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Introduction

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From a national security perspective, the space domain today is fundamentally different than it was 10 years ago. It is also likely to be very different 10 years from now than it is today. The role of the commercial sector, the nature of development of space capabilities, the ways satellites are gaining access to space, the uses of space capabilities, the organization of the U.S. Department of Defense when it comes to space, and the likelihood of conflict in space all look very different today than they did in the past. This issue of the *Journal of Advanced Military Studies* considers a variety of these shifts in detail. To provide context and background for the individual articles, this introduction describes some of the connections between the changes and gives an overview of each one.

Advent of Proliferated Low Earth Orbit in the Commercial Sector

One of the two key factors driving the dramatic shifts in the space domain has been the advent of proliferated constellations of small satellites, primarily in low Earth orbit. The advent of proliferated low Earth orbit (pLEO) constellations began in the early 2010s and was the confluence of multiple factors. Ever smaller and cheaper electronics, the availability of venture capital funds looking for risky and high payoff investments, and the ability to handle large amounts of data and pull knowledge from that data were all required enablers of the proliferated low Earth orbit revolution. The revolution also required recognition though that flying large numbers of cheaper satellite and/or rapidly iterating design and capability of a satellite provided an alternate means of reducing risk and increasing resilience relative to traditional satellite development. Until

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the proliferated low Earth orbit revolution, satellite developers, particularly the U.S. national security establishment, were caught in a negative spiral where every time they designed a satellite they wanted to ensure its reliability was high, so they increased mission assurance, testing, and complexity, which increased cost, which increased the desire for reliability, which increased the amount of mission assurance, testing, and complexity, and on and on. The high cost of satellites and particularly the high cost of launching them also led to a predilection to add capabilities to satellites in an unfortunate attempt to get more value out of all that cost. This again increased the complexity of satellite design and the types of testing and mission assurance that needed to be done. Large satellites will still be required for a number of different missions, particularly those requiring large apertures or high power for sensing or communications, but even for those it may be possible to break the cost/requirements/mission assurance spiral.

Beginning in 1999, the emergence of a standard for small satellites known as CubeSats was one other factor in enabling the proliferated low Earth orbit revolution. The CubeSat standard was developed by Cal Poly (California Polytechnic State University) and Stanford to allow students to experience what it meant to design, build, and fly a satellite.[1] Part of the standard was the definition of a standard size unit for CubeSats, where a 1U CubeSat measured 10 cm in height, width, and depth. As the standard matured, and CubeSats grew from the first 1U cubes to 3U and even 12U designs, commercial companies began to develop components specifically for CubeSats, even whole CubeSat kits. Nanoracks and other private space-focused companies built launchers to eject CubeSats from larger satellites or space vehicles. The CubeSat ecosystem helped generate a new class of components and subsystems that could be used in smaller, lower cost satellites with relatively rapid iteration on capability. Researchers and engineers began to see that CubeSats could be useful for real missions, not just for student projects.

Planet, then known as Planet Labs, was one of the first companies to recognize that a different model was now possible. Rather than building a single or a small number of large, high reliability satellites with many different capabilities, they focused on building small, cheap satellites with one function in mind: the ability to provide moderate resolution imaging of the Earth. They recognized that a large constellation of such systems could image the whole Earth every day and that technology existed to ingest that data and make sense of it given the advances in big data analytics and emerging capabilities in machine learning. Planet kept the cost of each satellite down by using lower cost components, by not requiring them to be built in ultra-pure clean rooms, and by doing some fraction of their testing on-orbit. They rapidly iterated the design of the satellites from launch to launch, and they launched larger numbers of satellites more frequently so that a single satellite failure was a relatively minor occurrence. The lower cost of the satellites also allowed them to use an automated, largely hands-off approach to operating their constellation as they did not need to obsessively monitor an individual satellite with tens of people per satellite. They built an infrastructure for data collection and analysis that allowed them to collect revenue off processed data. Currently, Planet is flying more than 180 Planetscope Dove 3U CubeSat imagers with 3-meter resolution along with more than 20 higher resolution SkySat imagers. BlackSky Global is developing similar concepts for somewhat smaller constellations of somewhat larger satellites. Hawkeye 360 uses a proliferated low Earth orbit constellation to monitor radio frequency signals like the maritime automatic identification system. ICEYE developed one of the first small synthetic aperture radar satellites and is now filling out that constellation.

