Soyuz-2.1b rocket lifts off from Baikonur Cosmodrome in Kazakhstan, together with 34 OneWeb communication satellites (Courtesy Roscosmos)

Proliferated Commercial Satellite Constellations

Implications for National Security

By Matthew A. Hallex and Travis S. Cottom

The falling costs of space launch and the increasing capabilities of small satellites have enabled the emergence of radically new space architectures—proliferated constellations made up of dozens, hundreds, or even thousands of satellites in low orbits. Commercial space actors—from tiny startups to companies backed by billions of dollars of private investment—are pursuing these new architectures to disrupt traditional business models for commercial Earth observation and satellite communications. The success of these endeavors will result in new space-based services, including global broadband Internet coverage broadcast from orbit and high-revisit overhead imagery of much of the Earth's surface.

The effects of proliferated constellations will not be confined to the commercial sector. The exponential increase in the number of satellites on orbit will shape the future military operating environment in space. The increase in

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the availability of satellite imagery and communications bandwidth on the open market will also affect the operating environment in the ground, maritime, and air domains, offering new capabilities that can address hard problems facing the U.S. military, such as tracking mobile targets, operating in the Arctic, or providing resilient space support in the face of growing counterspace threats. These trends will also create new challenges as adversaries ranging from Great Power competitors to hostile nonstate actors gain cheap access to space capabilities and the emergence of space-based Internet reshapes the cyber battlespace.

This article discusses some of the proposed commercial proliferated constellations being developed in the United States and abroad and explores the potential effects of proliferated constellations on the space, terrestrial, and cyber domains. It identifies the multidomain challenges and opportunities these trends create for the warfighter and proposes steps that the Department of Defense (DOD) and the broader national security community can take to prepare.

Table 1. Planned Proliferated Communications Constellations

Satellite Operator	Proposed Satellites	Satellite Design Life (Years)
OneWeb	> 2,000	7–10
SpaceX Starlink	~ 12,000	5–7
Boeing	> 3,000	10–15
Telesat	292–512	10
Kepler Communications	140	10
LEOSat	84	10

Sources: Tereza Pultarova and Caleb Henry, "OneWeb Weighing 2,000 More Satellites," *SpaceNews* (February 24, 2017); Jon Brodkin, "FCC Tells SpaceX It Can Deploy Up to 11,943 Broadband Satellites," *Ars Technica* (November 15, 2018); Grant R. Cates, Daniel X. Houston, Douglas G. Conley, and Karen L. Jones, "Launch Uncertainty: Implications for Large Constellations," *The Aerospace Corporation*, November 2018, 2; Caleb Henry, "Telesat Says Ideal LEO Constellation Is 292 Satellites, but Could Be 512," *SpaceNews* (September 11, 2018).

Emerging Commercial Proliferated Satellite Constellations

Commercial proliferated constellations will change how satellite communications and Earth observation services are provided. Not all the projects detailed below will enter service. The total market for high bandwidth communications is estimated to reach 3 terabits of data by 2024. If all the projected proliferated communications constellations and other projected satellite communications services become accessible, 20 to 30 terabits will be available by that year. The small satellite imagery market is expected to grow from its very small base, but government customers still dominate the demand for satellite imagery.[1] In addition to potential limits on demand, some industry experts have raised concerns about shortages in investment capital necessary to complete various competing efforts, and other critics have compared the current era to the failures of the large, disaggregated Teledesic constellation and the struggles of Iridium in the 1990s.[2]

Growing global demand for information services, the greater availability of capital compared to previous eras of commercial satellite growth, the increasing affordability of access to space launch, and greater economies of scale in producing small satellites, however, may make proliferated constellations more viable commercial endeavors. The availability of space-based broadband communications, for instance, will likely drive the growth of Internet-of-Things applications leading to further demand for communications services. Even if only a handful of proliferated constellation efforts succeed, it will produce both a paradigm shift in how space services are provided and a substantial growth in the number of satellites on orbit.

