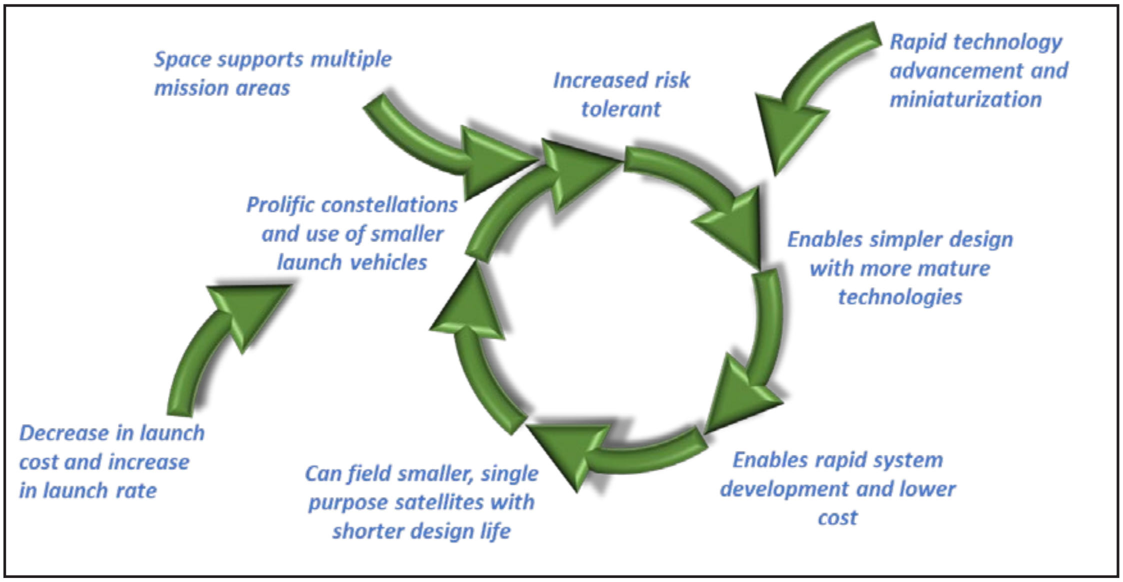

Figure 6: Representation of how reduced launch costs and SmallSats change the paradigm of satellite development.

Source: Mitchell Institute

Competitive Endurance, Space Superiority, & SmallSats

The opportunities introduced by SmallSats are not just optional extras but crucially important enablers to realizing Gen Saltzman's Competitive Endurance strategic approach. The goal of this theory of success is to bolster the ability of U.S. forces to deter offensive actions in space and, if necessary, enable U.S. space superiority during a conflict. The theory of Competitive Endurance encompasses three overarching core tenets: deny first-mover advantage, avoid operational surprise, and conduct responsible counterspace campaigning. SmallSats are already supporting a shift to increase the resilience of the USSF space architecture.

Deny First Mover Advantage. The legacy U.S. space architecture, with predictable orbits and a limited number of exquisite satellites, incentivizes hostile actors to take offensive actions in space preemptively.[42] Adversaries could land a knockout blow to our on-orbit assets that would yield an outsized impact against our air, land, and maritime forces. To alter this dynamic, the Space Force is actively adjusting its architecture to decrease the susceptibility to and consequences of attack.

Avoid Operational Surprise. This tenet reflects a core truth for all warfighters: domain awareness is key to both deterrence and effective operations. In other words, achieving better domain awareness is necessary for achieving space superiority.[43] Future military space operations in a contested environment will not be possible without improved awareness. This stands in contrast to legacy operations that rely more on programmed deconfliction and standardized orbits--management akin to civil air traffic control versus tracking combat flight activity in a contested air domain. More awareness means additional sensors to collect data in critical areas and the ability to rapidly process that data to deliver decision-quality information in operationally relevant timelines.

