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SMALL SATELLITES:
THE IMPLICATIONS FOR NATIONAL SECURITY

by Nicholas Eftimiades

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Cover: Several tiny satellites are featured in this image photographed by an Expedition 33 crew member on the International Space Station. The satellites were released outside the Kibo laboratory using a Small Satellite Orbital Deployer attached to the Japanese module's robotic arm on Oct. 4, 2012. Japan Aerospace Exploration Agency astronaut Aki Hoshide, flight engineer, set up the satellite deployment gear inside the lab and placed it in the Kibo airlock. The Japanese robotic arm then grappled the deployment system and its satellites from the airlock for deployment. Earth's horizon and the blackness of space provide the backdrop for the scene. *Source:* National Aeronautics and Space Administration, October 4, 2012, https://commons.wikimedia.org/wiki/File:ISS-33_Several_tiny_satellites_1.jpg.

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Contents

List of Acronyms

A2/AD—Anti-access/area-denial

AI—Artificial intelligence

ASAT—Anti-satellite

BRI—Belt and Road Initiative

CAGR—Compound annual growth rate

CCP—Chinese Communist Party

CONFERS—Consortium for Execution of Rendezvous and Servicing Operations

COTS—Commercial off-the-shelf

DASD—Deputy assistant secretary of defense

DHS—US Department of Homeland Security

DoC—US Department of Commerce

DoD—US Department of Defense

DSR—Digital Silk Road

FAA—Federal Aviation Administration

FCC—Federal Communications Commission

GAO—Government Accountability Office

GEO—Geostationary Earth orbit

GPS—Global Positioning System

HBTSS—Hypersonic and Ballistic Tracking Space Sensor

IADC—Inter-Agency Space Debris Coordination Committee

IBS—Integrated Broadcast System

IC—US Intelligence Community

ISAC—Information Sharing and Analysis Center

ISO—International Standards Organization

ITU—International Telecommunication Union

JROC—Joint Requirements Oversight Council

LEO—Low-Earth orbit

LINCS—Laser Interconnect and Networking Communication System

MDA—US Missile Defense Agency

MEV—Mission-Extension Vehicle

ML—Machine learning

NASA—US National Aeronautics and Space Administration

NDSA—National Defense Space Architecture

OADR—Open-Architecture Data Repository

OCT—Optical communication terminals

ODNI—Office of the Director of National Intelligence

OISL—Optical Inter-Satellite Links

OPSEC—Operational security

OSAM—On-Orbit Servicing, Assembly, and Manufacturing

OSC—Office of Space Commerce

PDUSD—Principal deputy under secretary of defense

R&D—Research and development

RF—Radio frequency

SDA—US Space Development Agency

SSA—Space situational awareness

STM—Space traffic management

UN—United Nations

UNOOSA—United Nations Office for Outer Space Affairs

Executive Summary

This report examines the relationship between what is often called the commercial "small-satellite revolution" and US national security. The relationship is complex and has many dimensions, not the least of which are organizational behavior, the government's lack of understanding of commercial markets, outdated institutional processes, and a defense bureaucracy unwilling or unable to adapt to the changing environment. It may be worth noting that several of these same problem areas brought about the catastrophe of September 11, 2001. This is not to suggest a "Space Pearl Harbor" event is imminent. However, the threat to space systems will increase proportionately to the degradation of the United States' ability to maintain space superiority; that is, the ability to ensure safe and secure access to, and in, space.

If the United States is to maintain space superiority, it will need to make substantive cultural, doctrinal, and operational changes to its multidimensional relationship with the commercial space industry. This is because, over the next decade or so, commercial space activities will increase the number of operational satellites by nearly a full order of magnitude, mainly through the development of small satellites. With the growth in the number of satellites come increased capabilities in remote sensing, communications, data processing, and on-orbit operations. A new space ecosystem is coming into being, with profound implications for the world's security and economic development. The speed at which commercial space companies are putting thousands—soon to be tens of thousands—of satellites into orbit presents unique challenges for US security in space, as well as for deployed armed forces. There will be increased congestion in certain orbits, competition for communications bandwidth, new types of space operations, increased transparency, and a changing threat paradigm. Competing in this changing environment will require the United States to make substantial changes in long-established defense acquisition processes, research and investment strategies, data classification and distribution, and the commercial space regulatory environment.

Key Findings

This report explores the trends and technological developments defining the future of the space domain. In doing so, it arrives at six key conclusions.

1. The United States will most likely lose space superiority to China within the next decade.

2. The Department of Defense (DoD) and the Intelligence Community (IC) are trying to take advantage of the small-satellite revolution. The IC is increasingly investing in commercial small-satellite data, to increase collection capabilities and provide military support.

3. The DoD does not generally take a "buy commercial first" approach to space services. Rather, there is an established culture that ignores legislated "commercial first" mandates, and that behavior has become increasingly detrimental to national security interests. Over the last decade, this negative culture has eroded US space superiority, and will continue to do so as the world moves toward quickly developed and deployed, low-cost commercial space systems.[1]

4. To date, no commercial small-satellite service has proven itself viable without government support. Yet, the growth of this industry will dramatically impact US national security.

5. DoD acquisition processes are designed to reduce risk and, as a result, are ill prepared for the high-speed commercial space environment. Senior DoD leaders are making efforts to speed up acquisition processes for small satellites and associated technologies. The results to date are mixed.

6. The US Department of Commerce (DoC) Office of Space Commerce (OSC) has made little progress over the last year in executing its responsibilities for Space Traffic Management (STM) and on-orbit mission authorities. Being subordinate to the National Oceanographic and Atmospheric Administration (NOAA) does not allow the office to function at the level required to effectively execute its mission.

Key Recommendations

The following key recommendations address areas of US space policy, the regulatory environment, coordination and cooperation with US allies, and support for the commercial space industry. These recommendations have the same

1 For decades, presidential policies directed the executive-branch agencies to buy commercial goods and services before developing government solutions. Almost all of the government and industry experts interviewed for this study believe DoD and the IC ignore those mandates for commercial space capabilities.

goals: to enhance global space security and advance the US commercial space industry. Advancing the US commercial space industry is a critical component of maintaining global space leadership, and ensuring the safety and security of space systems and national security.

1. Congress and the administration must conduct rigorous oversight to ensure DoD and IC organizations enforce policies (including their own) to "buy commercial first."

2. The secretary of commerce should move the DoC Office of Space Commerce out from under NOAA. OSC's recently expanded responsibilities for STM and on-orbit mission authorities make it a poor fit for an entity focused on oceanographic and atmospheric administration. Buried in NOAA, the OSC is also in a poor position to conduct the required interagency and international coordination.

3. Increasing the resilience of various US space systems necessitates that the DoD utilize commercial systems, including proliferated satellite architectures and responsive space-launch capabilities, at all levels of orbit and across different payloads, and that it considers buying data from allied and commercial providers.

4. Congress should direct the DoD and the Office of the Director of National Intelligence (ODNI) to conduct a study to identify national security missions that can be accomplished through commercial space. Congress should then earmark funds for those commercial services. This action will force a transition to commercial space services, ensure stable funding for commercial small-satellite development, and drive space innovation through competition.

5. The Department of Homeland Security (DHS) should conduct a study to determine if space systems should be included as one of the national critical-infrastructure sectors. If so, Congress should designate space systems as critical infrastructure with the Department of Commerce as the Sector-Specific Agency.

6. The Department of State, DoD Office of Space Policy, and Department of Commerce should enhance space diplomatic efforts, with the goal of establishing global norms of behavior in space.

Study Methodology

For this study, more than twenty-five interviews were conducted with current and former senior government officials, academics, and industry leaders. All had significant experience in the commercial space industry or national security space. In fact, the collective knowledge reflected more than two centuries of experience, far longer than the reality of spaceflight. Some of these senior experts were critical of the US government's performance, and a few requested anonymity. In addition, more than three dozen documents were reviewed, including government policies, legislation, space-industry studies, and financial and investment reports.

Chapter 1: Strategic Context

This report will begin by identifying the positive and negative disruptions caused by the emergence of commercial small satellites. The report will consider commercial-market growth projections, potential national security applications, and the threat posed by hostile nations with access to the same technology. Finally, it will offer policy recommendations and a brief conclusion.

This report identifies the security and policy implications arising from advancing technology such as artificial intelligence (AI), and the increasing capabilities and commercialization of small satellites. In recent years, new satellite business models and capabilities have emerged. They are still largely in the investment and development phase, with significant players not yet generating substantial revenue. Large constellations of commercial small satellites, tens or hundreds of kilograms in size, are providing new global imagery and communications services. Several companies and government agencies plan to service on-orbit satellites and remove orbital debris, a process with dual-use concerns. Some companies have more audacious plans to operate in the cislunar region of space and develop resources on the moon.[2] Expanded value-added applications relying on advanced data analytics and machine learning promise to exploit new layers of satellite data to provide commercial space situational awareness (SSA) and insight into the terrestrial economy.

It should be noted that, to date, no commercial small-satellite company has proven itself commercially viable without government support. That said, there is a widespread expectation among investors and institutions that commercial small capabilities will continue to advance, and that companies will expand their already considerable customer base. Commercial small-satellite companies providing remote sensing, communications, on-orbit servicing, and debris mitigation are expected to dominate the space industry in the decades to come.

Over the last two decades, advancements in aerospace microelectronics and new business models of space launch have allowed for the launch of tens of thousands of shoebox and larger-sized satellites, which complement or replace the more traditional bus-sized, billion-dollar satellites. Commercial space systems have evolved to show strong growth potential based on changing demographics and new technology drivers. These disruptive changes have positive and negative implications for US national security. A recent DoD Strategic Multilayer Assessment defined disruptors as actors "whose behaviors and innovations trigger broad change in a system."[3] A commercial space disruptor, therefore, is a business practice or "technology that significantly alters (for good or for bad) the ability of the United States to achieve its national security space objectives."[4] The small-satellite revolution has brought with it multiple challenges and opportunities for national security.

Background

Key Actors, Drivers, and Growth Trends

The commercial space small-satellite revolution changes the relationship between the US government and commercial space actors. One could argue that the nature of an emerging commercial space sector is disruptive and, therefore, threatens US hegemony in space activity and technology.

A key component of the small-satellite revolution is the sheer number of satellites slated to be launched in the coming years relative to earlier in the space age. Commercial space companies propose placing more than twenty thousand satellites in orbit in the next ten years. Up until 2020, approximately eleven thousand payloads had been placed in orbit in the entire history of the space age.[5] As of 2021, there are more than 7,389 satellites in orbit, with 4,084 operational and 3,305 inactive.[6] From 2020 to 2021, the number of active satellites has already increased by 27.9 percent.[7] If just half of those commercial space proposals are successful, the space traffic created would more than double the number of satellites deployed over the last sixty years, and create more than six times the number of active satellites. Small satellites represent 75

2 For the purposes of this paper, cislunar space is defined as the volume of space between geosynchronous Earth orbit (GEO) and the moon.

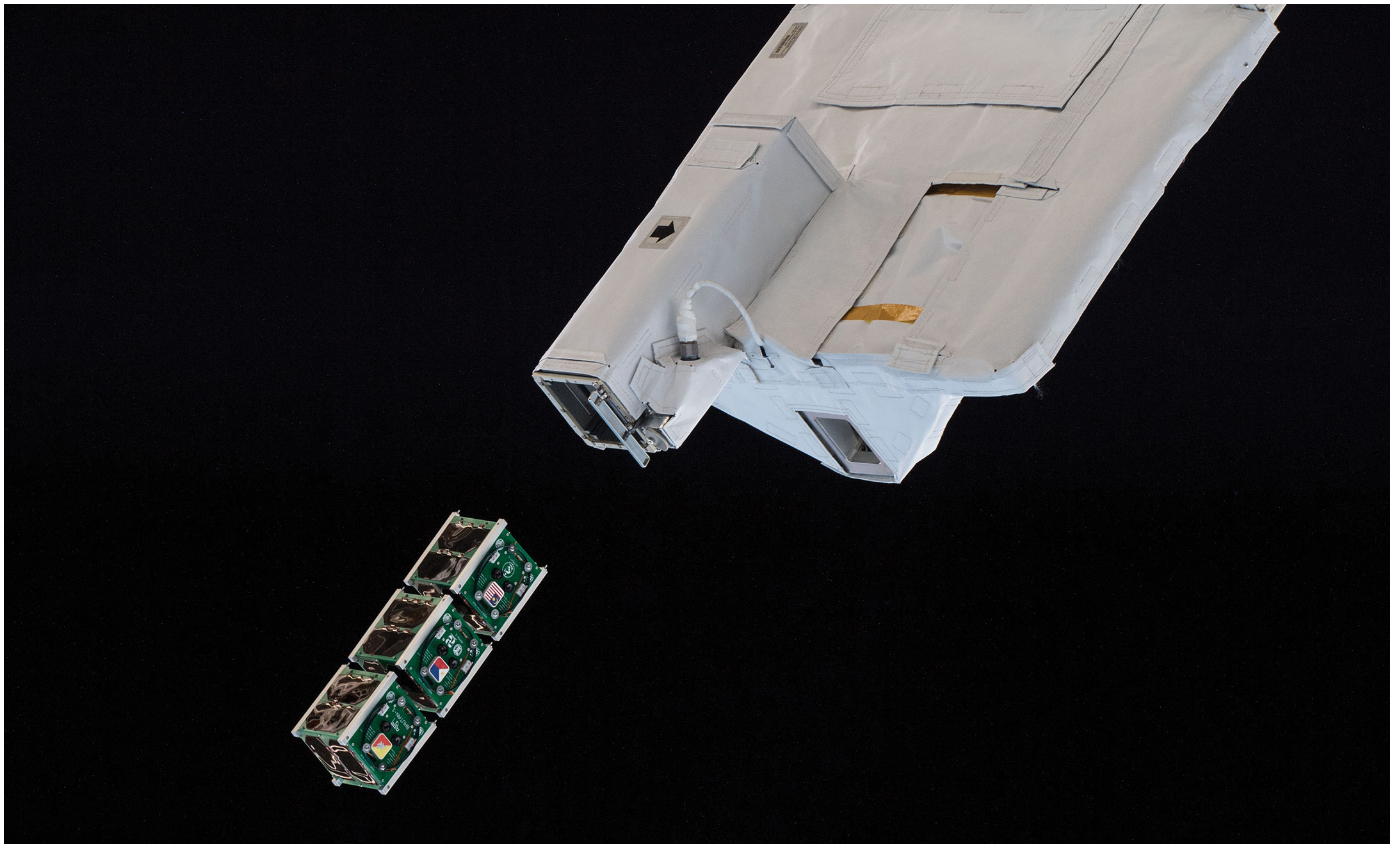
3 "Commercial Space Actors: Disruptors or Solid Partners for National Security," NSI, February 2018, https://nsiteam.com/commercial-space-actors-disruptors-or-solid-partners/.