Communications

Satellites in geosynchronous orbit (GEO) have traditionally provided satellite communications where satellites can broadcast to large areas of the Earth. These satellites have provided low data rates and relatively high latency communications, good enough for niche applications but not competitive with fiber optics and other terrestrial alternatives for broadband communications. Proliferated communications constellations, often referred to as mega-constellations because of their size, are in low-Earth orbit (LEO) and aim to provide high bandwidth, low latency communications competitive with terrestrial broadband communications. This will not only allow satellite communications to compete for long-distance backhaul and mobile users but also address underserved populations. Much of the developing world lacks access to terrestrial broadband infrastructure, and 57 percent of the global population does not have access to the Internet.[3] Mega-constellations could allow the developing world to skip laying costly fiber-optic cable in the same way the proliferation of cellular phone technology provided communications without the need to build phone lines in the developing world. LEO-proliferated constellations will also be able to provide communications to high-latitude populations in Alaska, northern Canada, Scandinavia, and Russia, which are poorly served by terrestrial communications infrastructure and outside the coverage of GEO communications satellites.[4]

OneWeb and SpaceX are pursuing the most ambitious proposals for LEO communications proliferated constellations (see table 1). OneWeb has raised more than $1.7 billion in investments to build a first-generation constellation of 648 satellites, expected to enter commercial service by 2020, and plans to expand the constellation with 2,000 satellites in the future.[5] Plans for SpaceX's Starlink proliferated constellation are even more ambitious. The first generation of Starlink is planned to consist of

Table 2. Planned Proliferated Earth Observation Constellations

Satellite Operator	Proposed Satellites	Resolution
Planet	˜ 150	0.72m–5m
Spaceflight Industries	60	1m
Satellogic	300	1m
Hera Systems	48	.5m
UrtheCast	16	0.75m–22m
Capella Space	30	1-30m SAR
Canon	> 100	1m
DigitalGlobe	6	0.3m

Sources: "Planet Imagery and Archive," *Planet.com*; Jeff Foust, "Spaceflight Raises $150 Million for BlackSky Constellation," *Space News*, March 13, 2018; Caleb Henry, "Satellogic on Its Way to Launching 300 Satellite Constellation for Earth Observation," *Satellite Today*, March 17, 2016; Bhavya Lal et al., *Global Trends in Small Satellites* (Washington, DC: IDA Science and Technology Institute, July 2017); "Sensor Technologies," *UrtheCast.com*; Nobutada Sako, "Utilizing Commercial DSLR for High Resolution Earth Observation Satellite," paper presented at the AIAA/USU Conference on Small Satellites, Logan, UT, August 2018, 1–3; "CE-SAT 1," *Space Flight 101*; Stephen Clark, "DigitalGlobe Books Two Launches with SpaceX for Earth-Imaging Fleet," *Spaceflight Now*, March 28, 2018.

more than 4,000 satellites, and SpaceX has secured U.S. Government approval for a final constellation of almost 12,000 satellites.[6] Other proliferated constellation proposals have come from established companies such as Boeing and Canada's Telesat, as well as smaller startups like Kepler Communications and LeoSat.[7] While these are only nascent projects, the potential for large quantities of communications bandwidth entering the market from LEO communications mega-constellations, as well as smaller numbers of high-throughput GEO communications satellites, have led traditional satellite communications providers to delay purchasing new and replacement communications satellites that could struggle to compete in the future business environment.

Earth Observation

The Earth observation market has already moved toward commercial constellations of large numbers of small satellites. While these constellations are smaller than planned communications mega-constellations, ranging from dozens to hundreds of satellites, this disaggregation of commercial space capability has increased access to Earth observation capabilities useful for national security applications.

The most mature of the disaggregated Earth observation constellations are those operated by Planet and Spire Global. By the end of 2017, Planet operated a constellation of 140 Dove imagery CubeSats, 5 RapidEye medium-resolution, and 13 higher resolution SkySat satellites that can image Earth's entire landmass daily.[8] In July 2018, Spire operated 61 of its Lemur satellites (out of a planned 125) that track the Automatic Identification System (AIS) beacons of ships that collect weather data by monitoring the radio occupation of GPS signals.[9]