Conduct Responsible Counterspace Campaigning. First and foremost, by definition, the U.S. Space Force, as a warfighting service, must possess the ability to hold adversary space assets at risk and deny their ability to close a space-enabled kill chain against friendly forces. This holds true

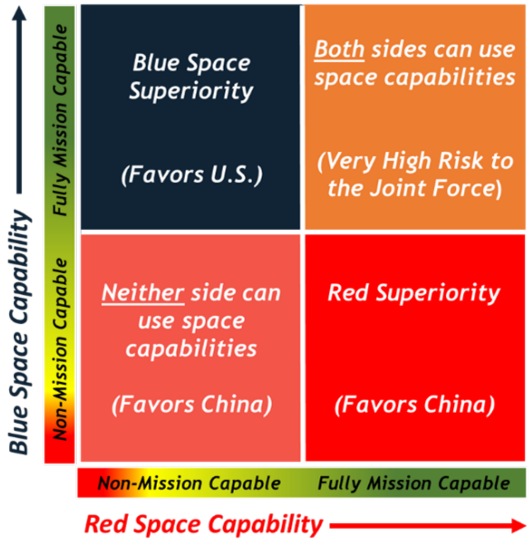

Figure 7: Chart from General Saltzman's remarks at Mitchell Institute's 2024 Spacepower Forum. Conditions of space parity between the United States and China favor China due to increased requirements of the United States to traverse and operate over extended distances. Only by maintaining space superiority can the United States hope to possess an advantage over China in a conflict.

Source: Office of CSO Gen Saltzman

in every other warfighting domain, and space is no exception. This tenet embodies the logic behind the creation of the Space Force as a separate military service—that space is now a warfighting domain and the space advantage the United States has enjoyed for decades is under threat. The Space Force must, therefore, have the means to conduct responsible counterspace campaigning.

The Space Force has expanded its discussion around Competitive Endurance to include gaining and maintaining space superiority—the ability to operate in space to achieve strategic and operational effects and deny similar use by adversaries. Gen Saltzman testified to Congress that achieving space superiority is "the linchpin" of successful U.S. deterrence, and he explained that "without it, we cannot provide vital effects, and without it we cannot protect the Joint Force."[44] Only when friendly forces can retain access to their full space capabilities during a conflict, and an adversary cannot, will the United States have the advantage it needs to win future wars. This is not just about space—all joint functions demand these capabilities. Convincing a potential adversary like China that the United States has the means to maintain space superiority in a conflict conveys a better posture to control escalation in a crisis and deter conflict in the first place.

SmallSats Today: Denying First Mover Advantage Through Proliferation

Today, the Space Force is making rapid progress in leveraging proliferated constellations of low Earth orbit SmallSat constellations to remove single points of failure and increase overall resiliency. The transition from large to small satellites shifts the risk-reward calculus in favor of defense by removing single points of failure and making it more costly for adversaries to degrade U.S. space capabilities. Instead of being able to shoot down a single "fat juicy target," adversaries would instead need to disable dozens to substantially degrade U.S. space capabilities. Director Tournear of the Space Development Agency noted that using cheaper small satellites means that "it will cost more to shoot down a single satellite than it will cost to build that single satellite. We just completely changed that value equation."[45]

The Space Force has already made substantial progress toward fielding a proliferated space architecture that is resilient against conventional ASAT threats. In February 2024, SDA completed Tranche 0 of its Proliferated Warfighting Space Architecture (PWSA), which included eight missile warning and nineteen data transport satellites. It is also on track to start deploying Tranche 1 by September 2024 and has already awarded contracts for Tranche 2 satellites.[46] Eventually, this architecture will comprise hundreds of satellites. Building on this initial progress is crucial to prepare the U.S. military for the new and more dangerous reality it faces in the space domain.

As a key illustration of this point, consider the Russian invasion of Ukraine. During initial hostilities in 2022, Russia conducted a sophisticated multi-pronged cyber-attack against Ukraine's primary satellite communications service provider, ViaSat. The attack rendered 40,000–45,000 modems useless across Europe and the Middle East.[47] In response, Ukraine requested access to the Starlink satellite communications network. Through active cyber defense of the agile network, Starlink satellites continue to provide communication services to the Ukrainian government and military. The constellation has also proved remarkably robust, resisting repeated Russian attacks using electronic warfare and cyber-attacks.[48]

SmallSats Tomorrow: Recommendations for Space Superiority & All Aspects of Competitive Endurance

Current SmallSat uses have primarily focused on denying first-mover advantage via proliferation in LEO. However, simply being able to absorb the first punch is not enough to achieve space superiority. There are further steps to take to harness their full potential in alignment with mission requirements and the threat. This is why the application of SmallSats to all three tenets of Competitive Endurance is vital. The Space Force and others are already demonstrating some of the potential benefits of SmallSats, but further adoption and operationalization of these capabilities will be essential to achieve space superiority.

