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The Military Use of Small Satellites in Orbit

Mariel BOROWITZ

Key Takeaways

- Small satellites offer unique economic opportunities, due to their shorter development time, their lower cost as well as their manufacturing in assembly line style processes.

- Many small satellite applications envision systems comprised of constellations of hundreds or thousands of satellites, which offer a number of advantages, such as the increase in temporal resolution, or revisit rate, as well as formation flying.

- Military users can take advantage of commercial systems for military purposes – leveraging existing capability without the need to develop new systems internally. Militaries must look for ways to harness these trends to their advantage, both by making use of commercial offerings, and by examining military-specific opportunities.

- Military leaders envision a time when battlefield imagery could be requested and received by commanders on the ground and used for real-time decision-making. The U.S. Army's Project Convergence experimented with this capability in October 2020.

Introduction

The number of small satellites in orbit has increased rapidly over the last decade, and the growth of this sector is expected to accelerate even more in coming years. In 2011, fewer than 100 satellites weighing less than 600 kilograms (kg) were launched into Earth's orbit. In 2020, more than 1,200 such satellites were launched – the vast majority of which were owned by commercial entities.[1] Licenses have been issued to allow the launch of thousands more. These trends have important implications for military users around the world. Small satellites offer unique capabilities and economic opportunities, but also pose new threats. This briefing provides an overview of benefits, weaknesses, and strategic implications of small satellite technology, discusses current government and commercial efforts in this area, and addresses potential future developments.

Due to technological innovation and ongoing miniaturization of key components, small satellites are now capable of providing high-quality data and services across many different mission areas, including remote sensing; communications; position, navigation, and timing; and on-orbit rendezvous and proximity operations. Satellites carrying out these missions have been developed by government and commercial entities, and many further developments are underway. While the technical capabilities of an individual small satellite are typically less than those of a large, complex satellite of the same type, there are a number of attributes of small satellites that make them advantageous.

Shorter Development Time

Small satellites typically focus on one relatively narrow payload technology or application, unlike large satellites that may carry many complex sensors or payloads. Their decreased size and complexity make it possible to develop the satellites much more quickly. While a large, one-of-a-kind satellite may take years to design and build, small satellites can be developed in a fraction of that time – in some cases, just days. Shorter development times have a number of important implications, including allowing for rapid refresh of satellites on orbit and increased training opportunities.

Rapid Refresh and Technology Upgrade

Because small satellites can be developed quickly, it is possible to replace on-orbit assets on a much shorter timeframe. Unlike traditional large satellites that may be designed to last a decade or more, small satellites are often expected to operate for just one to three years. Technologies can be tested on orbit, and this knowledge and experience can be incorporated into future designs. Rapid refresh also makes it possible to incorporate broader technological improvements. Given the rapid development in electronics and

1. "Smallsats by the Numbers 2021", BryceTech, August 2021, available at: https://brycetech.com.

space technology, the ability to use cutting edge technology, rather than technology that is a decade or more old, is significant. This type of technological edge can be particularly relevant for military applications.

Increased Training Opportunities and Process Improvement

The relatively short development cycle for small satellites creates important opportunities for training. With the long development timelines of traditional space systems, an engineer or program manager may only see a handful of satellite programs go from design to operation over the course of their career, which limits opportunities to learn and apply lessons from one program to another. The short development cycle for small satellites removes this barrier, allowing space professionals to experience the full design, development, and operations cycle many times, applying lessons learned and improving these processes.

Lower Cost

The relative simplicity of small satellites and their short development time typically results in lower costs. While traditional, large satellites typically cost hundreds of millions or even billions of dollars to develop, small satellites can be built for tens of millions of dollars or less. For example, while the Maxar WorldView-4 satellite, weighing 2,500 kg, cost $850 million to build and launch, each of Dove satellites developed by Planet weighs about 5 kg and is estimated to cost less than $1 million.[2] This reduction in cost has obvious advantages in terms of commercial feasibility and reduced government spending. In addition to its budgetary advantages, the lower cost of small satellites enables the development of large constellations, which enables new capabilities and applications.