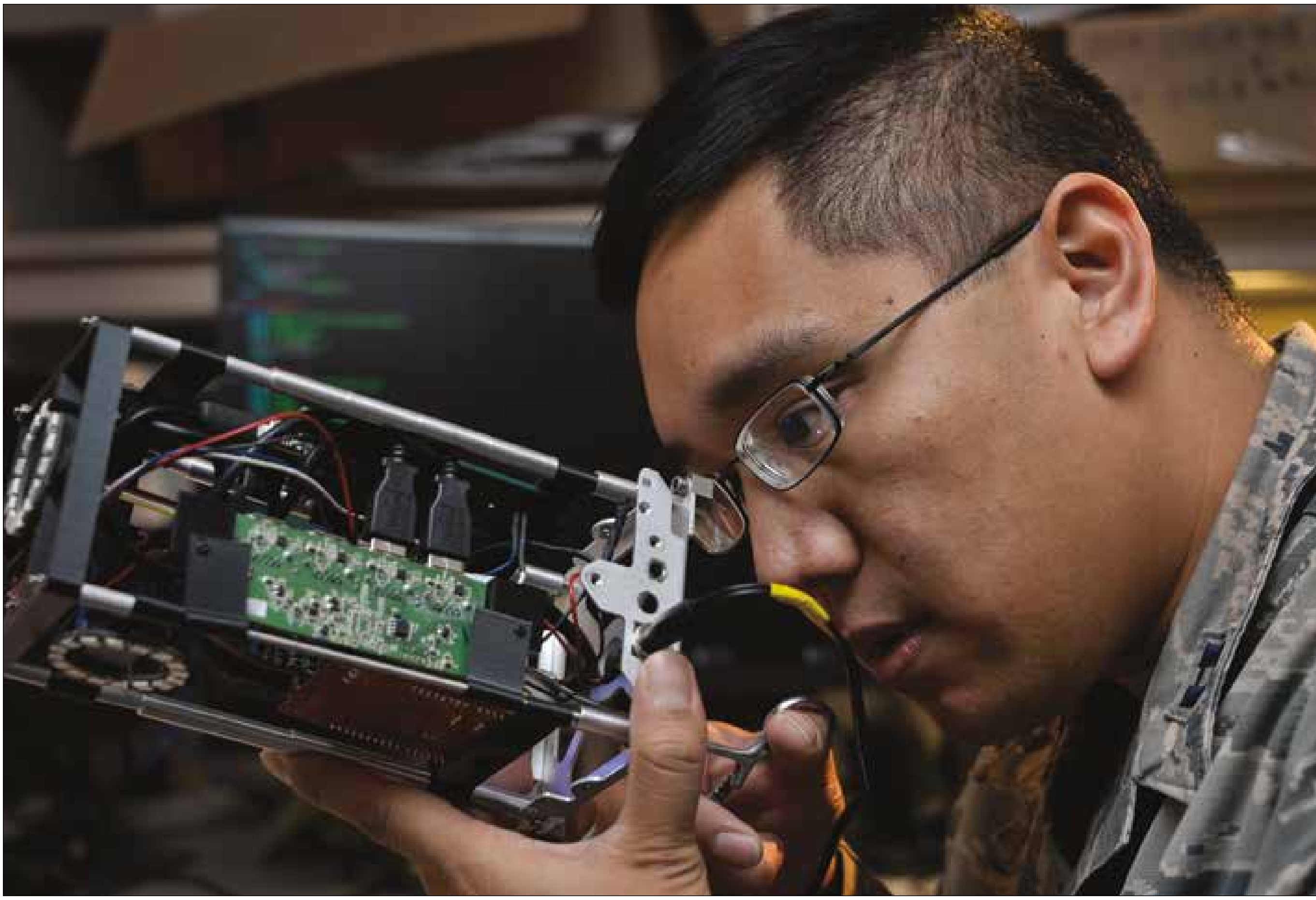
Traditional remote-sensing providers such as Digital Globe and other larger, established companies including Canon, the Japanese manufacturer of cameras and other imagery products, are planning disaggregated imagery constellations (see table 2). Additional startup companies are also aiming to join the ranks of the more mature Earth observation constellations offering optical imagery, high-revisit, all weather, and nighttime Synthetic Aperture Radar,[10] as well as radio signal collection satellites that can geolocate signals emissions—essentially offering commercial electronic intelligence capabilities that can support transportation and logistics, emergency search and rescue, or spectrum mapping in addition to its existing applications for national security and other government purposes.[11]

The U.S. Government has been the largest and most stable customer for commercial satellite imagery, including resources from new imagery proliferated constellations. For instance, a significant share of Planet's growth has been through multiple contracts with the National Geospatial-Intelligence Agency.[12] Commercial Earth observation companies, however, are seeking to diversify their customer base and reach new markets—to rely less on U.S. Government spending and, consequently, to potentially reduce its sway over commercial actors. With lower prices and increasingly on-demand imagery services, proliferated constellation companies are trying to focus on new, nontraditional satellite imagery markets: industrial monitoring, agriculture, utilities, marine transportation analytics, insurance, resource management, business intelligence, and other data-driven, decisionmaking practices.[13] This broader range of services will help drive market expansion, and the Institute for Defense Analyses' Science and Technology Policy Institute projects the overall commercial small satellite imaging market will grow from $15 million in 2015 to $164 million in 2020.[14]

Foreign Proliferated Constellation Efforts

Interest in proliferated constellations is not confined to the United States and Western commercial space actors—both China and Russia are pursuing their own proliferated constellation projects. The development of foreign proliferated constellations will allow not only their owners to access these capabilities, but potentially access also to a wider range of actors. Given China's willingness to allow for commercial dealings with countries hostile to the United States, these systems could pose a significant threat to U.S. interests.