Deny First Mover Advantage

Beyond proliferation, SmallSats can also make it much harder for an adversary to gain a first-mover advantage by using an array of tactics, including CCD, maneuver, and multi-orbit diversification. The combination of these tactics will complicate an adversary's understanding of U.S. space forces, degrade and delay their decision-making ability, and prevent them from accurately targeting elements of the U.S. space architecture.

Utilize camouflage, concealment, & deception techniques with SmallSats

SmallSats employing CCD tactics can help negate the first-mover advantage. The size of small satellites relative to large legacy models inherently makes them more difficult to find, fix, and track. Today, finding a satellite in orbit means locating the signature the satellite reflects or the signals the satellite emits, either optical or radar. Smaller objects simply have smaller optical and radar signatures. Using CCD tactics to further reduce these signatures or emit deceptive signals can make it even harder for adversaries to find, fix, track, and target SmallSats. Said another way, SmallSats add complexity for an adversary seeking to close a kill chain.

Some satellites have already begun to reduce their visible signatures. SpaceX, under pressure from astronomers to reduce Starlink's impact on ground-based astronomy that results from the thousands of additional dots populating the night sky, has already demonstrated the feasibility of reducing the visible signature of its small satellites. These methods include using a special "Low Reflectivity Black" paint, developed internally by SpaceX, on the complex geometries of satellite components and using darker materials on the solar panels to decrease their reflectivity. Additionally, SpaceX has employed techniques to optimize the orientation and positioning of the satellites during certain phases of their orbit to further minimize their brightness.[49] Similar approaches could prove as game-changing for spacepower as the stealthy F-117 and B-2 were to airpower at the end of the Cold War.

The sheer number and size of SmallSats also create opportunities to confuse potential adversaries. The growth of ridesharing and ESPA rings to operate and deploy small satellites means that operators can begin playing an increasingly sophisticated "shell game" by transferring mission and priority among multiple satellites, which was impossible with multi-billion-dollar, bus-sized satellites. Prior to rideshares being popularized, the median time to determine an object's orbit and mission was 3.3 days. For recent rideshares, this process can now take weeks.[50] The record for the most satellites deployed in a single launch is the Space-X Transporter-1 mission, which deployed 143 different satellites in 2021. This massive, near-simultaneous release of satellites created a significant challenge to accurately differentiate and track specific vehicles.[51] Intentional application of similar methods to confuse adversaries in a crisis or conflict could yield an advantage to the United States. By applying the combination of concealment and obfuscation, the Space Force can increase the passive defenses available to the overall architecture, making a first-mover attack less likely to succeed.

Increase multiple-orbit diversification & distribution

The lower cost and rapidly improving technical capability of SmallSats enable greater use of orbits previously dominated by larger satellites. By diversifying across low Earth orbit, medium Earth orbit (MEO), and geosynchronous orbit, the Space Force can improve survivability while continuing to provide a range of services to warfighters, terrestrially and in space.

As Frank Calvelli, Assistant Secretary of the Air Force for Space Acquisition and Integration, stated in a recent speech, "I'm an advocate of proliferation everywhere. I think we should be proliferating more at MEO and GEO as well."[52] The Space Force is exploring ways to leverage multi-orbit architectures that include plans to expand assets in MEO and GEO to augment existing constellations and provide enhanced capabilities for such missions as target tracking. At the same time, Space Systems Command is seeking industry input on building smaller, lighter, and cheaper GPS satellites in MEO to augment the existing GPS constellation.[53] The Space Force has expressed a similar desire for a fleet of small, maneuverable communications satellites in GEO to provide direct-to-cell communications.[54]

By pursuing a mix of proliferated LEO constellations and diversification into MEO and GEO orbits, the Space Force can create a robust, distributed space architecture. This approach simultaneously enhances deterrence, by complicating an adversary's targeting calculus, and enables the delivery of critical services, even if adversaries compromise individual satellites or orbits.