4 Ibid.

5 John E. Bradford, "The Small Satellite Revolution: From University Missions to Constellations," SpaceWorks presentation, September 2, 2021, 8.

6 "UCS Satellite Database," Union of Concerned Scientists, last visited March 29, 2022, https://www.ucsusa.org/resources/satellite-database.

7 Ibid.



A view of the BIRDS-2 Satellite Deployment during JSSOD-9 operations. The JEM Small Satellite Orbital Deployer (J-SSOD) provides a novel, safe, small satellite launching capability to the International Space Station (ISS). *Source:* Serena Aunon-Chancellor, NASA, August 10, 2018, https://images.nasa.gov/details-iss056e130478.

percent of spacecraft launched from 2011 to 2020, and 94 percent of spacecraft launched in 2020.[8]

The increased number of commercial satellites will present extraordinary challenges in SSA, space traffic management (STM), and threat detection, identification, and characterization. New national and commercial space-based communications, Internet, and remote-sensing capabilities will increase global transparency, presenting new challenges for US, allied, and partner forces to maintain operational security (OPSEC). Most countries can meet significant military support requirements with small satellites. As of 2021, eighty-eight countries are operating satellites, and forty countries have some space-based remote-sensing capabilities.[9]

New technologies, capabilities, and requirements are fueling this growth in the development of commercial space small satellites. These include the following:

- Ground-based economic drivers for small satellites
  - Autonomous vehicles
  - Precision agriculture
  - Global Internet penetration and the Internet of Things
  - Growth of the global middle class
  - Infrastructure and environmental management
- Space-related technologies as market drivers
  - Decreasing launch costs
  - Mass production of satellites, reduction of satellite size and cost (miniaturization technology)
  - On-orbit processing power
  - Artificial intelligence

8 "SmallSats by the Numbers," BryceTech, 2021, 5, https://brycetech.com/reports/report-documents/Bryce_Smallsats_2021.pdf.

9 "Licensing of Private Remote Sensing Space Systems," Federal Register, May 20, 2020, https://www.federalregister.gov/documents/2020/05/20/2020-10703/licensing-of-private-remote-sensing-space-systems.

The organizational advantages and capacity for innovation inherent in the commercial sector ensure that it is private companies that will become dominant across space activities and technology in the medium to long term. The US government's response to such a shift will determine the extent to which US space security interests are compromised or furthered. Partnering with commercial actors in the development of small-satellite capabilities would benefit US national security interests.

Unlike European countries and China, the United States does not have a successful history of promoting government-industry sharing and co-development programs. The United States is comparatively less active in conducting strategic planning to ensure the success of its commercial space industry.

While the commercial small-satellite industry is growing at an astonishing pace, there is also reason to be cautious. Many startup companies are struggling and, already, a period of consolidation appears to be beginning. It is difficult to determine if there is a substantial market for proposed services such as space-debris removal. Even if a market exists, it is unclear who (government or industry) would pay for those services and how much they would pay. SpaceX has launched more than sixteen hundred Starlink low-Earth orbit (LEO) communications satellites, with plans to launch up to forty-two thousand.[10] The company will operate at

The Key Commercial Small-Satellite Players.*

0–50 kilogram (kg)	50–250 kg	250–1,000 kg
Planet	Planet	SpaceX
Capella Space	OneWeb	Iridium
Aerial Maritime	Earth i	UrtheCast (In bankruptcy)
Hawkeye 360	Iceye	SpaceBelt
SpaceQuest	Axelspace	Globalstar
Satellogic	Guowang (National Network)	Kuiper Systems (Amazon)
Spire		
Astro Digital		
Astrocast		

*"The Small Satellite Revolution," 8.

Functions of Satellites in Orbit.*

Number of Satellites	Main Purpose
1,832 satellites	Communications
906 satellites	Earth observation
350 satellites	Technology development and demonstration
150 satellites	Navigation and positioning
104 satellites	Space science and observation
20 satellites	Earth science
10 satellites	Other

*Nibedita Mohanta, "How Many Satellites are Orbiting the Earth in 2021?" Geospatial World, May 28, 2021, https://www.geospatialworld.net/blogs/how-many-satellites-are-orbiting-the-earth-in-2021.

10 Adam Mann, "Starlink: SpaceX's Satellite Internet Project," Space.com, May 28, 2021, https://www.space.com/spacex-starlink-satellites.html.

a loss for years until it builds a market large enough to support the required launch, space, and ground-based infrastructure and operations.

Commercial Space Development: Technology Drivers

Commercial innovation in space launch is one of three significant factors driving the small-satellite revolution. The others are miniaturization of technology and increasing computer processing power. Over the last decade, the cost of launching a kilogram of mass to LEO has decreased by 90 percent.[11] SpaceX reduced satellite launch costs from approximately $200 million (at United Launch Alliance) to approximately $60 million. SpaceX aims to reduce these launch costs to about $5 million.[12] As the cost of launch is reduced, many more space missions become profitable.

Advances in several key technology categories are changing the cost-benefit analysis of the commercial and national security business case to employ small satellites.

- **Mass Production of Satellites:** The cost of creating a satellite could be reduced from its current cost, which is in the tens of millions of dollars, by approximately 10 percent through integrating mass production, according to OneWeb (a proposed network of up to nine hundred satellites providing Internet services).[13] Production time could then be reduced from years to a single day.[14] Advancing miniaturization technology will continue to reduce satellite size and cost.
- **Processing Power:** Planet, an Earth-imaging satellite company, recently launched eighty-eight "Dove" CubeSat satellites, each about the size of a shoebox.[15]
- **Time to Market:** Production time is significantly lower for small-satellite manufacturers. According to Planet's website, "the most advanced satellites [are] launching into orbit every 3-4 months," compared to years between ViaSat 1 and ViaSat 2.[16] (In 2012, ViaSat-1 was a record holder for highest-capacity Ka-band satellite in the world, providing broadband coverage to the continental United States.)

Commercial Small-Satellite Growth Trends

Overall, the entire commercial space sector has grown significantly in recent years. Startup space companies garnered 1,212 investments between 2000 and 2020. In the year 2020 alone, three hundred and forty-two companies and individuals invested in one hundred and twenty-four startup space companies in more than one hundred and forty business deals. Total investments in 2020 amounted to $7.6 billion. New investors continue to enter the ecosystem. Among two hundred and eleven first-time investors in 2020, one hundred and seventeen were venture-capital firms, twenty-nine were angel investors, and thirty-eight were corporations. Investors from the United States accounted for 36 percent of all investors in 2020.[17] It should be noted that not all investors care about advancing the small-satellite industry. Part of the planning cycle for many investors in small-satellite startup companies is a profit-bearing exit strategy.[18]

The global commercial space market is valued annually at $349 billion. In 2018, Morgan Stanley predicted that the space industry would triple in size by 2040. Morgan Stanley's research identified ninety private companies as being on "the forefront of space disruption."[19] Launch and satellite-manufacturing companies make up 39 percent of Morgan Stanley's list of the private space economy, by far the largest segment. In another study, Bank of America and Merrill Lynch projected that the global space industry would reach a value of at least $2.7 trillion in the next three decades (that is, by 2050).[20]

Demographics, Consumer Markets, and Small Satellites

Global demographic changes expected over the next decade are creating a large market for small-satellite services,

11 Noah Poponak, "Episode 64: Space—The Next Investment Frontier," Goldman Sachs, May 22, 2017, https://www.goldmansachs.com/insights/podcasts/episodes/05-22-2017-noah-poponak.html. Poponak is the senior aerospace and defense equity research analyst for Goldman Sachs Research.

12 "Space: Investing in the Final Frontier," Morgan Stanley, July 24, 2020, https://www.morganstanley.com/ideas/investing-in-space.

13 "About Us," OneWeb, 2021, https://onewebsatellites.com/about-us/.

14 Ibid.

15 Robbie Schingler, "Planet Launches Satellite Constellation to Image the Whole Planet Daily," Planet Labs, February 14, 2017, https://www.planet.com/pulse/planet-launches-satellite-constellation-to-image-the-whole-planet-daily/.

16 "Monitoring the World with Microsatellites and Open Source Data," Next Big Future, June 22, 2017, https://www.nextbigfuture.com/2017/06/monitoring-the-world-with-microsatellites-and-open-source-data.html.

17 Applies to all figures in paragraph. "Startup Space: Update on Investment in Commercial Space," BryceTech, 2021, https://brycetech.com/reports/report-documents/Bryce_Start_Up_Space_2020.pdf.

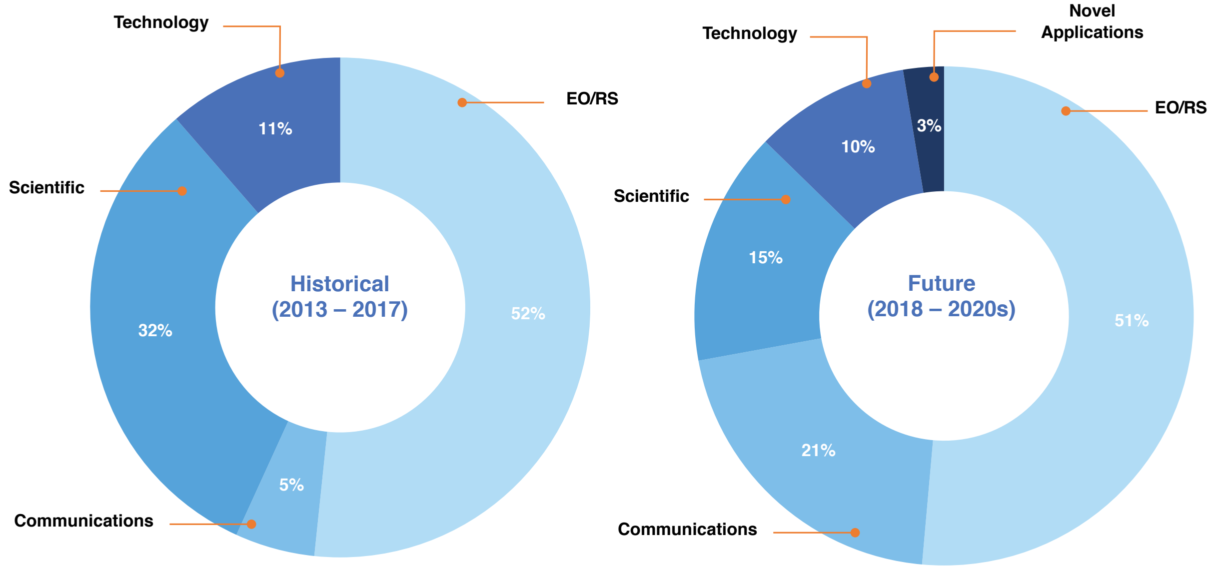
18 Online interview with Dr. Brian Weeden, director of program planning, Secure World Foundation, August 24, 2021.

19 "Space: Investing in the Final Frontier," Morgan Stanley, November 13, 2017, https://www.morganstanley.com/ideas/investing-in-space.

20 "To Infinity and Beyond—Global Space Primer," Bank of America and Merrill Lynch, October 30, 2017, 1, https://newspaceglobal.com/wp-content/uploads/imce/u3479/MerrillLynchSpace-Oct2017.pdf.