The state-owned China Aerospace Science and Technology Corporation (CASC) is planning the 300-satellite Hongyan LEO broadband communications proliferated constellation, and the



Airman with 707th Communications Squadron Special Missions Flight repairs connection on CubeSat, in Laurel, Maryland, January 2018 (U.S. Air Force/ Alexandre Montes)

state-owned China Aerospace Science and Industry Corporation plans its own 156-satellite Xingyun communications constellation. The first Hongyan satellite was launched in late 2018, and CASC has established a factory in Tianjin capable of producing 130 satellites a year. In 2015, China launched the first of its Jilin commercial imagery satellites to complement the Gaofen civil imagery constellation. The Jilin constellation is planned to reach 60 satellites by 2020 in order to provide global, 30-minute revisit rates, and then 138 satellites by 2030 to obtain 10-minute revisit rates worldwide.[15]

While ostensibly commercial, because China has raised private funds and intends to sell products and services to stakeholders beyond the government, Chinese proliferated constellations are likely to be less responsive to market pressures than Western commercial proliferated constellations. China is pursuing commercial space capability to bolster its military and civil space systems as part of its policy of "civil-military fusion," making militarily useful proliferated constellations likely candidates for government support.[16] Chinese proliferated constellations are also likely to be able to rely on government financing and other support to offer services to emerging markets in Africa, Central Asia, and Latin America as part of China's One Belt, One Road development and trade initiative.[17]

Russia also has proliferated constellation aspirations. Roscosmos, the Russian state-owned space corporation, has announced plans to build the 288-satellite Efir constellation to provide global broadband Internet by 2025. This project is part of a larger projected proliferated constellation comprising 600 communications and optical imagery satellites to provide global coverage from low orbits.[18] Given the difficulties facing the Russian civil and commercial space programs in recent years, Russia is a less likely proliferated constellation competitor than China.

Spillover Effects: Satellite Manufacturing and Space Launch

The emergence of proliferated constellations is reshaping other areas of the commercial space world by driving expansion of satellite manufacturing and space launch capacity. The large numbers of satellites that comprise proliferated constellations require satellites to be mass-produced quickly and less expensively—a shift from the usual paradigm of uniquely designed, exquisite, and expensive space systems. To produce the hundreds of satellites that will make up the OneWeb constellation, Airbus has opened a production line in Toulouse, France, and is planning an additional high-capacity satellite manufacturing plant in Florida.[19] In August 2018, Boeing agreed to acquire Millennium Space Systems, which is building a manufacturing center in California that will annually produce hundreds of small satellites.[20] Similarly, in 2018, Planet opened a facility in San Francisco that can produce 40 small imagery satellites each week.[21]

The deployment of proliferated constellations will continue to drive demand for space launch capacity. Small satellites have traditionally been launched as rideshare or secondary payloads, but the demand for these opportunities exceeds the rate of large payload launches. Rideshare opportunities also bound a satellite to the orbit of the primary satellite, which may not be the optimal inclination or orbit for smaller satellites. The lack of rideshare availability is driving the small launch vehicle market; companies such as Vector Launch, Rocket Lab, Firefly Aerospace, and Virgin Orbit are developing new vehicles to capture part of this demand. China also has an active small launch program with three operational small launch vehicles.[22]

Demand is not confined to small launch vehicles. Larger launch vehicles will permit proliferated constellations to be rapidly deployed by manifesting dozens to hundreds of small satellites in a single launch. For instance, in February 2017, Planet launched 88 Dove satellites on a single Indian Polar Satellite Launch Vehicle.[23] The relatively short planned lifespan of proliferated constellation satellites will also result in a continuous demand for launch services to replace satellites as they end their service lives, potentially resulting in larger economies of scale that reduce the cost of all launches.

Proliferated Constellations and National Security

While commercial interest is driving the development of proliferated constellations, these new space architectures can provide capabilities previously available only to a few spacefaring great powers. These new useful capabilities will not only be available to the United States. China wants to build its own proliferated constellations for communications and surveillance. The development of proliferated constellations will further the democratization of space; capabilities will become cheaper and more readily available to a range of state and nonstate actors.[24] Adapting to the emergence of proliferated constellation is not simply a problem for space warfighters. It requires a joint multidomain solution to take advantage of the operational opportunities provided by these systems and to address the new threats in the space, air, maritime, land, and cyber domains detailed below.