Avoid Operational Surprise

Through SmallSats, the Space Force can expand the distribution of space-based sensors to prevent operational surprise. The increased capacity and flexibility afforded by SmallSats can improve revisit rates over key regions in space and on Earth. These attributes can also increase data collection around friendly high-value space assets or of threat satellites. A dramatic increase in space domain awareness that enables observations of possible threats to space assets, from the Earth through to cislunar space, will help deter attacks.[55]

Expand space domain sensing architecture

SmallSats can deliver enhanced space domain awareness beyond what is currently available. USSF SmallSats are already acquiring essential space domain awareness data via systems like the five Geosynchronous Space Situational Awareness

Tactically Responsive Space (TacRS)

The combination of SmallSats with rapid launch results in **Tactically Responsive Space (TacRS)** capabilities, which can further support the theory of Competitive Endurance and help achieve space superiority.

In February 2024, Space Systems Command concluded Victus Nox—a demonstration of TacRS to rapidly field an additional sensor to support SDA. Space Systems Command now plans to conduct Victus Haze to demonstrate how two rapidly launched sensors might try to gain an advantage over each other by conducting rendezvous and proximity operations against each other. Such actions could be critical to counterspace campaigning. Future missions in the Victus family could demonstrate mission augmentation or replenishment to further support resilience.

Sources: "USSF successfully concludes VICTUS NOX Tactically Responsive Space mission."

Program (GSSAP) satellites currently in geosynchronous orbit.[56] However, while programs like GSSAP provide crucial capabilities to the Space Force, their low numbers and finite fuel supply limit their use.[57] Using a greater number of cheaper, smaller satellites would enable these satellites to "maneuver without regret," greatly enhancing their utility for monitoring and characterizing potential threats.[58] A larger number of such satellites would also allow for greater coverage of different orbital regimes, ranging from LEO to cislunar space.

Rapid responsiveness to emerging space threats will be another crucial capability as space's warfighting nature becomes more apparent. In February 2024, news revealed that Russia may be developing an on-orbit nuclear ASAT. The incident underlines the importance of the Space Force's ability to rapidly deploy new space domain awareness capabilities to monitor emerging threats. According to Gen Michael Guetlein, Vice Chief of Space Operations, the Space Force's upcoming Victus Haze demonstration aims to showcase the ability to "rapidly put up space domain awareness and operate it in real-time against a threat."[59] By establishing the capacity to rapidly launch and operate new satellites in response to urgent needs, the Space Force can significantly improve its readiness to counter unexpected adversary actions and maintain an edge in space.

Expand ability to monitor terrestrial threats to space

Remote sensing and missile warning SmallSats can also provide valuable insight into ground-based threats to U.S. space assets. The Space Force's eventual ground-based moving target indicator (GMTI) satellites, used to characterize vehicles and ships, and the Space Development Agency's growing number of missile warning and tracking satellites could, for instance, help track the deployment, emplacement, and launch of a road-mobile ASAT. Commercial SmallSats can provide valuable information in this role as well. The Navy awarded contracts to Planet and HawkEye 360, both SmallSat operators, for imaging and signals intelligence for maritime surveillance.[60] This data could help inform U.S. Space Command about potential ship-based ASATs and, potentially, ground-based threats. Rather than space simply supporting terrestrial combatants, intelligence from space could be used to monitor and warn of terrestrial attacks aimed at assets in the space domain.

Finally, the creation of a resilient proliferated satellite architecture will force adversaries to conduct larger-scale—and thus more visible—attacks during any attempt to effectively degrade or destroy a constellation. Intelligence analysts might easily dismiss one anomalous orbital path or deployment of a ground-based direct ascent ASAT as a coincidence; Two or more would clearly indicate preparations for a coordinated strike. The increased enemy mass required to attack a proliferated architecture provides an unambiguous identification of an attack and not just a "test" or "accident."

Responsible Counterspace Campaigning

Responsible counterspace campaigning tactics can be accomplished by capitalizing on the full range of attributes that differentiate SmallSats from legacy systems and offer distinct benefits. For example, SmallSats can help build on improved space domain awareness to find, fix, track, and target enemy satellites and leverage sufficient "affordable mass" to disrupt adversary space-enabled kill chains, which would simultaneously protect friendly space forces. The basic physical properties of SmallSats make them well-positioned to provide the space superiority the United States needs through conscientious counterspace measures.