Figure 1

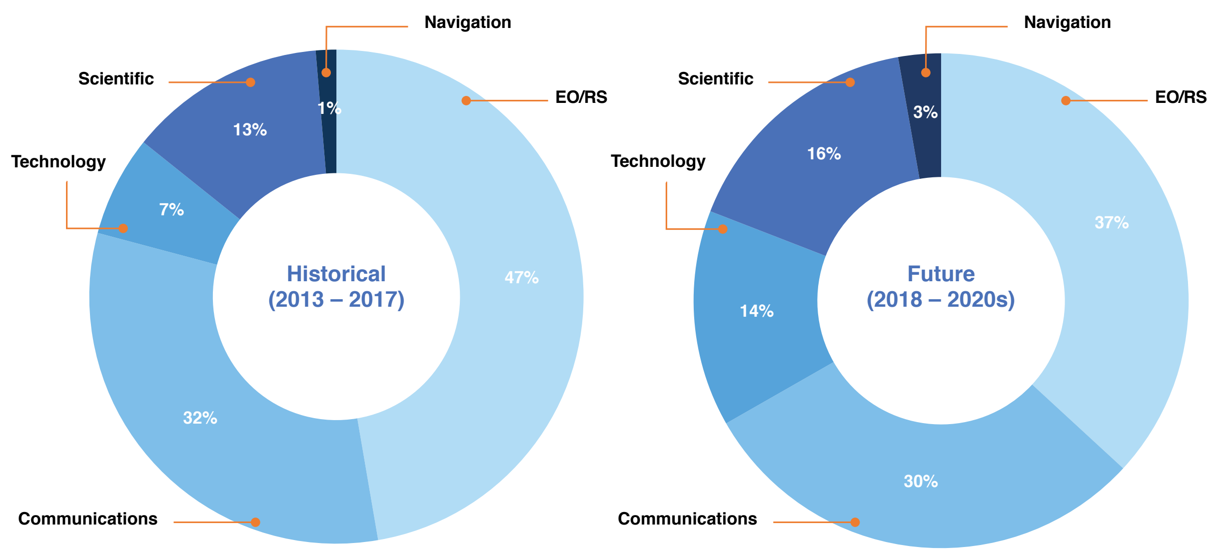
Satellite Applications (1–100 kg)



Earth Observation and Remote Sensing continue to dominate the market, driven primarily by growth of large commercial constellations.

Figure 2

Satellite Applications (101–500 kg)



Source: John E. Bradford, Ph.D. President & Chief Technical Officer, SpaceWorks Enterprises, Inc., DragonCon Presentation on September 3, 2021, Atlanta, Georgia.

including mobile and broadband communications, entertainment, and remote sensing. According to the European Commission, by 2030:

> The global middle class is expected to reach 5.3 billion people. This means an additional 2 billion people with more purchasing power than the earth contains today. Most of this growth will be in Asia. By 2030, China and India together will represent 66% of the global middle-class population and 59% of middle-class consumption.[21]

With the rise of the global middle class, Morgan Stanley expects demands for space-based and associated services to increase significantly.

> We estimate that the ~$350b Global Space Industry will grow to a $1.1t+ Global Space Economy by 2040. Our Bull Case of ~$1.75t (+400 bps v. Global GDP) assumes global internet penetration goes to 100% by 2040, while our Bear Case of ~$600b (-60 bps v. Global GDP) assumes that the new satellite networks fail.[22]

The services feeding into the global space economy are consumer television, consumer broadband, mobile satellite services, remote-sensing services, ground equipment, satellite manufacturing, and space-launch services. In time, other services, such as on-orbit satellite servicing and lunar/asteroid mining, may increase the above numbers.

The overall growth of small-satellite services will increase over the coming decade. However, there will be a shift in the applications of these spacecraft and the types of services provided. Figure 1 illustrates a shift primarily in scientific and communications satellites in the 1–100-kg class. Earth observation and remote sensing will continue to dominate the market, driven primarily by the growth of large commercial constellations.

In the larger (101–500-kg) classes of satellites, there will be an increase in technology demonstrators and scientific applications. The changes depicted in Figure 2 reflect percentage changes of the thousands of small communications satellites in orbit, and hundreds of remote-sensing and Earth-observation satellites.

21 “Growing Consumption,” European Commission, last visited March 29, 2022, https://knowledge4policy.ec.europa.eu/growing-consumerism_en.

22 “Investment Implications of the Final Frontier,” Morgan Stanley, October 12, 2017, https://www.fullertreacymoney.com/system/data/files/PDFs/2017/October/20th/msspace.pdf.

Chapter 2: The National Security Impact of the Small-Satellite Revolution

Small Satellites as Disruptors

Positive Disruptions of Small Satellites

Small satellites are a disruptive technology. Disruptions can be positive or negative within any industry, including national security. As a positive disruptor, small satellites allow the government to field numerous capabilities, such as communications and remote sensing, at significantly reduced costs. The average production and launch costs for small satellites are up to 90 percent lower than those of larger satellites. Because production and per-unit launch costs for small satellites are significantly lower than for larger satellites, on-orbit systems can be replaced as more advanced technology becomes available. This technology refresh rate (as quick as twenty-four months, compared to ten years for more traditional satellites) allows increased capabilities to be fielded at minimal cost and risk.

Another benefit of small-satellite disruption is resilience of space-based assets. Constellations of hundreds of satellites change the targeting dynamics for US and foreign counterspace capabilities. It is easier for a foreign anti-satellite (ASAT) capability to attack one large target than hundreds of smaller ones. This shift in the operational environment could obviate China's and Russia's investments in kinetic anti-satellite systems.[23] A LEO constellation can suffer the loss of one satellite, or even multiple satellites, and still maintain a degraded capability. Additionally, because those satellites are inexpensive to produce and launch, they can quickly be replaced.

The increase in numbers of inexpensive small satellites is a form of resilience, reducing the effectiveness of foreign direct-ascent anti-satellite and co-orbital satellite capabilities. This resilience is effective whether hostile counterspace systems are obstructive, kinetic, or space-based communications downlink jamming. Resilience will be even stronger if laser communications are employed in small-satellite constellations, with the benefits of both eliminating unintentional radiofrequency interference and denying foreign jamming and communications-signal interception. The use of small satellites will likely force hostile actors to shift tactics to cyberattacks and ground- or space-based directed energy. Even directed-energy counterspace systems will have limited effectiveness, given the numbers of small satellites. While adversaries are sure to change tactics to continue to target orbital assets, minimizing the kinetic threat will allow concentration of investment in defenses and make adversaries more vulnerable to counterforce attacks on their remaining offensive ASAT capabilities.

Another dimension of commercial small satellites that complicates decision-making and national security planning for space powers is the fact that these systems are nongovernmental by nature. They support a wide range of globally dispersed customers. Attacks against a commercial company complicate the decision tree for adversaries, particularly in times of peace or pre-crisis. There is little public justification to support attacking a commercial interest in the absence of outright hostilities.

Commercial small satellites offer the US national security apparatus cost-effective capabilities, to include communications and remote sensing. The DoD already uses a large amount of commercial communications, and most operational military remote-sensing requirements can be satisfied by commercial capabilities. Other commercially provided services could include position, navigation, and timing (using commercial space communications) and on-orbit servicing. Over the next decade, the US government's role as a primary consumer for many of these services will be reduced as global use rises. The presence of ubiquitous sensors and communications capabilities on small satellites will reduce costs to the government.

Another positive disruption of small satellites for the Department of Defense is the potential to have secondary payloads added to US or (potentially) allied commercial spacecraft. Secondary payloads could provide unwarned sensors to defeat foreign satellite-warning programs and characterize spacecraft. Small commercial remote-sensing satellites could even be employed to conduct space situational awareness by adding additional sensors and/or changing orientation to look away from Earth.

Negative Disruptions of Small Satellites

Commercial small satellites, new miniaturized technologies, and the dropping of launch costs offer significant positive contributions to US national security. However, the reverse is also true. As other countries employ and exploit commercial small-satellite capabilities, they can present

23 Telephone interview with Douglas Loverro, former deputy assistant secretary of defense for space, July 7, 2021.

A batch of 60 Starlink test satellites stacked atop a Falcon 9 rocket to be put in orbit. Source: SpaceX, Wikimedia Commons, May 24, 2019, https://commons.wikimedia.org/wiki/File:Starlink_Mission_(47926144123).jpg

significant challenges to US security in space. Small satellites can be used as undetected weapons or reconnaissance platforms.

Space technology has become dual use, given the expanded set of small-satellite missions. Any satellite could be used as a weapon. This is because satellites must attain a minimum speed of 17,500 miles per hour (mph) to maintain orbit. At that speed, even a small object, such as a bolt, could destroy a spacecraft if the two collided.

No domestic or international entity can globally regulate commercial small-satellite technology. Only on-orbit actions can be regulated, and that has proven extremely difficult for the international community. This situation leaves significant challenges for the security of US and allied space systems, not the least of which will be detecting, tracking, and characterizing uncontrolled or hostile small satellites and other objects.[24]

The increasing trend of small-satellite (CubeSat) launches failing in early orbit creates a problem of failed identification.[25] These are typically made by universities or amateur groups.

As more CubeSats are launched, and the number of CubeSats contained within a launch cluster increase, more CubeSats will be "dead on arrival." Unidentified CubeSats are nearly impossible to track back to their orbital insertion point, due to the thousands of possible orbital perturbations. Unidentified spacecraft violate guidelines and best practices at the US and international levels, adding to the volume of uncontrolled space debris in orbit.

Even when CubeSats are in their correct orbits, they can present a threat to US space systems. CubeSats could serve as a covert foreign collection platform, or could interfere with space systems. Because these spacecraft are so small, characterizing their onboard capabilities and independently determining their missions is nearly impossible. One can assume some capabilities and missions based on the observed pattern of life (mid-to-long-term behavior) of the satellite, but doing this with thousands of potential threats would be an overwhelming task.[26]

24 With this increased threat to space systems, diplomatic practices to establish on-orbit behavior are increasingly important.

25 CubeSats are small satellites built around a 10-centimeter (cm) building block (i.e., a one-unit or "1U" CubeSat is 10 cm x 10 cm x 10 cm; a 2U is 20 cm x 10 cm x 10 cm, etc.).

26 Artificial intelligence will be critically needed to correlate and analyze massive data pools, such as satellite ephemeris data, remote sensing, SSA, positioning, and telemetry.

US Space Command's recent Global Lightning exercise tested multi-domain space capabilities at the command's joint operations center. *Source:* Lewis Carlyle, US Space Command, April 2021, https://www.spacecom.mil/MEDIA/IMAGERY/igphoto/2002613932/.

Detecting, identifying, tracking, and characterizing small satellites will be equally challenging. There is currently little in the way of a rules-based global system that ensures countries will provide information to each other about satellite capabilities and intent. Satellite service providers are required to register communications capabilities with the International Telecommunications Union (ITU). However, there is no way to verify statements about the capabilities and intent of foreign small satellites. This situation presents a daunting challenge, due to the tens of thousands of small satellites that will be deployed over the next decade. Even if a global requirement to declare all capabilities and intent existed, there is no way to validate the claims.

Another negative disruption that presents challenges for US security in space is widespread cybersecurity vulnerabilities. Space and other mission systems are usually complex, requiring "serious attention to be paid to their people, organizational processes, and technologies—three interdependent elements."[27] Cybersecurity on space systems will present a large challenge for US commercial and national security planners. The use of tens of thousands of small satellites connected to global communications and data will exponentially increase the cyberattack surface area. Space systems are becoming an increasingly large sector in the US and global economy and global cyber infrastructure. This increasing attack surface area will present two specific challenges: to secure use of commercial capabilities for national security, and to protect commercial satellite systems as an element of US critical infrastructure.

The US government will have national security considerations in the use of commercial small satellites, as they present expansive targets for cyber exploitation. First, small-satellite communications architectures are complex, offering numerous opportunities for malicious attacks. The communications link between a ground station and a satellite consists of a wireless link between the satellite and ground station. The link must be encrypted and command authentication in place to prevent hostile takeover of the satellite.

The ground station is connected to a control center, which might be a local link or a link traversing the Internet. The control center itself will likely consist of industry-standard commercially available servers, and those will be

27 Simon Handler, et al., *Mission Resilience: Adapting Defense Aerospace to Evolving Cybersecurity Challenges*, Atlantic Council, May 12, 2021, 2, https://www.atlanticcouncil.org/in-depth-research-reports/report/mission-resilience-adapting-defense-aerospace-to-evolving-cybersecurity-challenges/.

connected to each other via a switch. Their entry point to the Internet is a router with a firewall. The firewall itself may be based on dedicated hardware, or it can be a commercial off-the-shelf (COTS) server with special-purpose software for routing and firewall functions. While the switches are not very vulnerable to attacks, the COTS computer infrastructure is. Attacks against industry-standard servers have proven successful, both against the server and its operating system, and against its baseboard management controller. Attacks against the baseboard management controller can be used to permanently alter the firmware of the server, thereby making the attack persistent and nearly undetectable. In either case, it is possible to take control of the server—and, by doing that, it is possible to issue malicious commands to the satellite. If the link between the ground station and the control center is not secured via a virtual private network, then attacks could be as simple as monitoring the traffic and injecting commands. That is easily done via a switch with port-replication features. Oftentimes, the control center allows for remote-control centers to connect and, as such, the remote-control centers and their links must be protected as well.[28]

There are a plethora of viable attack scenarios, depending on which part of the infrastructure is protected. To ensure safe operation, the following infrastructure must be secured and protected, including:

- ground-station/satellite link;
- control-center/ground-station link;
- control-center server infrastructure;
- control-center link to other remote-control centers; and
- remote-control centers.[29]

Second, defending against cyberattacks is closely tied to supply-chain security as an issue for commercial satellites. Cost is always a consideration for commercial spacecraft providers. The supply chain for commercial small satellites is already global, exposing a potential vulnerability to cyber intrusions and physical sabotage. This situation is not likely to change, as companies need to find the best product at the cheapest cost, regardless of origin. This rule applies to software development as well. This paradigm presents a security problem for the commercial space providers, as well as the US government relying on them.