Manufacturing at Scale

Because small satellites are often deployed in large constellations, with relatively short lifespans requiring fast refresh rates, it makes sense to mass produce them using efficient, assembly-line style processes. In 2019, OneWeb Satellites, a joint venture between Airbus and OneWeb, opened a factory that will ultimately be capable of building two satellites a day.[3] Increased commercial small satellite development has helped to drive increased availability of commercial off-the-shelf parts for these systems.[4] These trends produce positive feedback loops, further decreasing the cost and development time for small satellite systems.

2. W. Scott, "Maxar Space Solutions Brings a Commercial Mindset to Government Space Missions", Maxar.com, April 8, 2019, available at: https://blog.maxar.com.

3. J. Foust, "OneWeb Satellites Inaugurates Florida Factory", SpaceNews.com, July 22, 2019, available at: https://spacenews.com.

4. D. Vergun, "Nanosatellites Could Play Pivotal Role in Defense Against Enemy Missiles", Defense.gov, July 12, 2021, available at: www.defense.gov.

Formation Flying and New Capabilities

Due to their lower cost and development time, it is feasible to develop multiple small satellites designed to work in tandem. This creates new opportunities in the area of formation flying. For example, multiple satellites carrying different sensors can be designed to fly over the same area of Earth at the same time, allowing for the fusion of different types of data (different phenomonologies). This could offer the same type of benefit offered by the A-Train of Earth observation satellites, but at much lower cost.[5]

Synthetic Aperature Radar systems (SAR), of particular interest to the military due to their ability to collect observations regardless of lighting conditions and cloud cover, can also benefit from the use of multiple satellites working in tandem.[6] Other concepts foresee small satellites used in combination with larger, more complex satellites. For example, the "SAR Mirror" design envisions a large SAR satellite surrounded by a swarm of small satellites equipped with receivers each able to detect radar echoes and relay them to the primary satellite.[7]

Large Constellations and Revisit Rate

While formation flying systems typically include just a handful of satellites, many small satellite applications envision much larger systems comprised of constellations of hundreds or thousands of satellites. Typically referred to as megaconstellations, these systems offer a number of advantages. Perhaps the most significant is the increase in temporal resolution, or revisit rate, for the system. After passing over one area of the Earth, it will typically take a satellite at least a few days to pass over (or revisit) that same spot again.[8] However, with many satellites working together, that time can be significantly reduced. With its fleet of more than 150 satellites in low Earth orbit (LEO), Planet can collect imagery of any location on Earth at least five times a day.[9] When complete, SpaceX's 42,000-satellite Starlink constellation will be able to provide constant internet access to any location on Earth.[10] This type of ubiquitous, constant coverage is critical to military applications such as the combat cloud and the digitization of armed forces.

5. S. Bandyopadhyay *et al.*, "A Review of Impending Small Satellite Formation Flying Missions", 53rd AIAA Aerospace Sciences Meeting, 2015, pp. 1623.
6. S.W. Paek *et al.*, "Small-Satellite Synthetic Aperture Radar for Continuous Global Biospheric Monitoring: A Review", *Remote Sensing,* Vol. 12, No. 16, 2020, pp. 2546.
7. *Ibid.*
8. "Newcomers Earth Observation Guide", European Space Agency, November 8, 2020, available at: https://business.esa.int.
9. M. V. Ryswyk, "Planet's New Rapid Revisit Platform to Capture Up to 12 Images per Day", Planet.com, June 9, 2020, available at: www.planet.com.
10. M. Sheetz, "SpaceX's Starlink Internet Service Has More than 145,000 Users so Far", CNBC.com, January 6, 2022, available at: www.cnbc.com.