Satellite Proliferation and Space Security

The space operational environment is increasingly congested, contested, and competitive. The emergence of satellite proliferated constellations will accelerate these trends but will also offer opportunities for the United States to better deter adversaries from initiating conflicts and to address growing adversary counterspace capabilities.

The OneWeb satellite constellation alone would increase the number of operational satellites by almost 50 percent compared to today, and the SpaceX constellation would triple the number of operational satellites compared to today.[25] The addition of hundreds or thousands of proliferated constellation satellites would increase congestion, stress existing U.S. space situational awareness (SSA) and space traffic management capabilities, and could create a more dangerous debris environment. More satellites and associated debris would threaten orbital safety and, at the very least, increase the number of conjunction warnings—notices of possible collisions between satellites and other objects in space—that the Combined Space Operations Center issues, distracting it from its national security mission.

Proliferated constellation operators intend to address the risk of debris from their satellites by ensuring that they are disposed of through atmospheric re-entry at the end of their operating lives. A recent study by the National Aeronautics and Space Administration's Orbital Debris Program Office suggests that a 99 percent end-of-life disposal rate may be necessary to maintain a sustainable orbital environment.[26] The disposal level for LEO satellites, however, has not reached 20 percent in any of the last 25 years.[27] Unless proliferated constellations become far more reliable, they could pose a long-term threat to the ability of the United States and other space actors to operate safely in space.

While potentially threatening the sustainability of safe orbital operations, new proliferated constellations also offer opportunities for the United States to increase the resilience of its national security space architectures. Increasing the resilience of U.S. national security space architectures has strategic implications beyond the space domain. Adversaries such as China and Russia see U.S. dependence on space as a key vulnerability to exploit during a conflict. Resilient, proliferated satellite constellations support deterrence by denying adversaries the space superiority they believe is necessary to initiate and win a war against the United States.[28] Should deterrence fail, these constellations could provide assured space support to U.S. forces in the face of adversary counterspace threats while imposing costs on competitors by rendering their investments in counterspace systems irrelevant. Proliferated constellations can support these goals in four main ways.

First, the extreme degree of disaggregation inherent in government and commercial proliferated constellations could make them more resilient to attacks by many adversary counterspace systems. A constellation composed of hundreds or thousands of satellites could withstand losing a relatively large number of them before losing significant capability. Conducting such an attack with kinetic antisatellite weapons—like those China and Russia are developing—would require hundreds of costly weapons to destroy satellites that would be relatively inexpensive to replace.

Second, proliferated constellations would be more resilient to adversary electronic warfare. Satellites in LEO can emit signals 1,280 times more powerful than signals from satellites in GEO.[29] They

SpaceX Falcon 9 rocket launches Starlink at Cape Canaveral Air Force Station, Florida, on May 23, 2019, putting 60 satellites into orbit (U.S. Air Force/ Alex Preisser)

also are faster in the sky than satellites in more distant orbits, which, combined with the planned use of small spot beams for communications proliferated constellations, would shrink the geographic area in which an adversary ground-based jammer could effectively operate, making jammers less effective and easier to geolocate and eliminate.[30]

Third, even if the United States chooses not to deploy national security proliferated constellations during peacetime, industrial capacity for mass-producing proliferated constellation satellites could be repurposed during a conflict. Just as Ford production lines shifted from automobiles to tanks and aircraft during World War II, one can easily imagine commercial satellite factories building military reconnaissance or communications satellites during a conflict.

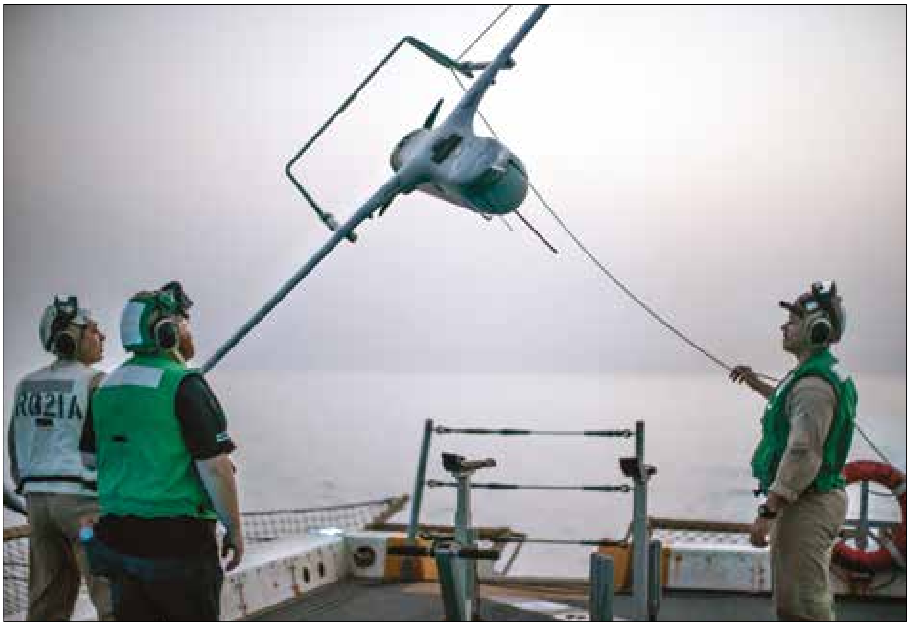
Fourth, deploying and maintaining constellations of hundreds or thousands of satellites will drive the development of low-cost launches to a much higher rate than is available today. Inexpensive, high-cadence space launch could provide a commercial solution to operationally responsive launch needs of the U.S. Government. In a future where space launches occur weekly or less, the launch capacity needed to augment national security space systems during a crisis or to replace systems lost during a conflict in space would be readily available.[31]