While national security priorities and "buy American" laws ensure that the vast majority of the development and production of defense systems occurs in the United States, the same is obviously not true for the production of commercial small satellites. The US government will have to employ some level of production and security standards for companies accepting the government as a customer. However, in the case of identifying and managing supply-chain security, this process will be difficult and costly. Primary manufacturers are often unaware of third- and fourth-tier partners, and electronic subcomponent production has largely migrated to China. Depending on how robust the commercial market becomes, there may be little incentive to acquiesce to government supply-chain security standards.

Cybersecurity standards, supply chain, and risk management will allow the DoD to work more easily with the private sector. However, the United States must not approach cybersecurity of commercial space systems in a wholly defensive posture. It will be necessary to develop robust cyberattack capabilities and declarative policies to deter hostile state cyber actors. It must be clear to hostile states that an attack against US satellite systems (commercial or government) will be met with a proportionate response.

Commercial remote-sensing small-satellite constellations will present numerous challenges to US national security. Perhaps one of the greatest challenges will not be in space, but for US air, ground, and sea forces. As global transparency increases, so does the risk to operating military forces. US forces are unlikely to retain the information superiority on which they have come to rely over the last several decades. Adversarial countries and other hostile actors will leverage near-real-time space-based remote sensing, increasing their own security and putting US forces at risk. Near-real-time remote sensing—combined with global ground sensors, tracking of personal communications devices, and DoD integration into the Internet of Things—will present extraordinary risks to deployed special operations and regular forces. The armed services will need to change operating tactics to fully incorporate OPSEC.

Civil-military coordination is going to become critical to the protection and resilience of commercial space systems. There are ongoing efforts by DHS and the private sector to ensure the cybersecurity of critical infrastructure. These efforts include the Barack Obama administration's Presidential Policy Directive 41, the Cybersecurity National Action Plan, the 2013 Executive Order (EO) Improving Critical Infrastructure Cybersecurity, the Donald Trump administration's EO 13800 Strengthening the Cybersecurity of Federal Networks and Critical Infrastructure, the Cybersecurity

28 Discussions and email exchanges with Axel K. Kloth, president and chief executive officer, Abacus Semiconductor Corporation, multiple occasions August through September 2021.

29 Ibid.

Information Sharing Act, and numerous Sector-Specific Plans for critical-infrastructure threat-sharing programs. More civil-military coordination will be necessary as small satellites become a bigger part of the US economy, defense, and critical infrastructure. This coordination will ensure cyber and supply-chain security standards are uniform (or at least understood), and that risk management is coordinated between interlocking critical-infrastructure systems.

Adversarial Capabilities

General David Thompson, the Space Force's vice chief of space operations, has stated that the Space Force responds to "reversible attacks" on US government satellites "every single day." Thompson further opined that China would surpass the United States as the world's global space power by the end of the decade.[30] This report concurs with that assessment.

Any foreign small-satellite service, whether government owned or commercial, could put secondary payloads on its satellites to collect against or destroy US systems. For example, on July 15, 2020, Russia demonstrated anti-satellite capabilities by detaching a small subject from its satellite Cosmos 2543 to trail a US National Reconnaissance Office satellite.[31] Russian satellites conducted similar tests in 2017. These actions threaten US satellites because they can characterize capabilities, interfere with operations, or even destroy the US satellites.

Determining capabilities on foreign small satellites would require exquisite intelligence collection and characterization capabilities, which are difficult now and will be much more so when the numbers of potential threats exponentially increase. The difficulty in determining satellite capabilities was noted as recently as November 2021. The US Space Force reported China's Shijian 21 in elliptical geostationary transfer orbit as high as 35,813 kilometers above Earth, with an inclination of 28.5 degrees to the equator.[32] On November 3, a new object with the international designator 2021-094C was cataloged alongside Shijian (SJ)-21 by Space Force's 18th Space Control Squadron. The object was believed to be an apogee kick motor (AKM) used to modify its transfer orbit to enter geostationary orbit.

Uncharacteristically, SJ-21 and the AKM flew alongside each other, which was unusual for a discharged AKM. Based on the synchronized orbits, the unidentified object was suspected to be conducting counterspace operational testing, to include rendezvous and proximity operations or manipulation using SJ-21's robotic arm.[33] If the AKM had performed maneuvers, it would not be the first time China deployed a small satellite that flew in formation with its larger host. The Tongxin Jishu Shiyan-3 (TJS-3) satellite released a payload in 2018 that performed coordinated maneuvers (perhaps an attempt to confuse space-tracking networks).[34] In January 2022, the SJ-21 maneuvered to capture a defunct Chinese satellite (Compass G2) and towed it to a higher (graveyard) orbit. The SJ-21 then returned to its original geosynchronous orbit.

China's *National Defense in the New Era* report stated in 2019 that "outer space is a critical domain in international strategic competition."[35] The Chinese Communist Party (CCP) incorporated its plans for space development in its foreign and economic policies. For example, the flagship Belt and Road Initiative (BRI) is a trillion-dollar global infrastructure-development program engaging one hundred and thirty-eight countries. This program is generally considered the largest of its kind in history.

One component of China's BRI is the Space Information Corridor. In addition to supporting all the companies China has in the BRI, the Space Information Corridor provides remote sensing, communications, and position, navigation, and timing data to all nations.[36] The Space Information Corridor almost certainly supports the newly established Belt and Road National Security Intelligence System, which is China's Ministry of Public Security using private security companies to provide force-protection information relative to the global BRI infrastructure.

In 2015, Beijing launched the Digital Silk Road (DSR) as an integrated part of the BRI and the Space Information

30 Josh Rogin, "A Shadow War in Space is Heating up Fast," *Washington Post*, November 30, 2021, https://www.washingtonpost.com/opinions/2021/11/30/space-race-china-david-thompson/.

31 Caleb Larson, "Space Wars: Meet Russia's New Anti-Satellite Satellites," *National Interest*, July 27, 2020, https://nationalinterest.org/blog/buzz/space-wars-meet-russia%E2%80%99s-new-anti-satellite-satellites-yes-real-165662; "Russia Conducts Space-Based Anti-Satellite Weapons Test," US Space Command Public Affairs, July 23, 2020, https://www.spacecom.mil/MEDIA/NEWS-ARTICLES/Article/2285098/russia-conducts-space-based-anti-satellite-weapons-test/.

32 "Shijian-21 Satellite Mission," European Space Agency Earth Observation Portal, 2022, https://directory.eoportal.org/web/eoportal/satellite-missions/s/shijian-21.

33 Andrew Jones, "An Object Is Now Orbiting Alongside China's Shijian-21 Debris Mitigation Satellite," *Space News*, November 5, 2021, https://spacenews.com/an-object-is-now-orbiting-alongside-chinas-shijian-21-debris-mitigation-satellite/.

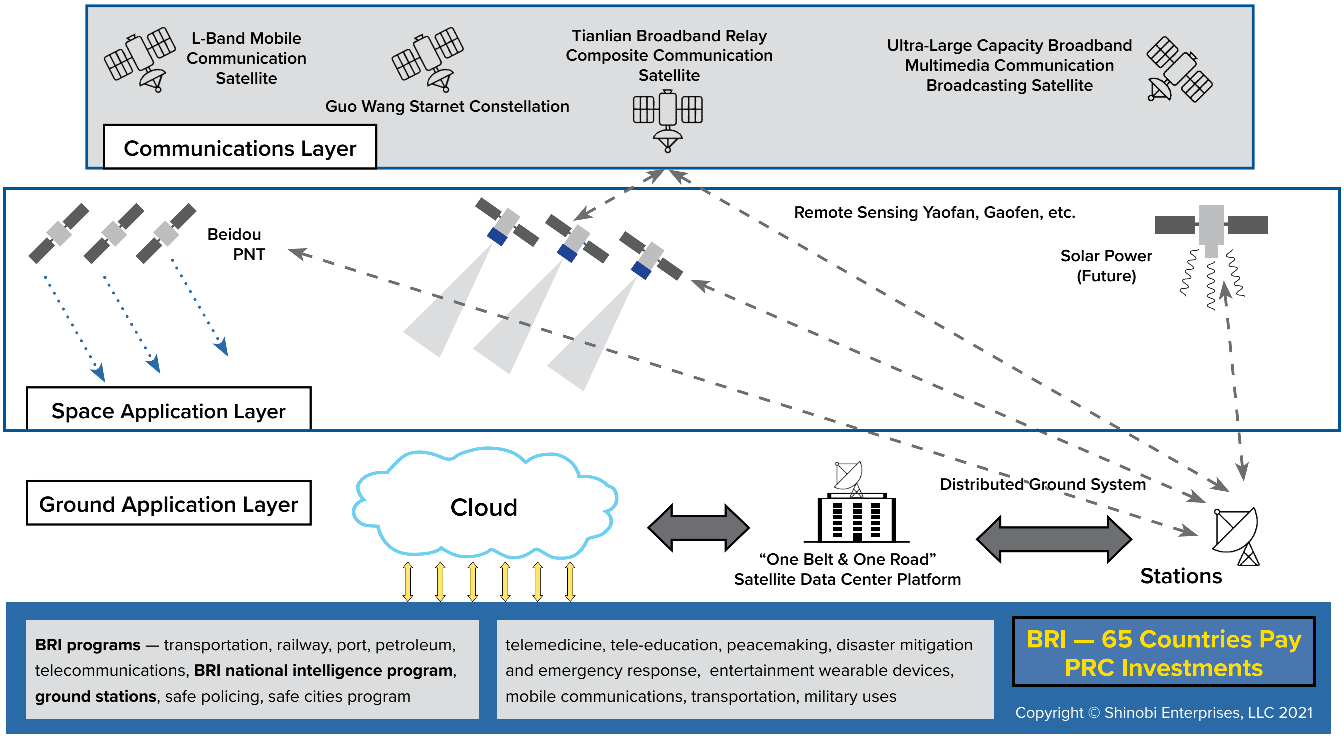
34 Paul Seaburn, "Mystery Object Detected Flying Near Chinese Satellite," Mysterious Universe, November 7, 2021, https://mysteriousuniverse.org/2021/11/mystery-object-detected-flying-near-chinese-satellite/.

35 "China's National Defense in the New Era," PRC Ministry of Defense, July 24, 2019, http://eng.mod.gov.cn/publications/2019-07/24/content_4846452.htm.

36 Jiang Hui, "The Spatial Information Corridor Contributes to UNISPACE+50," International Cooperation Department, China National Space Agency, 2018, https://www.unoosa.org/documents/pdf/copuos/stsc/2018/tech-08E.pdf.

Figure 3

China's Space Information Corridor OV-1



Source: Shinobi Enterprises, LLC 2021, based off information from Jiang Hui, Director of International Cooperation, China National Space Administration, Presentation to the United Nations Committee for Peace Use of Outer Space.

Corridor. Chinese telecommunications companies (Huawei, ZTE, Hikvision, etc.) develop the DSR, which supports BRI companies operating overseas. The DSR develops countries' "telecommunications networks, artificial intelligence capabilities, cloud computing, e-commerce and mobile payment systems, surveillance technology, and smart cities."[37] Some reports assess one third of BRI participants have contracts for DSR support.[38] Press reports over the years identified instances in which collected data through the DSR have been sent to China. China's cybersecurity law requires Chinese companies to store all data in the People's Republic of China. China's National Intelligence Law mandates that Chinese companies assist the government when requested.

The BRI includes other space-related initiatives, including university collaborations and engineering education throughout the emerging world. Through BRI, DSR, and the Space Information Corridor, China has effectively integrated its space programs, intelligence collection, economy, and foreign policy. This is being achieved throughout emerging economies globally by weaving space capabilities and digital infrastructure into China's global strategy for economic growth and development. If participation continues to grow as expected, China will democratize space for the world. In so doing, it will also dominate space information globally.

Adversarial governments are likely to leverage commercial small satellites for military and intelligence purposes. This threat is difficult to assess, because there is so little information in the public domain and competitor commercial small-satellite networks are not yet fully deployed. It is likely that the threat to US space systems will increase based on:

- Russia's use of small satellites to surveil US reconnaissance platforms;
- China's on-orbit proximity operations (testing); and
- China's Academy of Military Science writings on the use of national security space, along with similar publications like the 2019 *Defense White Paper* and *Space Science & Technology Plan 2050*.

37 Joshua Kurlantzick and James West, "Assessing China's Digital Silk Road Initiative: A Transformative Approach to Technology Financing or a Danger to Freedoms?" Council on Foreign Relations, https://www.cfr.org/china-digital-silk-road/.

38 Ibid.

Chapter 3: The DoD and IC Response to Commercial Small-Satellite Advancements

For more than a decade, the Defense Department and Intelligence Community were oblivious to the dynamic changes emerging in commercial space. In recent years, the defense establishment has been moving to take advantage of the capabilities offered by small commercial satellites in large constellations. Less attention has been paid to countering the growing threat from large numbers of foreign commercial small satellites and their collection capabilities. The challenge is complex and requires changes to national policies, acquisition processes, operational doctrine, and international relationships.

US Department of Defense

There are two organizations in the Department of Defense leading efforts to take advantage of the small-satellite revolution: the Space Development Agency (SDA) and US Space Force. Each has a role in developing, integrating, and making operational use of commercial space capabilities and services.