Deploy satellite bodyguards & hunter-killers

SmallSats increase the feasibility of satellites performing defensive and offensive missions.[61] Small "bodyguard" satellites with non-debris generating kinetic or non-kinetic effects could be stationed next to high-value satellites to protect them from attack. These satellites would play the same role as "fighter escorts" that protect high-value air assets (HVAA) like tankers or airborne radar. Such satellites might include communications and missile warning satellites in GEO or GPS satellites in MEO.

The low cost and rapid tech refresh of smaller satellites make them a potentially effective form of affordable mass to target the growing number of adversary satellite capabilities. The Space Force could employ a larger number of SmallSats as co-orbital weapons to disable adversary satellites using localized kinetic, EW, lazing, spoofing, or jamming techniques. These "hunter-killer" SmallSats could patrol near adversary assets, hide in less monitored orbits, or remain with a larger bus or an upper-stage vehicle waiting for activation. The ability to provide offensive counterspace capabilities at a moment's notice places additional strain on adversary planning and can credibly add to the deterrent posture of the United States.

Whether defending friendly or attacking adversary space assets, SmallSats can leverage their unique attributes and faster generational iteration cycles to take advantage of opportunities not available to larger, more expensive satellites. First, because SmallSat development and fielding timeframes are greatly reduced, the effectiveness of guardian or hunter-killer satellites can grow as EW and directed energy capabilities advance to solve the offense-defense balance challenge currently posed by drone and advanced missile attacks.[62] By enabling rapid technology insertion, SmallSats can stay on the cutting edge better than larger satellites. Second, the lower cost of SmallSats enables their employment in mass against adversary threat systems, granting the ability to confront an adversary simultaneously from multiple threat angles and potentially preventing effective adversary counter attacks altogether. Third, SmallSats could use the advantage of their small size coupled with additional CCD capabilities to remain near high-value friendly assets or near adversary systems—potentially without an adversary's knowledge. Being able to provide defensive or offensive effects with little to no warning will complicate and delay an adversary's response options. Finally, employing SmallSats equipped with EW or other non-permanent weapons will greatly reduce the chances of collateral damage during an engagement. Their increased precision is critical to minimize the potential impact of debris or other harmful effects to other spacecraft.

Recommendations to Optimize for Small Satellites

It is clear from these examples and demonstrations that the Space Force could employ SmallSats operationally to a much greater extent than it has already done to achieve space superiority. Given threat dynamics and mission needs, this path is not optional. The following recommendations are aimed at enabling the further adoption of SmallSats so they can achieve the decisive effects needed. These recommendations are not only for the Space Force but also for Congress and the industrial base, as these novel concepts of operations are useless without the personnel, training, supporting infrastructure, and funding needed to put them into practice. The United States can only achieve the necessary level of space superiority to credibly deter potential adversaries by properly aligning the focus of decision-makers with the materiel and non-materiel resources required.

The Space Force could employ SmallSats operationally to a much greater extent than it has already done to achieve space superiority. Given threat dynamics and mission needs, this path is not optional.

At a broad level, the first thing senior decision-makers must do is understand the full potential benefits of SmallSats. They offer capabilities far exceeding today's present efforts tied to proliferation and support for research and development efforts. The rapid acceleration of technology development, merged with the inherent ability of SmallSats to easily integrate advancements, means the rate of change for SmallSats will also continue to increase. Maintaining awareness of the current and near-future state-of-the-art is critical for military and civilian leaders. Naturally, an understanding of the limitations of SmallSats is equally important to ensure investments are focused wisely to field a balanced architecture. Large, exquisite satellites must continue to provide foundational capabilities for no-fail missions. Fielding a hybrid architecture, mixing large, highly capable satellites with small, cheaper, and more flexible SmallSats better ensures sustainable security for the space domain from both a mission assurance and mission capability perspective. Some missions simply require larger payloads on larger spacecraft. Having a hybrid architecture with a diverse set of tools to accomplish different missions maintains the flexibility, capability, and capacity necessary to achieve space superiority.