The Fight on Earth: Opportunities and Threats

The emergence of proliferated constellations will lead to easier access to satellite communications, space imagery, and other capabilities that can support U.S. and adversary military operations in the ground, maritime, and air domains. Adapting to these changes will likely require the development of new joint operational concepts to better exploit space systems in support of the joint fight as well as address new force protection challenges when fighting space-enabled state and nonstate actors.

Proliferated constellations will substantially increase the availability of communications bandwidth for military operations. These satellites would provide high bandwidth to forces with less latency than existing GEO satellites,[32] which, in turn, would improve access to reachback communications to forward-deployed military forces, and would also help meet the growing demand for transfer capacity for data collected by unmanned systems and other forward sensors.

Proliferated LEO communications constellations would also offer coverage in theaters that are poorly served by commercial satellite communications today. Satellites in GEO do not sufficiently support operations in the Arctic



Marines lower RQ-21A Blackjack unmanned aerial system from recovery system aboard USS *John P. Murtha*, Gulf of Aden, July 2019 (U.S. Marine Corps/Adam Dublinske)

and other high-latitude regions that are growing in economic and national security importance.[33] Similarly, naval and air forces operating in the Pacific theater have less access to commercial communications than other theaters due to the lack of commercial customers in the open ocean. Proliferated commercial LEO constellations would provide greater communications handling in both regions because of their global coverage.

While unable to provide the high-resolution imagery and other specialized capabilities of existing national security satellites, proliferated LEO constellations could help to address some of the intelligence challenges the U.S. military faces. During the first Gulf War, the United States was unable to track and target Iraq's Scud missile systems despite enjoying almost total air superiority. Since then, mobile missiles and other elusive targets have multiplied as potential adversaries seek to defeat U.S. conventional precision and nuclear strike systems. Imagery proliferated constellations could provide continuous or near-continuous coverage of missile operating areas to better enable the United States to find and eliminate these threat systems.

The near continuous imagery coverage proliferated constellations offers—particularly if they include radar satellites that can see through clouds—combined with ground processing capabilities that can automatically detect changes in imagery would also make adversary deception operations less effective.[34] Because the United States is likely to be on the defensive in the most worrying scenarios for conflict—such as defending allies in Eastern Europe or East Asia—these new capabilities will support U.S. efforts to detect adversary mobilization and to avoid operational surprise.

Of course, these new capabilities will also be available to potential adversaries. The development of proliferated constellations allows other nations to replicate the U.S. ability to support space global power projection. The global coverage LEO communications constellations enable would also allow China to support forces deployed far from its mainland, including ships deep in the Pacific or deployed to Djibouti or elsewhere in Africa.

These capabilities will also heighten the challenge of protecting U.S. forces and bases. High-revisit commercial imagery could also track mobile targets like U.S. naval vessels or U.S. aircraft using smaller "adaptive bases" in Europe or the Pacific to avoid attack. In support of its "counter-intervention" strategy, China, like the Soviet Union before it, has invested substantially in optical imagery, radar, and electronic intelligence satellites in order to track U.S. carrier groups. Chinese commercial imagery proliferated constellations would bolster these capabilities and provide a resilient capability to track U.S. forces worldwide.