Space Development Agency

The SDA is moving to develop an integrated, distributed space architecture of small satellites. This architectural concept seeks to integrate layers of newly developed LEO small-satellite constellations to provide operational support to warfighters. The SDA is developing small-satellite constellations to populate what it calls the National Defense Space Architecture (NDSA). The SDA envisions that the NDSA will be a single, integrated, proliferated space architecture with seven layers: Transport (Communications), Tracking, Custody, Battle Management, Navigation, Deterrence, and Support.

The NDSA integrates these layers of newly developed LEO small-satellite constellations to provide operational support to warfighters. This type of support is distinguished from strategic-level capabilities provided by a variety of national systems. The SDA has started developing small satellites and payloads in what it hopes to be two-year cycles, using commercially available technology as much as possible.[39]

The NDSA will attempt to integrate capabilities in a mesh network comprising seven capability layers. The completion of a high-bandwidth, low-latency constellation is necessary to achieve the critical priorities for military operations support identified by the Joint Requirements Oversight Council (JROC). However, the JROC process can take months, or even years, thereby ensuring the most immediate and evolving warfighter requirements will not be met.[40] Theoretically, if the refresh rate on NDSA small satellites is adequate and maintained, it will be possible to update capabilities on a biannual basis. In numerous telephone interviews conducted with DoD space officials, former senior leadership, and private industry, the JROC process was identified as a major stumbling block to securing cutting-edge small-satellite capabilities for operational support to warfighters.

The SDA's Transport Layer is critically important, providing global connectivity to warfighters. Final modeling for this constellation of support satellites varies, from as few as three hundred to more than five hundred satellites in 750–1,200-km LEO orbit. A fully operational Transport Layer would provide 95 percent of anywhere on Earth with at least two satellites in view and 99 percent of Earth with at least one satellite in view. Such a support architecture would provide warfighters with connectivity anywhere, anytime. Optical Inter-Satellite Links (OISLs) will provide the Transport Layer with significantly enhanced radiofrequency (RF) crosslinks. Synchronized communication between OISLs and satellites in LEO will reduce path loss and latency, ensuring prosecution in time-sensitive targeting.

The SDA's Transport Layer is likely to initially operate over the Ka band, offer stereo coverage, and be networked to maximize bandwidth and fault tolerance.[41] Other satellite constellations will have comparatively limited capabilities. The Tranche 0 constellation (expected in 2022) will consist of just twenty satellites with different configurations of laser/optical communication terminals, along with RF.[42]

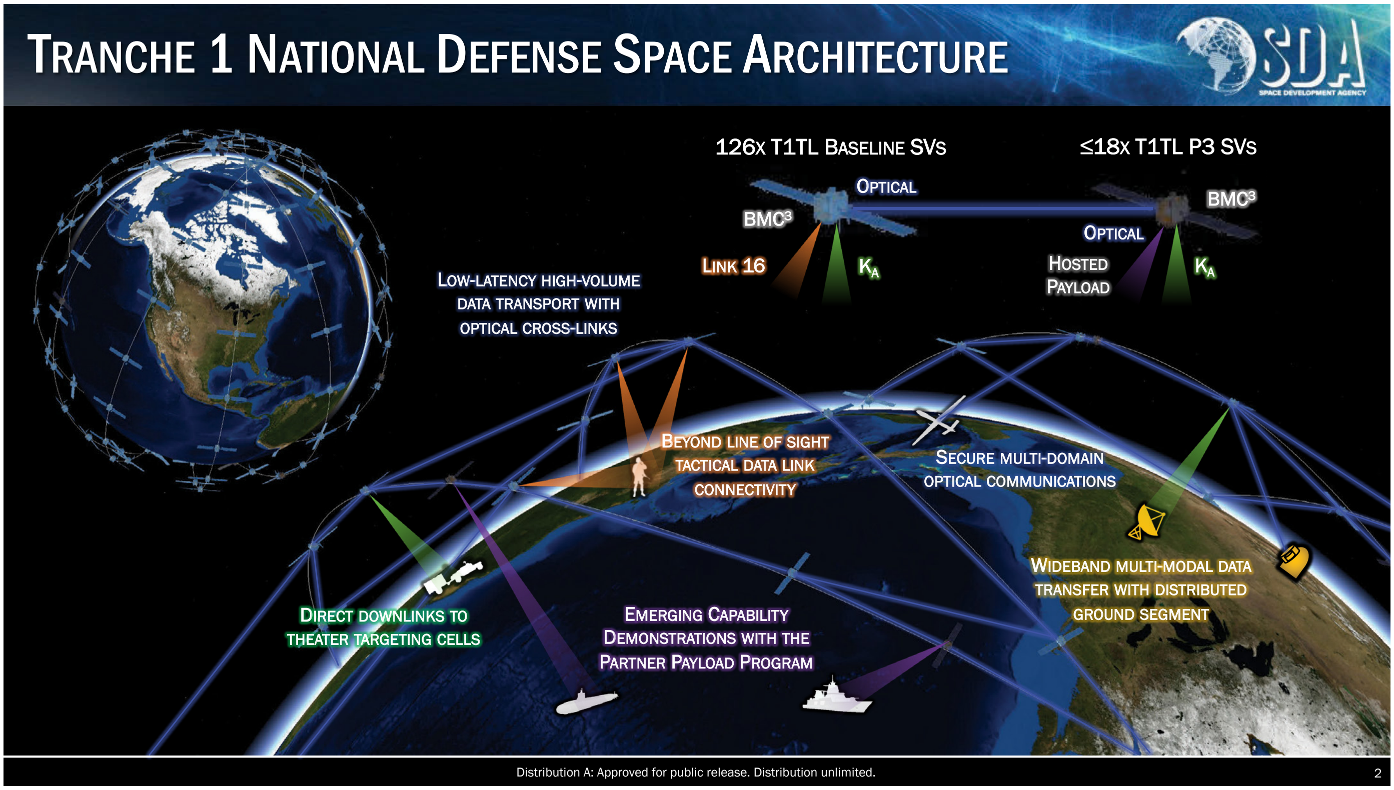
39 Sandra Erwin, "Space Development Agency lays out five-year plan in $11 billion proposed budget," *Space News*, October 6, 2019, https://spacenews.com/space-development-agency-lays-out-five-year-plan-in-11-billion-proposed-budget/; Telephone interview with Dr. Derek Tournier, director SDA.

40 General John E. Hyten, former vice chairman of the Joint Chiefs of Staff, has, on several occasions, publicly commented on the unacceptably slow processes of the JROC and is attempting to accelerate processes. Sandra Erwin, "Hyten Blasts 'Unbelievably' Slow DoD Bureaucracy as China Advances Space Weapons," *Space News*, October 28, 2021, https://spacenews.com/hyten-blasts-unbelievably-slow-dod-bureaucracy-as-china-advances-space-weapons/.

41 Ka-band services use the 26.5–40-gigahertz (GHz) segment of the electromagnetic spectrum.

42 Email exchange with SDA, September 20, 2021.

Figure 4



The Space Development Agency is working to establish the foundation for Tranche 1 Transport Layer (T1TL), a mesh network of 126 optically interconnected space vehicles to be launched by 2024. This network of satellites will provide a resilient, low-latency, high volume data transport communication system. *Source:* Space Development Agency, SDA Tranche 1 Transport Layer (T1TL) Virtual Industry Day Presentation, August 26, 2021. https://www.sda.mil/special-notice-sda-tranche-1-transport-layer-t1tl-industry-day/.

SDA announced a space-to-air optical-communications demonstration in summer 2021.[43]

Future upgrades would include Link-16 and the Integrated Broadcast System (IBS), and would improve data-routing capacities.[44] Integrating IBS and Link-16 will ensure the Transport Layer's capacity to provide timely threat-warning and situational-awareness information worldwide. The Transport Layer constellation will eventually integrate OISLs, providing an upgrade in performance over initial RF crosslinks.[45]

If all planning goals are achieved, SDA's Transport Layer will grow to more than two hundred and fifty small satellites by 2025. The satellites would beam communications signals to weapons systems on the ground, at sea, and in the air.[46]

The Tracking Layer is a shared responsibility between SDA and the Missile Defense Agency (MDA). SDA's national defense space architecture will eventually also include MDA's Hypersonic and Ballistic Tracking Space Sensor (HBTSS) system. Successful integration of HBTSS would enable the Tracking Layer's network of satellites with medium and wide field-of-view sensors to identify and track weapons traveling and maneuvering at speeds faster than sound. The SDA further aims to incorporate capabilities such as tracking ballistic missiles with dim upper stages. Space Force's next-generation Overhead Infrared missile-warning constellation (now in development) would be significantly

43 Sandra Erwin, "DoD Space Agency to Launch Laser Communications Experiments on SpaceX Rideshare," *Space News*, June 2, 2021, https://spacenews.com/dod-space-agency-to-launch-laser-communications-experiments-on-spacex-rideshare.

44 Link 16 is a standardized communications system used by US, NATO, and coalition forces for transmitting and exchanging real-time tactical data using links between allied military network participants. "On Orbit," Space Development Agency, https://www.sda.mil/on-orbit. IBS is a program to replace legacy intelligence broadcast systems with a single worldwide intelligence-dissemination service. "Integrated Broadcast Service (IBS)," Global Security, https://www.globalsecurity.org/intell/systems/ibs.htm.

45 Telephone interview with Derek Tournier, director, SDA, August 3, 2021; "Transport," Space Development Agency, https://www.sda.mil/transport.

46 Ibid.

abetted by the Tracking Layer.[47] The SDA is targeting 2024 for having operational satellites. The Government Accountability Office (GAO) found this time estimate overly optimistic, citing "significant technical and managerial challenges."[48] In addition, the GAO notes that Space Force did not provide congressional defense committees accurate insights into the schedule risks in its recent quarterly reports to congressional defense committees.[49]

The capability to track ground targets will be accomplished by a third constellation, the Custody Layer. Development currently involves an enmeshed series of projects being carried out by the National Reconnaissance Office, Navy, Army, and Space Force. The SDA will oversee the deployment of more than two hundred satellites carrying a mix of sensors. The Transport Layer and Custody Layer will interact, such that those individuals monitoring and operating within the capabilities of the Custody Layer can seamlessly transmit target data to tactical weapons systems.

The Battle Management Layer is a support software (not another constellation) that will integrate upgrades to tasking, mission command and control, data dissemination, and "sensor to shooter data products."

The Navigation Layer will supplement the Global Positioning System (GPS) with alternate timing, navigation, and positioning data. This effort is expected to use the Transport Layer's communications signals to allow forces to operate in GPS-denied environments.

The Deterrence Layer will gather information from geostationary orbit, the cislunar space between Earth and the moon. This information will support space situational awareness. Current architecture captures data supporting situational awareness from low-Earth orbit to twenty-three thousand miles above Earth, in geostationary orbit. Modern models have been largely limited to the boundaries of geostationary orbit, and not beyond.[50] In the United States, the National Aeronautics and Space Administration (NASA) and commercial space companies have shown interest in, and have developed plans for, travel to the moon. China, Russia, Europe, and other entities have shown similar interest in lunar development. Satellites positioned in the cislunar region could control access to the moon, or launch undetected attacks against space systems.

The final architecture component is the Support Layer, which is envisioned to provide approximately forty launches and the required ground infrastructure, including systems and user terminals.[51]

Key Technologies for SDA Small-Satellite Development

A few keystone technologies will be critical to SDA plans for the NDSA. Those technologies will also allow for the foundation of the DoD and the private sector's future employment of small satellites. These technologies include laser communications, encryption, and ground systems.

Laser Communications

SDA will need to develop laser communications (space-to-space, space-to-air, and space-to-ground) to be successful in the NDSA. Laser communications will be necessary to fully utilize the Transport Layer and meet the time-latency demands of other architectural components and warfighters. In addition, laser communications (space-to-air and space-to-ground) will be necessary for operational forces to defeat anti-access/area-denial (A2/AD) strategies targeting RF communications. China employs an extensive A2/AD capability in the South China Sea to potentially inhibit movement and deny freedom of action to US and allied forces. The ability to jam, intercept, or detect communications has profound consequences, but would be mitigated with laser communications, which offer comparative communications security with high data rates across ground, air, and space domains.

Radiofrequency-band systems will not provide the low-latency high throughput necessary to fully support warfighters, particularly for ballistic and hypersonic missile defense. Optical links (i.e., laser communications) offer data rates of about one gigabit per second, as well as lower latency between space, air, and ground assets, when compared with conventional radiofrequency links, making them a viable pathway of getting real-time data to warfighters.