SmallSat Acquisitions

The adoption of small satellites as a key element of future force design is a commitment that enables the procurement of systems in mass. This commitment will necessitate changes to existing paradigms built around the acquisition of limited quantities of large, exquisite spacecraft. A family of satellites once meant a dozen or fewer systems; the USSF can now procure hundreds or even thousands of satellites all sharing enough similarities to be considered a single program. It follows that such a shift will have significant implications for how these systems are funded by Congress, managed by the Space Force, and built by contractors.

Scaling up & large block buys. Large block buys of similar SmallSat buses with options for different payloads are the first step to assuring rapid delivery of capability. The procurement of a SmallSat family to perform a given mission over 20 years may include ten iterations of shorter-lived SmallSats with several trusted vendors. This makes continued funding an imperative throughout the duration of the overall program. Rather than extensive delays caused by inconsistent funding, Congress can enable the Space Force to move ahead with families of systems on scales not previously implemented in the space domain, perhaps even larger than many aircraft lines. The increase in quantity from large block buys can further decrease the per-unit cost of each satellite. Maintaining options in contract language to pivot to different payload configurations to meet evolving demands will likewise be essential to staying ahead of potential adversaries. This flexibility does not mean the Space Force should allow requirements creep to exist. In fact, because of the rapid development times possible with SmallSats, locking the requirement set for one iteration will be much easier to achieve because the new requirement can be addressed in the subsequent iteration.

Grow funding tied to Competitive Endurance. The Space Force requires assured, consistent funding growth in each of the three areas of Competitive Endurance. As Gen Saltzman noted, space superiority can provide the United States with an asymmetric advantage, but that also means that "every dollar cut creates asymmetric risk against a near-peer adversary."[63] Artificial spending gaps, reductions in real growth, and delays to new programs forced during periods of continuing resolution prevent the Space Force from doing what it must. Ultimately, this leads to a weaker defense posture, signals a lack of commitment to our adversaries, and invites continued hostile and belligerent actions. Additionally, budget and planning cycles are still mired in an antiquated bureaucracy that is better suited to decades-long development timelines. The rapid development pace currently possible with small satellites, much less in the future, will require a different approach. Addressing these fundamental barriers is essential to gaining the speed and flexibility needed to maintain an advantage over competitors and potential adversaries.

Artificial spending gaps, reductions in real growth, and delays to new programs forced during periods of continuing resolution prevent the Space Force from doing what it must.

Support the industrial base to ramp up SmallSat production. The industrial base must shift to mass production and manage critical supply chains to meet the increased demands of large procurements of SmallSats. Stable funding from Congress and consistent direction from the USSF are foundational to achieving these goals. The increase in quantities will drive changes to long-lead items and demand more effective management of components common to multiple families of satellite systems. Shifting from hand-building one-of-a-kind satellites to manufacturing systems in standardized ways more closely resembling assembly lines will not be easy. However, some large satellite companies are already beginning to make the change, driven by the incredible pace of the SDA in fielding the PWSA. Further adoption to support even more SmallSat development for multiple missions is the next step.

Continue to develop & scale launch. The architectural shift to SmallSats will drive a corresponding shift to space launch. The traditional national security space launch enterprise centers around large satellites and offers rideshare for secondary payloads based on excess capacity. SpaceX has demonstrated large quantities of SmallSats can now be the primary payload. Manifesting national security space launch capacity to meet the new cadence and volume could open the door for alternative launch providers with a greater tolerance for risk.

SmallSat Operations

Adopt TTPs for SmallSats supported by new technologies. Once larger numbers of SmallSats are in orbit, they will force new thinking about satellite operations. The existing force of operators will not be able to effectively manage thousands of satellites in the legacy manner. Exploiting advances in artificial intelligence to perform routine tasks will likely be required. It follows that operator training will need to adjust to the new paradigm, including the new challenges of countering potential attacks. These attacks could manifest in orbit or in cyberspace.

Increase cyber & sensing capabilities. Improved cyber defense will be critical to ensure the small number of ground stations can assuredly maintain positive control of the growing number of satellites. Finally, improvement in space domain awareness to increase the understanding of the location of the growing number of satellites will be essential. If the position uncertainty of satellites does not improve, the number of predicted conjunctions will increase to the point of being unmanageable. However, if the Space Force can improve the precision of positional data, it can drastically decrease the number of conjunction warnings. Further improvements to domain awareness are also essential to perform timely and accurate battle damage assessment. This includes insight into visibly observable indications of success and assessments of vehicle performance.