Nonstate actors will also be able to conduct global surveillance using commercial proliferated constellations. Global Fishing Watch, an environmental nonprofit organization that aims to reduce overfishing, already uses commercial satellites as part of what is essentially a space-based kill chain to eliminate environmental crime at sea.[35] It monitors AIS beacons that seagoing vessels are required to carry to track their locations to avoid collisions. When they detect unusual behavior, such as ships turning off their AIS signals, they use Planet's imagery constellation to locate the ship and then cue higher resolution satellites to collect images of illegal activity. Hostile actors with goals less noble than environmental conservation—such as pirates, antiship missiles, or armed Houthi rebels—could use commercial proliferated constellations to track and target ships at sea with similar effectiveness.

Space Internet and the Cyber Battlespace

Proliferated constellations may also shape the future cyber battlespace by supplanting the traditional physical infrastructure that underlies the Internet and creating a new orbital layer for cyber operations.

Today, more than 90 percent of Internet traffic is carried by undersea fiber optic cables that stretch over thousands of miles of ocean floor. These cables are vulnerable to accidental cuts and are likely targets of enemy action during wartime. Speaking at the opening of SpaceX's Seattle location in 2015, Elon Musk highlighted SpaceX's goal of carrying "more than half of the long-distance traffic" on its satellite network.[36] Satellite constellations would become increasingly critical infrastructure for the U.S. and global economy if they facilitated a larger share of global telecommunication traffic.

Ownership of the infrastructure that underlies the Internet can produce intelligence and cyber warfighting advantages. Analysts have raised concerns over the cyber security implications of the increasing number of Chinese companies that own and operate long-distance fiber optic cables. Chinese commercial proliferated constellations could augment these cables to compete for global Internet traffic, exacerbating the trend identified by Eric Schmidt, former Google CEO, of a bifurcation into Chinese and non-Chinese Internets that operate on different infrastructure, standards, and levels of government control.[37]

Proliferated constellations themselves are a likely target for cyber operations. The mass production of satellites for a proliferated constellation could easily result in the cyber vulnerabilities of any particular satellite replicating across a network, making it easier to attack the entire architecture. It may also be easier to carry out a cyber attack on satellites intended to directly interface with the Internet than on satellites that require more specialized communications interfaces.[38] The challenge of attacking proliferated constellations with kinetic counterspace weapons may lead adversaries to a greater reliance on cyber threats against U.S. national security and commercial space architectures. As the joint force makes greater use of proliferated satellite constellations, cyber defense of U.S. and commercial satellite systems will likely become an increasingly important mission.

A Path Forward for DOD

Making use of the new capabilities provided by proliferated satellite constellations and addressing the threats posed by new adversary space capabilities is not a niche issue for space warfighters. Adapting to the future that these new space capabilities will create requires a joint, multidomain effort. The heart of this effort should be a joint campaign of experimentation—including wargaming, discovery exercises, and prototyping—that develops understanding of the challenges and opportunities proliferated constellations create for warfighters in space and other domains, to develop new operational concepts to make U.S. forces more capable and lethal in this future, and to better understand the strategic consequences that shifting balances in space and other domains will have for the competitive balance among the United States, China, Russia, and other space-enabled state and nonstate threats.[39]

Potential starting points for this effort include examining how best to integrate new communications and intelligence, surveillance, and reconnaissance (ISR) capabilities at the tactical level, and what kind of denial and deception capabilities will best enable U.S. operations in a future characterized by ubiquitous orbital surveillance. Experimentation need not be limited to tabletop exercises or simulations—the lower cost of manufacturing and launching space systems will allow DOD to operate more on-orbit experiments. Along with demonstrating and maturing new space technologies, DOD can make greater use of prototype space systems and architectures to support field exercises and experiments aimed at discovering how best to use these new space technologies to support U.S. forces.

A joint, multidomain campaign of experimentation will also help to define new requirements for DOD use of proliferated satellite constellations. This should help DOD determine the best path to making use of new space capabilities and the balance between acquiring DOD-operated satellites and improving engagement with industry to make better use of the commercial proliferated satellite capabilities discussed above.

This could involve DOD deploying its own proliferated constellations. The Space Development Agency (SDA), established in 2019, aims to develop proliferated constellations that can provide communications, ISR, missile warning, and an alternative to legacy GPS satellites.[40] The SDA builds on existing efforts to leverage emerging commercial constellations such as the Defense Advanced Research Projects Agency's Blackjack program.[41] These efforts would produce new satellites to augment existing national security architecture, but at a much lower cost, and could allow for fast and inexpensive expansion of U.S. military space capabilities in response to new threats.