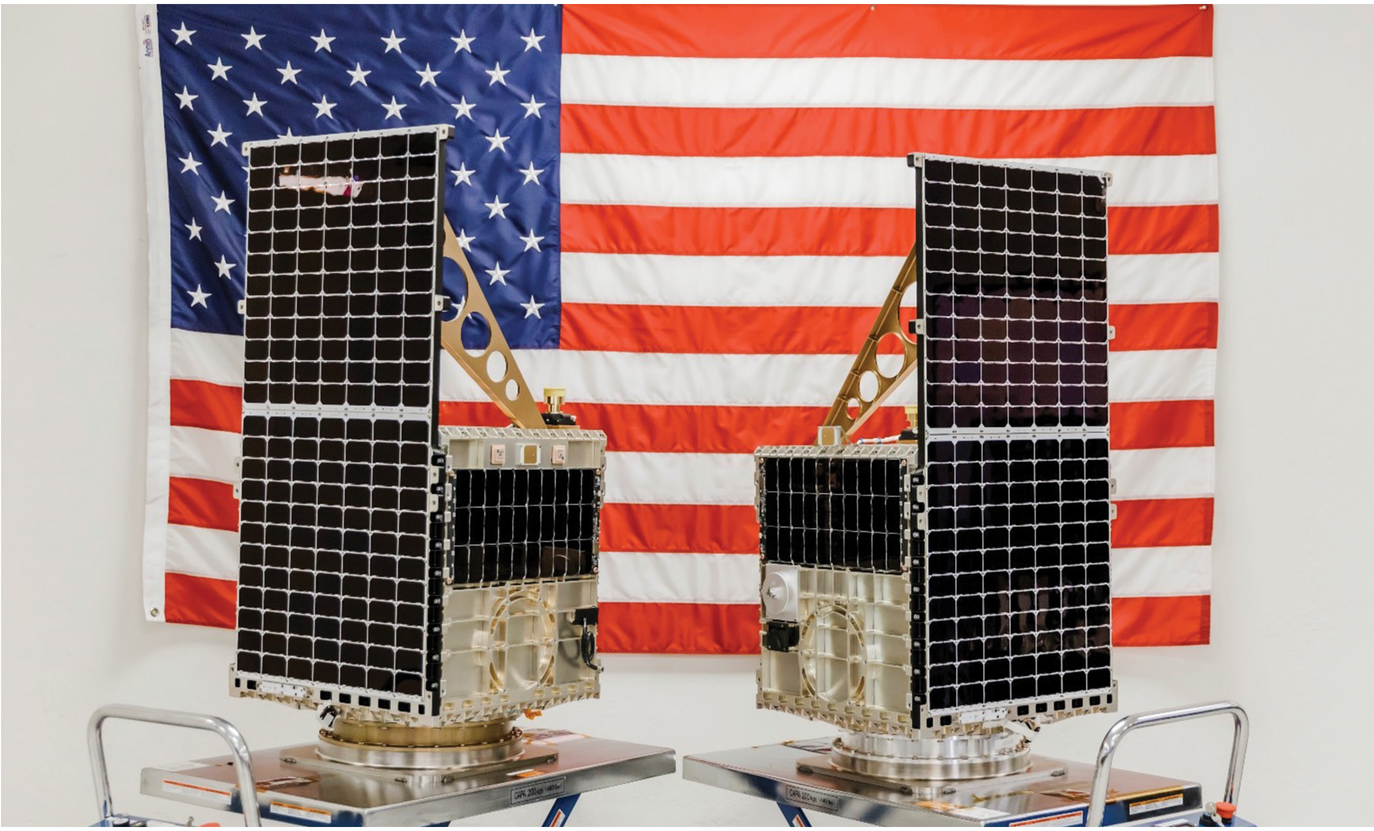
47 Sandra Erwin, "Congress Reviewing New Request to Reprogram Funds for Next-Generation OPIR Satellites," *Space News*, July 29, 2019, https://spacenews.com/congress-reviewing-new-request-to-reprogram-funds-for-next-generation-opir-satellites/.

48 "Comprehensive Cost and Schedule Information Would Enhance Congressional Oversight," US Government Accountability Office, September 2021, 12, https://www.gao.gov/assets/gao-21-105249.pdf.

49 Ibid.

50 Stew Magnuson, "Details of the Pentagon's New Space Architecture Revealed," *National Defense Magazine*, September 19, 2019, https://www.nationaldefensemagazine.org/articles/2019/9/19/details-of-the-pentagon-new-space-architecture-revealed.

51 "National Defense Space Architecture (NDSA), Systems, Technologies, and Emerging Capabilities," Space Development Agency, January 25, 2021, https://sam.gov/opp/04658bc6d1884a8f9b67f0cfdc5d6cbe/view?keywords=HQ085021S0002&sort=-relevance&index=&is_active=true&page=1; Sandra Erwin, "Space Development Agency Lays out Five-Year Plan in $11 Billion Proposed Budget," Space News, October 6, 2019, https://spacenews.com/space-development-agency-lays-out-five-year-plan-in-11-billion-proposed-budget/.



Mandrake 2 spacecraft Able and Baker pre-launch. *Source:* Astro Digital, Defense Advanced Research Projects Agency, July 7, 2021, https://www.darpa.mil/news-events/2021-07-07.

Space-based laser communications are a challenging technology requiring highly stable attitude control and fine-grade pointing and tracking.

The idea of satellite laser communications is not new, although their employment on small satellites is quite new. Several companies and governments are in different stages of developing this capability. In 2008, the United States and Germany established the first successful and stable orbital laser link between two operational satellites in LEO (the German radar satellite TerraSAR-X and the US Missile Defense Agency satellite NFIRE).[52]

SDA, along with the Defense Advanced Research Projects Agency and Air Force Research Laboratory, began a laser communications experiment called Mandrake II. Launched in June 2021, this experiment will test optical links at increasing ranges, with an expected maximum distance of twenty-four hundred kilometers, based on orbital limitations.[53]

The SDA's Laser Interconnect and Networking Communication System (LINCS) experiment consists of two 12U CubeSats featuring laser communications terminals. The two LINCS space vehicles were launched in June 2021 to test space-to-space, space-to-air, and space-to-ground optical communication terminals. As of late September 2021, the two satellites were tumbling and unresponsive to ground controllers.[54]

Another key technology that will be required to realize the business case for the NDSA is medium-field-of-view sensors. The MDA's HBTSS will track inbound ballistic hypersonic missiles from LEO. HBTSS medium-field-of-view sensors deployed on small satellites will enable the capacity to detect, track, and discriminate among threats. This capability would exchange data with wide-field-of-view systems, which have global coverage and can detect and track fairly dim targets, particularly hypersonic glide systems. The wide-field-of-view systems would pass information to HBTSS, which provides fire-control information to

52 "Laser Communication," Airbus, https://airbusus.com/laser-communication.

53 "Mandrake II Overview," Space Development Agency, https://www.sda.mil/on-orbit.

54 "On Orbit," Space Development Agency, https://www.sda.mil/on-orbit.

warfighters.[55] The MDA is also working with industry to develop and test additional medium-field-of-view, multi-spectral infrared imagers to advance imaging and processing capabilities. These capabilities also have implications for weather forecasting and climate monitoring.[56]

Encryption

As the cyberattack surface grows with small satellites, so will the requirement to implement encryption capabilities. Presidential Directive, Space Policy Directive-05 issued in September 2020, established the following key cybersecurity principles of space systems:[57]

- Space systems and their supporting infrastructure, including software, should be developed and operated using risk-based, cybersecurity-informed engineering.

- Space-systems operators should develop or integrate cybersecurity plans for space systems that include capabilities to ensure operators or automated control-center systems can retain or recover positive control of space vehicles, and verify the integrity, confidentiality, and availability of critical functions and the missions, services, and data they provide.

- Space-system cybersecurity requirements and regulations should leverage widely adopted best practices and norms of behavior.

- Space-system owners and operators should collaborate to promote the development of best practices and mitigations, to the extent permitted by law and regulation.

- Space-system security requirements should be designed to be effective, while allowing space operators to manage appropriate risk tolerances and minimize undue burden to civil, commercial, and other nongovernment space-system operators.

These recommended courses of action are general principles, which is probably all that can be pursued by the Department of Homeland Security's Cybersecurity and Infrastructure Security Agency. If commercial space systems are designated critical infrastructure, as proposed in a recent bipartisan bill—the Space Infrastructure Act—a Sector-Specific Agency would assist in sharing and integrating best practices in cybersecurity.

Secure encryption is required now, but the need for capability will increase over the next decade. China recently established a two-thousand-kilometer communication line connecting Beijing and Shanghai with the launch of the world's first quantum satellite. Further, China unveiled a super-advanced sixty-six-qubit quantum supercomputer prototype.[58] The rate of advances in quantum computing suggests the need for quantum encryption for space systems will grow over the next decade.

Ground Storage, Networking, and Processing

The Defense Department will need to expand data-processing capabilities to include advanced analytics, AI, machine learning (ML), and global distribution if it is to realize SDA's vision for using small satellites.[59] The SDA LEO architecture will produce streams of data that, as of yet, the DoD can neither move nor process in an operationally relevant timeframe. In the case of ballistic or hypersonic missiles, that timeframe might be seconds. AI, data management, and analytics will be key components of DoD's ability to support warfighter decision-making through the NDSA.

To develop the required ground infrastructure, the Defense Innovation Unit contracted Ball Aerospace and Microsoft to demonstrate how cloud processing could handle the increased data produced by SDA's distributed constellation of small satellites. In May 2021, the Commercially Augmented Space Inter Networked Operations Program Office successfully demonstrated an initial data-processing capability. This test was accomplished by injecting simulated data into the cloud, where it was processed. The processed data were then disseminated to multiple endpoints.[60]

55 Sandra Erwin, "Missile Defense Agency Selects Four Companies to Develop Space Sensors," *Space News*, October 30, 2019, https://spacenews.com/missile-defense-agency-selects-four-companies-to-develop-space-sensors.

56 Ibid.

57 The following bullets are from "Trump Administration Launches First Cybersecurity Principles for Space Technologies," US Department of Homeland Security, September 4, 2020, https://www.dhs.gov/news/2020/09/04/trump-administration-launches-first-cybersecurity-principles-space-technologies.

58 "China's Quantum Technology Realizes Industrial Application," CGTN, September 19, 2021, https://news.cgtn.com/news/2021-09-19/China-s-quantum-technology-realizes-industrial-application-13G8NZRcY24/index.html; David Nield, "Record-Breaking Chinese Supercomputer Marks New Quantum Supremacy Milestone," MSN, July 14, 2021, https://www.msn.com/en-us/news/technology/record-breaking-chinese-supercomputer-marks-new-quantum-supremacy-milestone/ar-AAM7VFM.

59 Telephone interview, with Kari Bingen, former principal deputy under secretary of defense (PDUSD) for intelligence, July 2, 2021.

60 Nathan Strout, "A Pentagon Experiment to Process the Torrent of Data from Space," C4ISRNET, September 26, 2019, https://www.c4isrnet.com/battlefield-tech/space/2019/09/26/a-pentagon-experiment-to-process-to-the-torrent-of-data-from-space/; "The Team Of Ball Aerospace + Microsoft Complete Cloud Demos That Securely Deliver Actionable Intelligence To Warfighters," Sat News, May 19, 2021, https://news.satnews.com/2021/05/19/the-team-of-ball-aerospace-microsoft-complete-cloud-demos-that-securely-deliver-actionable-intelligence-to-warfighters/.

Space Force

The US Space Force is attempting to incorporate the speed and capabilities of commercial space companies.

In 2021, Space Force launched a new outreach program, awarding startups and small businesses with contracts totaling as much as $50 million.[61] SpaceWERX, Space Force's space-focused spinoff of the Air Force's 2017 AFWERX, taps into investments available within the private sector to seed developing technologies pertinent to national security.

On August 19, 2021, SpaceWERX hosted a virtual Space Force Pitch Day. Each of the participants had already received $50,000 Phase 1 awards for Space Force study contracts. At the event, companies pitched technologies to compete for up to $34 million in Small Business Innovation Research Phase 2 contracts.[62]

The SpaceWERX program replicates many "industry day" and similar investment efforts conducted throughout the DoD. Similar programs have existed at different agencies in DoD for decades. The program will likely be minimally effective in moving smaller companies to develop nascent technologies. There is little evidence to suggest that this approach will significantly improve the commercialization of these technologies or the department's ability to acquire them in a timely fashion. Even successful companies complain these programs only move them through the initial stages of research and development (R&D), and do little to help them advance the technologies or bring them through to market.

The DoD has at its disposal other prototype-development programs that should be utilized for small-satellite development efforts. Other Transaction Authority (OTA) is a streamlined contracting mechanism that allows DoD organizations to avoid certain contract requirements. The organizations are thereby able to solicit, evaluate, and award contracts in reduced timeframes.[63] SDA is using OTA authorities to develop Transport Layer Tranche 1 after its initial Request for Proposals selection was protested by Maxar technologies.[64] SDA also used OTA to contract to produce eight missile-tracking Tranche 0 satellites.

Since 2015, the OTA procurement process was used for commercial space prototyping and technology development. DoD awarded SpaceX a $150-million contract, and Blue Origin $220 million.[65] These are quite small amounts given that OTA contracts represent less than 3 percent of research, development, test, and evaluation (RDT&E) spending. Another option for rapid procurement of proven small-satellite technologies is Middle Tier of Acquisition under Section 804 of the National Defense Authorization Act for Fiscal Year 2016 (Public Law 114-92).[66] This authority allows the Defense Department "to rapidly prototype and/or rapidly field capabilities under a new pathway, distinct from the traditional acquisition system. Middle Tier of Acquisition is a rapid-acquisition interim approach that focuses on delivering capability in a period of two to five years, with rapid prototypes and rapid fielding with proven technology."[67] The Middle Tier allows for rapid prototyping (up to five years) and rapid fielding (up to five years).[68] However, small-satellite capabilities have a technology refresh rate of approximately twenty-four months.