The Space Force can leverage the affordable mass offered by SmallSats to achieve the objectives of Competitive Endurance

SmallSat Sustainment

Prioritize architecture sustainability. As the number of SmallSats increases, the Space Force must pay careful attention to disposal plans. In LEO, this is a relatively easy problem to address by simply de-orbiting satellites to burn up in the Earth's atmosphere. In higher orbits, however, the disposal of large numbers of SmallSats could prove to be more challenging. The Space Force could boost them to higher orbits, but such an action may further limit the operational usability of the SmallSat. Another option is to design the SmallSats in higher orbits to either refuel or rejoin with an upper stage for subsequent transport to a disposal orbit. If the Space Force chooses to refuel, it could also enable the SmallSats to receive hardware and software upgrades, enabling technology refresh for even the higher orbits.

Conclusions

SmallSats are already making huge changes to the Space Force architecture, but they can do even more to increase the mass and flexibility the Space Force and the broader defense enterpise needs to achieve space superiority and deliver on the promise of Competitive Endurance. To support these objectives, the Space Force should pursue the following operational and architectural opportunities enabled by SmallSats:

- Utilize camouflage, concealment, and deception techniques with SmallSats to further increase the resilience of the USSF architecture and complicate adversary operations.
- Increase multiple-orbit diversification and distribution to expand the hybrid architecture approach.
- Expand space domain sensing architecture hosted on SmallSats in critical areas and around high-value satellites.
- Expand the ability to monitor terrestrial threats to space through proliferated sensors hosted on SmallSats.
- Host a range of defensive and offensive weapons to field satellite bodyguards and hunter-killers to protect high-value satellites and disrupt adversary space-enabled kill chains.

The Space Force can leverage the affordable mass offered by SmallSats to achieve the objectives of Competitive Endurance: deny first mover advantage, avoid operational surprise, and responsible counterspace campaigning. By including CCD techniques and diversification across multiple orbital regimes, SmallSats will further enhance the resilience of the architecture beyond the proliferation that Space Force is fielding with PWSA. The ability to expand the location of sensors will increase domain awareness and improve the ability to monitor terrestrial activities that could threaten friendly satellites. Finally, by hosting a number of non-debris-generating weapons, SmallSats can enable the effective defense of satellites and protection of joint and coalition air, land, and maritime operations by denying, degrading, or destroying an adversary space-enabled kill chain. The combination of effects possible through the further adoption of SmallSats will preserve the space advantage of the United States.

To fully realize the potential of SmallSats, the Space Force, Congress, and the industrial base must continue to adjust old paradigms built around legacy space capabilities and consider the following steps:

- Scale up SmallSat procurement, including large block buys to protect funding streams, and continue trends that reduce costs and increase employment flexibility and technology refresh rates. This includes removing harmful budget caps presently in place.

- Grow the funding tied to the theory of Competitive Endurance to meet requirements needed to address each tenet.

- Support the industrial base in ramping up SmallSat production to shore up its supply chains and streamline production for large-scale procurement.

- Continue to develop and scale launch to improve affordability and frequency.

- Adopt TTPs for SmallSats associated with their operating requirements, which are unique and distinct from operations for legacy systems that accomplished fewer missions with less risk.

- Increase cyber security and sensing capabilities for greater resiliency and situational awareness.

- Prioritize architecture sustainability and make management, disposal, and reconstitution part of the strategy for the U.S. space architecture.

The further adoption of SmallSats will require new approaches previously impractical for space systems. The lower cost of SmallSats compared to legacy or traditional systems makes wholesale satellite procurement possible, and the Space Force will subsequently need to make changes to satellite operations and spacecraft sustainment to effectively and safely manage the larger numbers of total vehicles. These changes will be necessary to realize the goals of the three tenets of Competitive Endurance. SmallSats can and should continue to transform how the United States looks at space; The increased flexibility and mass of highly capable SmallSats are exactly what the Space Force needs to stay ahead of rapidly evolving threats and to achieve the space superiority the United States needs. ✪

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