These early companies were largely focused on Earth imaging. Somewhat more recently, there has been a move to provide internet access and resilient communications based on similar proliferated low Earth orbit constellations. Starlink, the constellation developed by SpaceX, is the largest player in this space and as of 2022 had nearly 5,000 satellites in orbit, more than the rest of the world combined. SpaceX's highly vertical approach to its supply chain has meant that it has not generated as much change in the wider commercial space industry to support its production, but the example it provides is leading other companies to work to provide similar capabilities. OneWeb had a constellation of more than 600 satellites as of 2022, also providing radio frequency connectivity. Kuiper is working to develop a similar capability as are others.

Change in Launch Capabilities

The large increase in the number of satellites to be launched has helped drive and/or been enabled by changes in the costs and availability of launch services. SpaceX is once again the biggest player here. Its development of the Falcon 1 in 2006, then the Falcon 9 in 2010, and then a highly reusable version of the Falcon 9 in 2015 has significantly lowered the price per unit mass of launch to low Earth orbit. Their assembly line approach to building Falcon 9 is unprecedented in the space community. SpaceX now performs multiple launches per week, with a goal of reaching one launch per day in the near future, and it is expanding the Falcon 9 and Falcon Heavy capabilities with even more payload capability via Starship.

There are also a growing number of companies working to offer small payload launches. One of the first of these was RocketLabs, with its Electron launch vehicle now having launched around 177 satellites to low Earth orbit with a 300 kg payload capacity with a reusable orbital-class small rocket.[2]

As early as 2018, the U.S. General Services Administration established a cost schedule for launches of small payloads with NanoRacks and has had a similar agreement with SpaceX for somewhat larger payloads since at least 2021.[3]

Change in the Nature of the Space Threat

Another, less positive change in the space environment is the growing capability and perceived intent by potential U.S. adversaries to attack satellites in the event of conflict. These capabilities range from nonkinetic and reversible effects like jamming, to nonreversible kinetic effects generating significant amounts of debris. A watershed moment in this area was the Chinese test of a ground launched, direct ascent, hit to kill space weapon against one of their own dead satellites in 2007. That test has been followed by a significant expansion in antisatellite capability by both China and Russia.

According to the U.S. Space Force, China officially designated space as a new domain of warfare in 2015.[4] Their test in 2007 has been followed with what is now an operational capability for direct ascent capability against low Earth orbit systems with a test more than 10 years ago in 2013 to geosynchronous orbit indicating that they may have capability against that orbital regime as well. The Chinese are also developing repair satellites that may be placed in orbit and used at a later time to engage and damage an adversary's satellites.

According to the U.S. Space Force, the Russians have demonstrated cyberattacks against commercial space systems as part of their operations in Ukraine. They have developed ground-based, high-energy lasers to blind intelligence, surveillance, and reconnaissance satellite sensors and tested a direct ascent ASAT missile in 2021. Russia has also deployed orbital prototypes that eject smaller payloads, which may be used as weapons.[5]

The National Air and Space Intelligence Center (NASIC) has provided similar reporting, including describing how in 2022 China's Shijan-21 was used to tow a defunct satellite in geostationary orbit to the graveyard belt and how Russia's COSMOS 2504, 2519, and 2536 were all used to test low Earth orbit kinetic kill capabilities. NASIC mentions adversary antisatellite capabilities including ground site attack, cyberattack, directed energy weapons, electronic warfare, and kinetic attacks.[6] Similar reporting has been done by the Defense Intelligence Agency.[7] The United States recognizes the potential impact of these threats, declaring that United States "space forces must protect U.S. interests in a manner that preserves the safety, security, stability, and long-term sustainability of the domain."[8]

Implications for National Security

These changes around use of space have resulted in some significant impacts on national security. The U.S. military and others have reacted to these changes in a variety of ways; the examples below largely revolve around the U.S. national security enterprise.

National Security Adoption of the Proliferated Low Earth Orbit Approach

In 2019, then undersecretary of defense for research and engineering, Michael D. Griffin, directed the stand-up of the Space Development Agency (SDA).[9] The goal of SDA was to much more rapidly and affordably field national security space capabilities using the same proliferated low Earth orbit model employed by Planet, SpaceX, and others. Since its stand up, SDA has focused on delivering capabilities for tracking adversary ballistic and hypersonic missiles as well as providing resilient communications capabilities. They launched their first 10 Tranche 0 satellites to support data transport and missile tracking in April 2023, less than three years from initial contract award, a relatively short time for a U.S. government satellite program. The final Tranche 0 satellites were launched in February 2024, bringing the total in orbit to 27 systems. The transport satellites are also relatively inexpensive for a Department of Defense system, costing around $15 million (USD) per satellite.[10] SDA plans to launch its Tranche 1 satellites in 2024 and is working on Tranche 2 with more than 100 satellites as well as developing new capabilities as part of its Fire-control on Orbit support to the warfigher (FOO-fighter) satellites.[11] While not yet at the scale of Starlink or Planet, SDA demonstrates that the national security enterprise can implement the principles of the proliferated low Earth orbit in its own development efforts.