Tactical Use of Satellites

Constellations with many satellites and rapid revisit times create new opportunities for the tactical use of satellites by military users. Military leaders envision a time when battlefield imagery, for example, could be requested and received by commanders on the ground and used for real-time decision-making. The U.S. Army's Project Convergence experimented with this capability in October 2020. During the exercise, military leaders leveraged both commercial and government satellites to take images of the battlefield, and they used communications satellites, including commercial constellations, to rapidly transmit targeting information. Combined with new capabilities in data fusion and artificial intelligence, the Army reported cutting down the sensor to shooter timeline from 20 minutes to 20 seconds.[11]

Large Constellations and Resilience

Large constellations of satellites offer another benefit of particular interest to military users: resilience. General Hyten, former Vice Chairman of the United States Joint Chiefs of Staff, once referred to large, exquisite military satellites as "big, juicy targets" for adversaries.[12] By contrast, large constellations of small satellites complicate adversaries' targeting. Even if one satellite is lost, the constellation would continue to function. In this way large constellations of small satellites can provide deterrence by denial – if an attack will not meaningfully degrade the capability, an adversary may choose not to carry out an attack at all. LEO systems deployed in addition to existing assets can also help to provide redundancy that further contributes to resilience, since functionality could be retained, even in the event of an attack on the primary system.

It is important to note that while this provides resilience against kinetic anti-satellite weapons – missiles that directly target a satellite – constellations are still vulnerable to other types of attacks. For example, a nuclear explosion in space would create an electro-magnetic pulse and residual radiation that would indiscriminately destroy a large number of satellites, including small satellites. Similarly, a cyberattack could potentially target a constellation as a whole.

Operationally Responsive Space

Due to their very short development times, it is possible to rapidly replace small satellites in orbit. This could be used to increase capabilities – adding new technologies or decreasing revisit times – in the event of a conflict. It can also be used to reconstitute a constellation that has been attacked by an adversary, once again increasing resilience and

11. N. Strout, "Satellites Played a Starring Role at Project Convergence", C4ISRNET.com, October 12, 2020, available at: www.c4isrnet.com.
12. S. Erwin, "Hyten Blasts 'Unbelievably' Slow DoD Bureaucracy as China Advances Space Weapons", SpaceNews.com, October 28, 2021, available at: https://spacenews.com.

offering deterrence by denial. Taking advantage of the low cost of small satellites, it would also be feasible to stockpile a number of small satellites, further increasing the speed at which a satellite constellation can be reconstituted or improved.

Satellite Tracking, Safety of Flight, and Space Traffic Management

While the minimal size of small satellites provides a number of advantages, as discussed above, it can also pose challenges. One of these is the difficulty of detecting and tracking small satellites on orbit. The ability to detect and track satellites is essential to Space Domain Awareness – the ability of the military to understand and predict activities in the space domain. Tracking information is used to predict the future location of objects in space and provide warning of potential on-orbit collisions (typically referred to as conjunction warnings). The inherent challenges of detecting small satellites can inhibit the ability to carry out this analysis, increasing the risk of collisions in orbit, which can lead to the loss of space assets and debris that pollutes the space environment, creating further hazards. While there are a number of technological solutions that have been proposed to address this issue, such as increasing reflectivity or adding tiny RF transmitters, current regulations do not require these, and they are not in widespread use.

The large number of small satellites increases the challenges of ensuring safety of flight

The large number of small satellites, particularly the rise of megaconstellations made up of thousands of satellites, increases the challenges of ensuring safety of flight. As the number of satellites in orbit increases, the number of potential conjunctions increases, and the number of satellites maneuvering to avoid these conjunctions increases, as well. These maneuvers can further complicate efforts to track satellites and accurately predict their future location. There is currently no internationally-agreed-upon process for dealing with these conjunctions – no international Space Traffic Management system. Each situation is dealt with on an *ad hoc* basis at the discretion of the satellite operators involved. As the number of small satellites in orbit increases, it is likely that this *ad hoc* system will become untenable for ensuring safety of flight.