Other models in the government have proven successful in developing and fielding technologies through public-private partnerships. For example, the IC, led by the Central Intelligence Agency, has had extraordinary success creating and using the company In-Q-Tel to attract investor funding to develop commercial technologies that would need little or no modification to support IC requirements.[69] In-Q-Tel is a US not-for-profit venture-capital firm that invests in high-tech startup companies with technologies that could increase US intelligence capabilities. In-Q-Tel makes one investment per week, and has more than five hundred investments in its portfolio. "Every $1 invested by In-Q-Tel leverages $18 in private sector investment."[70] The technologies are developed at a rapid pace to compete

61 Sandra Erwin, "Space Force to Kick off New Program to Attract Small Businesses and Startups," *Space News*, August 12, 2021, https://spacenews.com/space-force-to-kick-off-new-program-to-attract-small-businesses-and-startups/.

62 Sandra Erwin, "A Little Love from the Air Force Can Put a Space Business on the Map," *Space News*, March 22, 2021, https://spacenews.com/a-little-love-from-the-air-force-can-put-a-space-business-on-the-map/.

63 Sandra Erwin, "DoD Space Agency Changes Course on Satellite Procurement in Wake of Maxar's Protest," *Space News*, October 28, 2021, https://spacenews.com/dod-space-agency-changes-course-on-satellite-procurement-in-wake-of-maxars-protest.

64 Ibid.

65 Doug Berenson, "Three Myths (and Realities) around OTA Contracts," Avascent, September 22, 2021, https://www.avascent.com/news-insights/avascent-proving-ground/three-myths-and-realities-around-ota-contracts.

66 "Middle Tier of Acquisition," AcqNotes, https://acqnotes.com/acqnote/acquisitions/middle-tier-acquisitions.

67 S. 1790 (116th): National Defense Authorization Act for Fiscal Year 2020, US Congress, December 19, 2019, https://www.govtrack.us/congress/bills/116/s1790/text.

68 "Middle Tier of Acquisition," Mitre Corporation, July 2019, 4, https://aida.mitre.org/wp-content/uploads/2019/07/Middle-Tier-of-Acquisition-23-Jul-19.pdf.

69 Telephone interview with Douglas Loverro.

70 "How We Work," In-Q-Tel, https://www.iqt.org/how-we-work/.

in commercial markets. In-Q-Tel has invested in thirteen companies to develop small-satellite space capabilities to include space-based radar, launch, micro-propulsion, communications, IoT, and the global navigation satellite system.[71] At least one of those companies (Rocket Lab) went public on the US stock exchange in 2021.

Other public-private-sector models have proven successful in developing and fielding needed technologies, including semiconductor and energy-storage technology. For example, the US Advanced Battery Consortium directs electrochemical energy storage R&D relevant to stakeholders in the automotive industry, energy storage-system manufacturers, the Department of Energy, national laboratories, universities, and others.[72] NASA's Commercial Orbital Transportation Services began investing approximately $800 million toward cargo space transportation flight demonstrations. That investment was made in two phases to several companies from 2006 to 2012, and eventually culminated with Space Act Agreements for commercial logistical support to the International Space Station (ISS). The Space Act Agreements provided a NASA commitment to purchase services to provide logistics support for the ISS.[73] This program is largely responsible for the growth and success of SpaceX as a commercial space disruptor.

The Intelligence Community

The IC has taken advantage of commercial imagery generated through small satellites. In 2017, the National Geospatial Intelligence Agency (NGA) gave responsibilities for commercial imagery procurement to the National Reconnaissance Office (NRO). In 2021, the NRO announced new initiatives aimed at taking advantage of commercial space services, including those offered by small-satellites operators. The NRO announced plans to incorporate commercial imagery in two programs.

1. In October 2021, the NRO announced a new acquisition strategy to acquire commercial remote-sensing capabilities. The Broad Agency Announcement (BAA) Framework for Strategic Commercial Enhancements focuses on new and emerging phenomenologies, such as commercial radar, hyperspectral imagery, radiofrequency sensing, and emerging and evolving electro-optical capabilities.[74]

2. In November 2021, the NRO released a request for proposal (RFP) for commercial acquisition of an Electro-Optical Commercial Layer (EOCL). The EOCL will deliver "the next generation of commercial imagery to meet the intelligence, defense, and federal civil agency user communities' mission needs."[75] The RFP indicates that the NRO plans to shift from its current single-source imagery provider to multi-vendor agreements. Recent NRO study plans have included two small-satellite constellation operators.

NRO's acquisition of commercial imagery is currently valued at $300 million annually. It is unknown whether the government expects to increase this amount, and, if so, by how much. It is likely there will be some increase in the commercial imagery budget to satisfy military, environmental, disaster response, and other less-sensitive government imagery requirements. Multiple imagery suppliers would spur commercial innovation and enhance the small-satellite remote-sensing industry.

In addition to the NRO acquisitions, the National Geospatial Intelligence Agency (NGA) awarded a five-year, $30-million contract to BlackSky to provide real-time geospatial intelligence and global monitoring. According to the project's website, "BlackSky will use advanced AI and multi-sensor analytics to detect and understand objects of significant economic interest. The project will employ automated methods to provide analysts and decision makers with insights on relevant global economic indicators."[76]

71 "In-Q-Tel Portfolio," In-Q-Tel, https://www.iqt.org/portfolio?&taxonomy=tech_areas&tax_id=220.

72 "U.S. Advanced Battery Consortium LLC," US Advanced Battery Consortium, 2021, https://www.uscar.org/guest/teams/12/U-S-Advanced-Battery-Consortium-LLC.

73 "NASA Commercial Orbital Transportation Services," NASA, last updated March 2, 2012, https://www.nasa.gov/offices/c3po/about/c3po.html; telephone interview with Dr. John Olds, SpaceWorks, September 23, 2021.

74 "NRO Announces Acquisition to Explore New and Emerging Commercial Capabilities," National Reconnaissance Office, press release, October 7, 2021, https://www.nro.gov/Portals/65/documents/news/press/2021/BAA_Press_Release_Oct_7_2021.pdf.

75 "NRO Announces Acquisition for Next Generation of Commercial Imagery," National Reconnaissance Office, press release, November 3, 2021, https://www.nro.gov/Portals/65/documents/news/press/2021/EOCL_Press_Release_11032021.pdf.

76 "BlackSky Awarded Five Year $30 Million NGA Contract," BlackSky, press release, September 7, 2021, https://www.blacksky.com/2021/09/07/blacksky-awarded-five-year-30-million-nga-contract.

Chapter 4: The Civil Space Response: Domestic and International Cooperation

Civil space operations (i.e., those not for military or commercial purposes) are increasingly essential to national security, and will be revolutionized by small-satellite applications. Three civil space applications particularly susceptible to the small-satellite revolution are space traffic management, regulatory regimes, and on-orbit mission authority.

Space Traffic Management

One of the consistent messages from government and industry experts interviewed during this study was the necessity for effective STM. No interviewee believed that current management practices were adequate. The lack of an effective system for STM is probably the greatest threat to small-satellite industry growth and the sustainability of space operations. Absent any advances in STM, the probability of satellite collision will increase significantly by 2030, potentially rendering orbital regimes less safe for operations.

To support commercial, civil, and scientific space operations, the commercial United States needs the best possible data to help track the estimated five hundred thousand to one million space objects (satellites and debris) in orbit now, and the estimated fifty thousand new satellites expected to be on orbit by 2030.[77] In addition to the increased number of satellites, rendezvous and proximity operations and orbital transfers will increase the complexity of the operational environment. Space situational awareness based on accurate data will be an essential capability for the global space industry.

Space Policy Directive-3 (Space Traffic Management Policy) of 2018 designated the Department of Commerce's Office of Space Commerce as the lead civilian agency for providing basic SSA data and STM services to space operators.[78] This responsibility was affirmed by the 2020 National Space Policy and a congressionally directed study.[79]

The US Congress identified $10 million in funding for the OSC in the Consolidated Appropriations Act of 2021, of which $5.9 million is available to begin developing an STM prototype known as the Open-Architecture Data Repository (OADR). The OADR demonstration phase was completed in the late fall of 2021. The OADR demonstration is being designed to ingest data and services from commercial and government sources into a prototype cloud-based data repository. The OADR prototype will provide data regarding the location of space objects to improve transparency and promote safety for space assets and operations.

The OADR is not DoC's only responsibility in its STM mission. Another key responsibility is to learn (and then develop) standards and best practices from industry, and advocate for those for inflight safety, sustainability, and advancing the US commercial sector.

DoC leadership states that "OADR will create opportunities for US companies, especially small businesses, to play an innovative role in the commercial space management arena."[80] At this point in the development of the OADR, there is little indication that this is the case. DoC plans to incorporate "features and source data within the platform targeted to enable industry innovation and development of new space technology."[81] And yet, after three years, the DoC has only recently produced the prototype OADR, and no funds have been expended on commercial data. Competition between industry providers of SSA data provides opportunities for cost reduction and innovation. To date, the OSC has not purchased any commercial data, and industry engagement seems to be limited to one publicly released industry request for information and hosting an Industry Day. The OSC has requested $88 million in

77 Note: these figures consider all orbital regimes, not just LEO. "Space Debris by the Numbers. Number of Debris Objects Estimated by Statistical Models to Be in Orbit," European Space Agency, last updated September 20, 2021, https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers.

78 "Space Policy Directive-3, National Space Traffic Management Policy," White House, June 18, 2018, https://trumpwhitehouse.archives.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/.

79 "Space Traffic Management: Assessment of the Feasibility, Expected Effectiveness, and Funding Implications of a Transfer of Space Traffic Management Functions," National Academy of Public Administration, August 2020, https://napawash.org/academy-studies/united-states-department-of-commerce-office-of-space-commerce.

80 Don Graves and Rick Spinrad, "Commerce Department, NOAA Ensuring U.S. Remains a World Leader in Space Commerce," *Space News*, July 21, 2021, https://spacenews.com/op-ed-commerce-department-noaa-ensuring-u-s-remains-a-world-leader-in-space-commerce/. Graves is the deputy secretary of the US Commerce Department, and Spinrad is the NOAA administrator and the under secretary of commerce for oceans and atmosphere.

81 Ibid.

funding from Congress for FY 2023. If allocated, these funds will need to be expended expeditiously to commercial SSA providers to ensure the US establishes a lead in global STM.

OSC is misplaced under NOAA, which does not appear to have made substantive movements over the last year to execute the OSC mission, particularly its responsibilities in STM and on-orbit mission authorities.[82] Subordination to NOAA does not allow OSC to function at the interagency level, a requirement to be effective in executing its mission.

Because of the expansion of commercial space, including dozens of nations and international consortia, the sharing of SSA data will be a critical element of ensuring safety on systems and regulating on-orbit operations. So much information is now available publicly or in private commercial channels that the challenge for the United States will be providing incentives for private SSA companies to provide data. To date, the satellite location accuracy of commercial SSA companies rivals those of the US Space Force's Space Surveillance Network—and is available at a fraction of the cost. The commercial viability of these companies, and the safety of on-orbit systems, rests on the DoC commitment to fully integrate commercial data and make it available globally. The slow movement in engaging the commercial SSA industry is not directly related to lack of available budget. The OSC continues to spend its increased budget on studies conducted by federally funded R&D centers.

The United States will not take a leadership role in providing STM until DoC moves forward with purchasing commercial data. Given the lack of progress, it is possible that foreign governments and satellite owners and operators will pursue their own solutions outside of the US government. Some are already doing so. It is in the interest of the US government to lead in this effort to ensure the growth of the commercial space industry, operate small satellites in a safe environment, and maintain its global leadership in space.

Regulatory Regimes for Commercial Space Activities

The US regulatory environment presents challenges for commercial small-satellite operations. A number of departments and agencies share responsibilities for spaceflight, operations, and exports. The lack of clarity in regulations and the necessity of coordinating activities among several government agencies increase cost and risk for commercial satellite operators, and limit opportunities to expand the industry. The United States has a well-established, if overly bureaucratic, regulatory system providing oversight of space transportation, frequency allocation, and select aspects of remote sensing. The United States and other countries abide by their obligations under the Outer Space Treaty—primarily Article VI, which requires state authorization and oversight of commercial space activities.

> States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the Moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty. The activities of nongovernmental entities in outer space, including the Moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty.[83]

Almost one hundred countries operate spacecraft, and many states have almost no experience and little in the way of space regulatory regimes. Within the US federal government, there are three primary agencies that regulate commercial space activities. NOAA regulates commercial remote sensing; the Federal Communications Commission (FCC) allocates radiofrequency spectrum, and the Department of Transportation, through the Federal Aviation Administration (FAA), regulates commercial launch and reentry. These are generally well-established missions and processes. However, those authorities and processes will not be adequate for future small-satellite and other space operations.

Even now, with the United States' well-established regulatory system, commercial small-satellite operations have the potential to damage national security. In early January 2020, Iran launched a missile strike against the US al-Asad airbase in Iraq, an attack that injured US military personnel. The event was captured that same day by Planet Labs' small-satellite remote-sensing constellation. Planet boasts a temporal resolution of twenty-four hours for each spot on the Earth. The images were analyzed by the Middlebury Institute of International Studies at Monterey, and appeared widely in the worldwide press. The images were of sufficient quality to provide battle damage assessment for Iran.[84] As this example illustrates, the US regulatory processes will

82 Ibid., and several interviews with government and industry officials who requested anonymity.

83 Article VI of the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies ("Outer Space Treaty").

84 Diana Stancy Correll and Aaron Mehta, "See the Damage at al-Asad Airbase Following Iranian Missile Strike," *Military Times*, January 8, 2020, https://www.militarytimes.com/news/your-military/2020/01/08/see-the-damage-at-al-asad-airbase-following-iranian-missile-strike/.