Leveraging Commercial Proliferated Low Earth Orbit

At the same time, the national security enterprise in the United States is working to leverage the capabilities developed by the commercial sector as part of the pLEO revolution. The U.S. intelligence community has been particularly involved in working with the pLEO commercial space sector with some more nascent efforts on the part of the U.S. Department of Defense. The National Geospatial-Intelligence Agency (NGA) signed an introductory contract with Planet for imagery in 2017, purchased a subscription for Planet imagery in 2017, and followed that with a larger contract in 2018.[12] In 2022, after taking over responsibility for commercial space for the intelligence community, the National Reconnaissance Office (NRO) awarded contracts for commercial imagery to BlackSky, Maxar, and Planet. Although Maxar is more of a traditional large satellite developer, both BlackSky and Planet fall into the proliferated low Earth orbit category.[13] The U.S. Space Force has a contract with SpaceX involving StarShield, which may provide a Department of Defense-unique variant of Starlink capabilities.[14]

Protecting U.S. Commercial Systems

Given the U.S. government's reliance on commercial space systems—sensing and communications—and demonstrated willingness of adversaries to target commercial systems, there is an increasing realization by the U.S. government of the need to provide mechanisms to better protect critical commercial space partners.

Reorganization of U.S. Department of Defense—Space

The United States has emphasized the critical nature of space to its national security through the creation within the last five years of both a dedicated combatant command for space, U.S. Space Command (USSPACECOM), and of a dedicated Service, the U.S. Space Force (USSF), which is part of the Department of the Air Force. These two organizations have put increased attention at leadership levels to developing and protecting U.S. space capabilities.

The NRO, NGA, and USSPACECOM recently announced a tri-seal commercial space protection framework to improve the bilateral sharing of threat information with contracted commercial space companies to ensure the timely protection and availability during a time of escalation.[15] Other published strategies also highlight the need for improved integration and joint tactics, techniques, and procedures for dynamic space operations between U.S. government and commercial with the Space Force articulating the desire for a Commercial Augmentation Space Reserve to allow for the Service to gain access to additional commercial space capability in a time of crisis through voluntary, prenegotiated contracts and relationships that can be immediately exercised in a time of crisis.[16] In some cases, the protection of commercial assets for collision avoidance now falls on the Department of Commerce given the transition of the mission from the Department of Defense to the new space traffic coordination office under the Space Policy Directive-3.[17] The U.S. government recognizes the need for consolidated storefronts to access commercial space capabilities—for example, Space Systems Command's Commercial Space Office—although across the entirety of the U.S. government, there are still multiple offices acquiring different levels—pixels, value added services, launch services—to using the same vendors and suppliers to develop U.S. government operated capabilities. While promising, commercial space companies must follow and track multiple U.S. government strategies (USSPACECOM, Space Force, NRO, NGA) storefronts, and civilian agencies to accomplish their commercial objectives while supporting the Department of Defense.

Push for Dynamic Space

The Air Force has executed dynamic operations for more than 60 years using aerial refueling from the Boeing KC-135 Stratotanker to enable global reach and almost geographically and temporarily unconstrained operations for fighter and other aircraft. Refueling operations have been extended to the use of commercial tankers as demonstrated in the aerial refueling with a Boeing E-3 Sentry and Boeing RC-135.[18] The Space Force is now similarly looking to expand the notion to dynamic space operations and using commercial technology. Many legacy Department of Defense systems have not been designed to conduct dynamic space operations, often remaining in a single orbit with enough maneuvering capability for station keeping. Those space systems cannot maneuver to respond to a dynamic threat without a reduction in mission life given the inability to refuel in the same way we can with a fighter aircraft at risk who may need to deviate a flight plan. USSPACECOM and the Space Force have challenged the commercial space sector to offer solutions.[19] Recent contracts by Systems Space Command are investing in on-orbit refueling vehicles and standard ports for military satellite refueling.[20] Space in the national security context looks very different today than it did as recently as ten years ago. The articles in this issue will describe in more detail a number of aspects of that evolution.

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