The short life-span, rapid refresh nature of many small satellite constellations also means that we can expect to have many more pieces of debris in orbit – both satellites that have failed on launch as part of owners' acceptable failure rate as well as those that have reached the end of their lifespan, but not yet deorbited. This will further complicate efforts to avoid accidental collisions in space. Current international guidelines require that satellites deorbit within 25 years. With constellations of thousands of satellites being reconstituted every few years, this timeframe may no longer be sufficient.[13]

Detectability, Offensive Capabilities, and Threats

In addition to the challenges of tracking and space traffic management, the difficulty of detecting small satellites also creates more opportunities and threats in the area of space weapons. Small satellites have the capability to be used in rendezvous and proximity operations. This enables them to approach an adversary spacecraft to inspect it. Such satellites could also be used as anti-satellite weapons, damaging or destroying an adversary's satellite. The difficulty in detecting small satellites means that they have the potential to carry out such missions without being detected. Even if they are detected, the large number of expected conjunctions and increased potential for accidental collisions increases the difficulty of determining whether an incident was purposeful or accidental. While some military leaders may see this application of small satellite technology as an opportunity, its potential use by adversaries is a clear threat.[14]

Commercial Capabilities

Much of the recent development in small satellite systems has occurred in the commercial sector. Once again, this poses both opportunities and challenges for military users. The most obvious benefit is the ability of military users to take advantage of commercial systems for military purposes – leveraging existing capability without the need to develop new systems internally. This can also result in significant cost savings, as the costs of these systems are spread among multiple users. However, the use of commercial systems may pose risks, if such systems are not as resilient to attack, such as cyberattack, as military systems. Use of commercial systems by the military may also create uncertainties with regard to deterrence. It is not clear whether adversaries would be more or less willing to attack commercial systems compared to military systems.

Current Developments

It is not feasible to discuss all ongoing small satellite development programs. However, this section provides an overview of some of the most significant commercial and military efforts underway at this time.

13. J.C. Liou *et al.*, "NASA ODPO's Large Constellation Study", *Orbital Debris Quarterly News*, Vol. 22, No. 3, 2018, pp. 4-7.
14. M. Borowitz *et al.*, "National Security Implications of Emerging Satellite Technologies", *Orbis*, Vol. 64 No. 4, 2020, pp. 515-527.

Commercial Remote Sensing

Commercial remote sensing companies relying on small satellites have been founded in a number of countries, offering a wide arrive of services. Perhaps the most well-known is Planet, based in the United States. Planet has built and successfully launched more than 450 satellites, and maintains a constellation of 150 satellites in orbit, the smallest of which are about the size of a shoebox. They offer a rapid revisit rate and a range of spatial resolutions.[15] Argentina-based Satellogic also uses a fleet of small satellites to provide daily updates on a global scale. While the company currently only has 17 satellites in orbit, it plans to have a constellation of 300 satellites by 2025, each roughly the size of a microwave oven.[16] The company will use a new manufacturing facility in the Netherlands capable of producing 100 satellites a year.[17]

China is also home to companies offering optical remote sensing satellite data based on a constellation of small satellites. Chang Guang Satellite Technology Co., Ltd. (CGSTL) currently operates an initial constellation of about 25 satellites, but plans to grow to over 100 satellites in orbit.[18] Zhuhai Orbita Aerospace Science & Technology Co. Ltd. has 10 satellites in orbit and uses its constellation to provide a range of data and services.[19]

There are a number of commercial remote sensing satellite companies that do not rely on optical sensors. Spire operates a constellation of 110 satellites that carry radio occultation, automatic identification system, and automatic dependent surveillance sensors. These allow the company to monitor weather, maritime traffic, and aviation activities.[20] Capella Space utilizes synthetic aperture radar technology to allow all-weather day and night surveillance of the Earth. The company has launched the first two satellites in its 36-satelllite constellation.[21] Hawkeye 360's nine satellites use formation flying and RF sensors to collect information relevant to maritime and military users.[22]

Communications

Commercial entities have operated communications satellites for decades. However, a new wave of companies is taking advantage of small satellite technology to develop megaconstellations of hundreds or thousands of satellites in low Earth orbit. Compared to past systems, these constellations offer very low latency and consistent global coverage. Many of these companies are focusing on providing internet connectivity to areas of the globe that are not well-served by terrestrial networks, such as rural or remote areas.