In addition to developing and deploying its own satellites, DOD could improve its engagement with the industry to better capitalize capabilities offered by new commercial proliferated architectures. The Defense Department has strong ties with traditional aerospace companies, some of which are part of the manufacture and launch of proliferated constellations. Many of these new space systems, however, are being developed by small and agile startup companies—Silicon Valley tech companies that build satellites rather than apps—that DOD has struggled to connect with. A key part of the effort to improve DOD's relationship with Silicon Valley and its broader ability to harness commercial innovation is improving the acquisitions process. Commercial proliferated constellation operators aim to offer data and information services rather than the raw imagery or transponder leases of traditional commercial space operators. These companies also aim to move quickly—inexpensive, rapidly manufactured, frequently launched satellites with short lifespans that enable rapid technology refresh and evolution of capability. DOD processes need to move at the speed of the commercial sector to exploit these new space services or to develop U.S. Government proliferated constellations to meet military and intelligence needs. One step in this direction would be the expanded use of waivers that allow venture capital funded companies to participate in DOD Small Business Innovation Research contracts they are otherwise excluded from.[42]

In addition to developing space capabilities to address the needs of the joint warfighter, DOD needs to prepare for new requirements for SSA and space traffic management resulting from increases in satellites and debris on orbit. Beyond investing in new military capabilities, the Defense Department should consider investments to improve the integration of foreign and commercial SSA data into its systems. Alternatively, DOD could support the transfer of space traffic management responsibilities to a civilian agency, which would reduce the burden on existing military organizations.[43]

The Defense Department can also play a large role in shaping the future commercial space environment by protecting commercial proliferated constellations and related technologies from interference by foreign companies and governments. It should be prepared to address the failures of commercial proliferated constellation efforts and to act to maintain the viability of commercial constellations with particular strategic value.

Acquiring access to technologies developed by U.S. companies is a key part of China's long-term strategy to match U.S. economic and military power. Tactics include hacking, industrial espionage, and investments in U.S. technology startups. DOD should push to improve the whole-of-government approach to protecting U.S. technologies and expanded use of existing tools for monitoring and blocking foreign efforts to acquire strategic technologies from the United States. For instance, foreign investments in the operators and manufacturers of commercial proliferated constellations should be an ongoing priority for review by the Committee on Foreign Investment in the United States, the interagency committee with the power to regulate foreign investment that could threaten U.S. national security. DOD could also include commercial constellation operators in the new Trusted Capital Marketplace, which links companies crucial to defense supply chains with trusted sources of commercial investment.[44]

The DOD part in preserving Iridium—the $5 billion LEO communications constellation that was a forerunner of today's emerging proliferated constellations—exemplifies another role it could play in managing the future commercial environment. When Iridium faced bankruptcy in 1999, its corporate parent Motorola planned to deorbit the satellites to avoid risking future liability resulting from satellite collisions. The DOD offer to indemnify Motorola against future liability, as well as a multimillion-dollar, 2-year contract for communications services, allowed Iridium to restructure its debt through bankruptcy. This intervention enabled Motorola to spin off Iridium as an independent company that has since become economically viable and provides vital communication services to U.S. forces around the world.[45] As commercial proliferated constellations enter service, DOD should identify systems with particular military value and use its unique role as one of the largest consumers of space services to preserve capabilities in case a future economic downturn threatens the viability of strategic commercial capabilities. **JFQ**

Notes

[1] Bhavya Lal et al., *Global Trends in Small Satellites* (Washington, DC: IDA Science and Technology Policy Institute, July 2017), 3-4, 3-7.

[2] Debra Werner, "Analysts See Demand for Two or Three Megaconstellations," *Space News*, October 9, 2018, available at <https://spacenews.com/megaconstellation-demand/>; Caleb Henry, "LEO and MEO Broadband Constellations Mega Source of Consternation," *Space News*, March 13, 2018, available at <https://spacenews.com/divining-what-the-stars-hold-in-store-for-broadband-megaconstellations/>.

[3] Sarah Scoles, "SpaceX Wants to Launch Thousands of Satellites. What on Earth For?" *Wired*, June 8, 2017, available at <www.wired.com/story/spacex-wants-to-launch-thousands-of-satellites-what-for/>. Mega-constellations in low-Earth orbit plan to offer latency on the order of 30 milliseconds (ms), comparable to the 10–50 ms latency of terrestrial fiber systems, and far lower than the ~ 600 ms latency of geosynchronous orbit communications satellites. See Ward A. Hanson, "Satellite Internet in the Mobile Age," *New Space* 4, no. 3 (September 2016), 143; Jon Brodkin, "Low-Latency Satellite Broadband Gets Approval to Serve U.S. Residents," *Ars Technica*, June 23, 2017, available at <https://arstechnica.com/information-technology/2017/06/low-latency-satellite-broadband-gets-approval-to-serve-us-residents/>.

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