15. "Our Constellation", Planet.com, 2019, available at: www.planet.com.
16. "Low Earth Orbit: The Best Vantage Point to Monitor the Earth", Satellogic, available at: https://satellogic.com.
17. R. Jewett, "Satellogic Expands with Manufacturing Plant in Netherlands", *SatelliteToday.com,* January 3, 2022, available at: www.satellitetoday.com.
18. "Profile", Chang Guang Satellite Technology Co. Ltd., available at: www.charmingglobe.com.
19. "Company Overview", Zhuhai Orbita Aerospace Technology Co. Ltd., available at: www.obtdata.com.
20. "Spire Satellites and Orbits", Spire, available at: https://faq.spire.com.
21. "Our Story", Capella Space, available at: www.capellaspace.com.
22. "Pushing the Boundaries of Space-based Geoanalytics", Hawkeye 360, available at: www.he360.com.

Companies also anticipate increased demand based on the growing "Internet of Things." Space-based constellations can provide the constant coverage that allows these internet-enabled devices to connect from anywhere. This capability will play a key role in extending 5G connectivity to air, sea, and other remote areas not covered by cell networks.[23]

SpaceX's Starlink constellation is the most developed in this market, having already launched nearly 2,000 satellites by the beginning of 2022.[24] Eventually, Starlink will include up to 42,000 satellites in its constellation.[25] OneWeb, jointly owned by the UK government and multinational organizations, has nearly 400 satellites in orbit, and will bring that up to 648 for its full constellation.[26] Project Kuiper, in development by Amazon, plans to begin launching satellites for its 3,236-satellite constellation in 2022.[27] China-based Guodian Gaoke and Commsat Tech Dev Co. are also operating in this market. Both have already begun launching satellites to develop their constellations.[28] French start-up Kinéis plans to launch 25 satellites to low Earth orbit in 2023.[29]

Military Developments

Military organizations in the United States, Russia, and China have all invested in small satellite technology, and each of these is already operating numerous such satellites in orbit. While little information is typically available about the nature of these assets, some activities and plans have been made public, particularly in the United States.

The U.S. Army has been experimenting with the use of small satellites for a number of years. Under the Kestral Eye program, it launched two small satellites in 2017 and 2018, designed to deliver imagery in a manner relevant to tactical users.[30] Three bread loaf-size Gunsmoke satellites were used to further test this capability in 2021.[31] In the first iteration of Project Convergence, held in 2020, the Army demonstrated the use of both imaging and communications satellites for tactical use on the battlefield. As part of the program, officials made use of both national assets as well as commercial constellations.[32]

23. "5G from Space – The Role of Satellites in 5G", Nokia, available at: www.nokia.com.
24. S. Clark, "SpaceX's First Launch of 2022 Will Deploy more Starlink Internet Satellites", Space Flight NowJanuary 2, 2022, available at: https://spaceflightnow.com.
25. A. Mann and T. Pultarova, "Starlink: SpaceX's Satellite Internet Project", *Space.com*, January 7, 2022, available at: www.space.com.
26. "Keep Up With OneWeb", accessed January 14, 2022, One Web, available at: https://oneweb.net.
27. M. Sheetz, "Amazon Plans to Launch its First Internet Satellites in Late 2022", CNBC, November 1, 2021, available at: www.cnbc.com.
28. "Smallsats by the Numbers 2021", BryceTech, August 2021, available at: https://brycetech.com.
29. J. Rainbow, "French Satellite Startup Kinéis Gets Regulatory Nod for U.S. Expansion", Space News, November 19, 2021, available at: https://spacenews.com.
30. T. Hitchens and S.J. Freedberg, "Army Seeks Small Satellites to Support Ground Troops", Breaking Defense, August 7, 2019, available at: https://breakingdefense.com.
31. N. Strout, "With All Three Gunsmoke-J Satellites on Orbit, the Army Is Ready to Test Space-Based Targeting", C4ISRNet, July 12, 2021, available at: www.c4isrnet.com.
32. N. Strout, "Satellites Played a Starring Role at Project Convergence," C4ISRNet, October 12, 2020, available at: www.c4isrnet.com.

The U.S. Defense Advanced Research Projects Agency's (DARPA) BlackJack program aimed to spur the development of small satellite capabilities in low Earth orbit that would benefit national security users. The program provided funds to a wide range of contractors to develop capabilities related to communications, targeting, missile warning, and navigation.[33] In June 2021, the program deployed two small satellites to demonstrate advanced laser communications, each of which took less than nine months to develop.[34]

Military organizations in the U.S., Russia, and China have all invested in small satellite technology

The U.S. Space Development Agency, created in 2019, has put forth an ambitious plan involving small satellites as part of its National Defense Space Architecture. The expansive project includes seven constellations providing multi-layered capabilities for national security users. The tracking layer will include satellites that can monitor developments around the world, including ballistic and hypersonic missile launches. The transport layer, eventually made up of up to 500 small communications satellites, would use optical communications to receive information from the tracking layer and securely transmit it to military command centers. Contracts have been issued for initial development, with launches expected to begin in 2024.[35]

Since 2017, China has been launching satellites to contribute to its Yaogon-30 constellation. Chinese media have described the spacecraft as remote sensing satellites, and experts believe it may be used for electronic and signals intelligence, in addition to optical and radar imaging. The constellation enables frequent revisit capabilities.[36]

Future Developments

The small satellite revolution is well-underway, led primarily by the commercial sector. Militaries must look for ways to harness these trends to their advantage, both by making use of commercial offerings, and by examining military-specific opportunities. Small satellites will enable militaries to save cost and leverage the newest technologies. Rapid re-visit rates will enable near-constant surveillance of areas of interest, further increasing transparency and allowing for tactically-relevant satellite imagery. Large constellations of small communications satellites will enable the transfer of this and other critical

33. S. Erwin, "Parsons to Develop Ground Operations Center for DARPA's Blackjack Satellites", Space News, December 11, 2021, available at: https://spacenews.com.
34. "Blackjack Program Successfully Deploys Two Mandrake 2 Satellites", U.S. Defense Advanced Research Projects Agency, July 7, 2021, available at: www.darpa.mil.
35. S. Erwin, "Space Development Agency to Acquire 28 Missile-Tracking Satellites to Launch in Late 2024", Space News, December 8, 2021, available at: https://spacenews.com; S. Erwin, "Space Development Agency to Acquire 144 Satellites from Multiple Vendors", Space News, August 30, 2021, available at: https://spacenews.com.
36. A. Jones, "China Launches New Group of Classified Yaogan-30 Satellites", Space News, June 18, 2021, available at: https://spacenews.com.

information at greater volumes and on shorter timescales, providing a backbone capability for digitization of military forces.

While these benefits are significant, military leaders should also be aware of the potential for small satellites to complicate issues of space tracking and space traffic management; these developments may pose a threat to space sustainability, if not properly managed via domestic regulation and international norms and agreements. Small satellites offer a host of new and exciting opportunities, and strategic benefits will accrue to those who leverage them in a thoughtful and proactive way.

Mariel Borowitz is an Associate Professor in the Sam Nunn School of International Affairs at Georgia Tech. Her research deals with international space policy issues, including international cooperation in Earth observing satellites and satellite data sharing policies. She also focuses on strategy and developments in space security and space situational awareness. Dr. Borowitz earned a PhD in Public Policy at the University of Maryland and a Masters degree in International Science and Technology Policy from the George Washington University. She has a Bachelor of Science degree in Aerospace Engineering from the Massachusetts Institute of Technology.

The Initiative on "European Space Governance" is intended to provide analysis pertaining to the international competition in space and its impact on the European space industry as well as its governance. Through a series of publications and public events, the goal of the initiative is to raise awareness among stakeholders in the European Union about the challenges presented by the transformation of the global space industry. It is coordinated by Éric-André Martin, General Secretary of the Study Committee on Franco-German relations (Cerfa) at Ifri.

Ifri's **Security Studies Center** analyzes traditional defense issues as well as the evolution of the broader field of security. The Center's programs are designed to be enduring and cross disciplinary, and are conducted with the help of other Ifri research units. Through its innovative work, the Center has two objectives: influencing a wide public with its publications – in particular its two electronic paper series "Focus stratégique" and "Proliferation Papers" – and making recommendations to all the actors involved in public security. Accordingly, various reports and projects are realized on behalf of the Ministries of Defense, the Interior and Foreign Affairs.

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75740 Paris cedex 15 – France

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