SpaceX's Falcon 9 rocket PSN VI launches from Cape Canaveral Air Force Station, FLA., February 21, 2019. The satellite launched provided communication and internet services for Indonesia and Southeast Asia. *Source:* Airman 1st Class Dalton Williams, US Air Force Flickr, February 22, 2019, https://www.flickr.com/photos/usairforce/47228872232.

not be able to keep pace as commercial satellites operate with near-real-time capabilities. In addition, even if Planet did not publish the images, some other imagery provider (foreign or domestic) would have done so. The presence of ubiquitous commercial sensors in space from dozens of countries and companies has surpassed the point that any single nation can limit distribution of data.

On-Orbit Mission Authority

Even with the extensive regulatory environment in the United States, there is no government entity that has on-orbit mission authorities—meaning, no government entity regulates the on-orbit operations of commercial satellites, other than imaging and communications. Designating a government agency (e.g., DoC's Office of Space Commerce) with this responsibility is one of the most important actions that needs to be completed. The next decades will bring extraordinary expansion in commercial small-satellite operations. To date, the United States has used its existing regulatory frameworks to address commercial space activities. However, it is unlikely to continue to do so without regulatory and process changes to provide mechanisms through which the US government can fulfill its Article VI obligations, while supporting industry in newly contemplated commercial space activities.

Private Missions Beyond Earth's Orbit

Several US companies announced plans for commercial ventures to the Moon. These plans include transportation of payloads to the lunar surface, commercial lunar habitats, and technology-demonstration missions involving vehicles maneuvering on the lunar surface. SpaceX plans commercial missions to Mars.[85]

85 Letter to Congress, Executive Office of the President Office of Science and Technology, April 4, 2016, https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/csla_report_4-4-16_final.pdf.

New On-Orbit Servicing Activities

Two companies have already demonstrated on-orbit servicing activities. Japan-based Astroscale has demonstrated satellite-capture technology for on-orbit space-debris mitigation. Several other US companies have announced plans for debris mitigation and other new on-orbit activities, such as:[86]

- end-of-life extension modules, which attach to a satellite to aid in station keeping or transfer to a graveyard orbit;
- satellite repair utilizing robotic arms;
- satellite refueling, utilizing fuels launched from Earth;
- satellite refueling, utilizing fuels derived from space resources; and
- seven companies have announced plans to build commercial orbital habitats. Another twenty-eight companies are exploring the business model for commercial space stations.

Space Resource Utilization

US companies have created plans to extract rare-Earth minerals from asteroids and the moon for use on Earth. Companies are also exploring using the mineral resources on asteroids to support deeper exploration and a longer-term human presence in space.[87]

Space Tourism

Space tourists have already visited the International Space Station, and this market is expanding. In 2021, Virgin Galactic and Blue Origin took tourists to the edge of space. In September 2021, SpaceX took tourists into orbit. Japanese billionaire Yusaku Maezawa is tentatively planning to travel around the Moon on a SpaceX ship in 2023. As human spaceflight for tourists has been safely achieved, it is very likely the space tourism industry will expand over the next decade.

The National Space Policy issued in 2020 addressed the issue of Mission Authorization of Novel Activities.

> The Secretary of Commerce, in coordination with the National Space Council, shall:
>
> - Identify whether any planned space activities fall beyond the scope of existing authorization and supervision processes necessary to meet international obligations; and
> - Lead, if necessary, the development of minimally burdensome, responsive, transparent, and adaptive review, authorization, and supervision processes for such activities, consistent with national security and public safety interests, with a presumption of approval and prompt appeals process.[88]

To date, the US government has taken no steps toward implementing this directive.

There are several international bodies, including government organizations, quasi-government organizations, and industry alliances all attempting to develop and coordinate standards and policies for the commercial space industry. These bodies have made gains over the years, and are generally successful over the long term. However, the growth and deployment of small satellites and new space capabilities are far outstripping the government and industry coordination processes. Experts interviewed for this report agreed on the necessity to increase the pace of governmental-level global space diplomacy, and to expand Track 2 discussions with secondary institutions.

The United Nations (UN) Office for Outer Space Affairs (UNOOSA). UNOOSA is the only UN office that addresses space affairs. UNOOSA responsibilities include creating or resolving policy, legal, technical, and scientific issues to ensure the peaceful use of outer space. UNOOSA engages with stakeholders from international organizations, regional and national space agencies and a range of private, public, academic, and civil-society institutions. UNOOSA is the secretariat for the UN's Committee on the Peaceful Uses of Outer Space (COPUOS).

The Consultative Committee for Space Data Systems. Several space agencies formed this committee in 1982 to provide a forum for discussion of common problems in developing and operating space data systems. The committee comprises eleven member agencies, thirty-two observer agencies, and more than one hundred and nineteen industry organizations. The committee develops "standards for data-systems and information-systems to promote interoperability and cross support among cooperating space

86 All bullet points below Ibid.

87 Ibid.

88 "National Space Policy of the United States of America," White House, December 9, 2020, https://history.nasa.gov/NationalSpacePolicy12-9-20.pdf.

agencies, to enable multi-agency spaceflight collaboration, and new capabilities for future missions."[89]

The International Telecommunication Union (ITU). The ITU is the United Nations' organization for information and communication technologies: "ITU allocates global radio spectrum and satellite orbits in the GEO belt. ITU's membership includes 193 Member States as well as some 900 companies, universities, and international and regional organizations."[90]

The Inter-Agency Space Debris Coordination Committee (IADC). The IADC is an international forum for governments to coordinate activities related to the issues that result from natural and human-made space debris. The IADC's primary purposes are to "exchange information on space debris research activities between member space agencies, to facilitate opportunities for cooperation in space debris research, to review the progress of ongoing cooperative activities, and to identify debris mitigation options."[91]

NATO. NATO identifies space as a "dynamic and rapidly evolving area essential to the Alliance's deterrence and defense."[92] In 2019, NATO adopted a space policy. This policy recognized space as a new operational domain, alongside air, land, sea, and cyberspace. This policy guides NATO to ensure support to the Alliance's operations and missions. The NATO policy addresses areas such as navigation, communications, and intelligence.[93]

To support this policy, NATO created a Space Centre, which will integrate space-derived data, products, and services, and will directly liaise with member nations.[94] The United States, United Kingdom, France, and Italy made significant force-structure changes to elevate the role of space and support enhanced space capabilities.[95] The newly created NATO Space Centre could serve as an important body to deconflict and integrate allied national security space operations.

US Allies and Partners

In December, the National Space Council published the *United States Space Priorities Framework*. High among the established priorities is to "broaden and deepen" international alliances on space.[96] The framework emphasizes the need "to [strengthen] global governance of space activities," to "bolster space situational awareness sharing and space traffic coordination," and to "engage the international community to uphold and strengthen a rules-based international order for space."[97]

There are current and projected relationships between the United States and its allies, partners, and competitors that support the priorities identified in the framework. In July 2021, US Space Command signed its one hundredth Space Situational Awareness Services and Information Agreement.[98] The IC also works with numerous nations to share space-related intelligence. There are many challenges to these sharing relationships, including the cost imposed on smaller nations, data formats and standardization, systems and software integration, third-party intelligence-sharing restrictions, and US over-classification of data. The overall challenge for the United States will be to develop policies for several consumer groups. For example, the United States will need to develop domestic policy for commercial small-satellite operators, including mission operations, cybersecurity standards, etc. It will also need to develop policies for government-to-government relationships with allied nations and other like-minded countries. Lastly, the United States will have to develop policies and strategy for how it intends to engage with more competitive or hostile nations and their commercial systems.

SDA recently published a draft optical communication terminals (OCT) standard for Tranche 1, aiming to enable foreign participants to interoperate with the Transport Layer by establishing an industry standard useful for all market participants. Within the document, SDA identified several

89 "About CCSDS," Consultative Committee for Space Data Systems, 2021, https://public.ccsds.org/about/default.aspx; Online interview with Dr. Brian Weeden, August 24, 2021.

90 "About International Telecommunication Union (ITU)," International Telecommunication Union, 2021, https://www.itu.int/en/about/Pages/default.aspx.

91 "Welcome to the Inter-Agency Space Debris Coordination Committee Website," Inter-Agency Space Debris Coordination Committee, https://iadc-home.org/what_iadc.

92 "NATO's Approach to Space," North Atlantic Treaty Organization, June 17, 2021, https://www.nato.int/cps/en/natohq/topics_175419.htm.

93 Kestutis Paulauskas, "Space: NATO's Latest Frontier," NATO Review, March 13, 2020, https://www.nato.int/docu/review/articles/2020/03/13/space-natos-latest-frontier/index.html.

94 Henry Heren, "NATO Space Panel Introduction," Joint Air & Space Power Conference 2021: NATO's Fifth Operational Domain, September 7–9, 2021, https://www.japcc.org/nato-space-panel-introduction/.

95 "Ufficio Generale per lo Spazio," Ministerio Della Difesa, Aeronautica Militare, http://www.aeronautica.difesa.it/organizzazione/loStatoMaggiore/organigramma/Pagine/UGS.aspx.

96 *United States National Space Priorities Framework*, White House, December 2021, 4, https://www.whitehouse.gov/wp-content/uploads/2021/12/United-States-Space-Priorities-Framework-_-December-1-2021.pdf.

97 Ibid., 7.

98 "USSPACECOM Signs 100th Commercial Agreement to Share Space Data, Service," US Space Command Public Affairs Office, July 21, 2021, https://www.spacecom.mil/News/Article-Display/Article/2680576/usspacecom-signs-100th-commercial-agreement-to-share-space-data-service/.

potential paths for international collaboration with US allies and partners.

Potential allied and partner participants might act on the following options.

- Fly OCT meeting SDA's standard on their own sensing satellites for direct connection to the NDSA.
- Build optical ground terminal site(s) to receive data from the NDSA based on a negotiated agreement with SDA. Attendant requirements are currently being evaluated. Foreign participants with access may also receive data from SDA via Link 16 and other future tactical data links.
- Team their industry with US partners already (or potentially) participating in the NDSA. SDA understands that some foreign participants have already reached out to companies providing Tranche 0 space vehicles and are exploring architectural extensions based on these ongoing efforts. This is of great value to both US allies and partners and to SDA, in that it represents one of the quickest means to identify specific partnership opportunities to pursue technologies with high technology and manufacturing readiness levels.
- Invest in systems, components, and technologies for proliferated architectures, such as sensing payloads and OCT. As SDA begins to procure Tranche 1, it fully expects international participation above and beyond that ongoing within Tranche 0 development activities. Adherence to SDA-published standards and demonstrated ability to manufacture at scale will be central to inclusion within the Tranche 1 provider enterprise.

Any international partnership would be subject to specific security and data information-sharing standards. SDA plans to publish a Security Classification Guide and additional international participation guidelines to ensure all allies, partners, and industry participants are aware of opportunities and limitations going forward.[99]

Business Alliances Impacting Small-Satellite Development

Despite long-standing activities, international business alliances—when used as a mechanism for standardization and coordination—are inadequate. There are many successes, such as the global coordination on updating standards for orbital debris management.[100] But, the international coordination process moves slowly, and the small-satellite industry is rapidly growing. As such, suggested international standards are not necessarily sufficient in light of recent scenarios that incorporate steep increases in commercial space activities, such as small-satellite constellations with larger numbers of spacecraft than those deployed in previous decades.

Several international efforts led by commercial interests can be categorized by functions.

Standards and Coordination

Standardization—International Standards Organization (ISO/TC 20/SC 14), Space Systems and Operations

ISO is an industry group that attempts to establish commercial standards for operations and disposition of space satellites. The Space Systems and Operations group was formed in 1992 and currently has fifteen members and eleven observing members, each representing their respective nation. Since 1992, the ISO/TC 20/SC 14 has promulgated one hundred and eighty-two standards in the areas of:

- terminology;
- design engineering and production;
- system requirements, verification and validation, interfaces, integration, and test;
- operations and support systems;
- space environment (natural and artificial);
- space-system program management and quality;
- materials and processes; and
- orbital debris disposition.[101]

Forty-three more standards are in development. Much of ISO's current work is focused on supporting UN sustainable-development goals.[102]

Space Safety

There are at least four international groups working to ensure the safety of space flight. These public-private membership groups include representatives from multiple countries. They address issues such as safety and data

99 Email exchange with SDA.

100 "Inter-Agency Debris Coordination Guidelines," IADC, March 2020, https://orbitaldebris.jsc.nasa.gov/library/iadc-space-debris-guidelines-revision-2.pdf.

101 "ISO/TC 20/SC 14 Space Systems and Operations," ISO, 2021, https://www.iso.org/committee/46614.html.

102 Ibid.

standards, information sharing, Space Traffic Management, guidelines and practices, and best practices.

The Space Data Association states on its website that it is an "international organization that brings together satellite operators to support the controlled, reliable and efficient sharing of data critical to the safety and integrity of the space environment. SDA membership includes the world's major satellite communications companies."[103]

The SDA was formed in 2009. Its goal is to enhance flight safety via operational data sharing and promoting best practices across the industry. According to its website, the SDA is "also working to improve the accuracy and timeliness of collision warning notifications, as well as working with all interested entities to help define the next generation of Space Traffic Management systems and capabilities."[104]

The Space Safety Coalition describes itself as "an *ad hoc* coalition of companies, organizations, and other government and industry stakeholders that actively promotes responsible space safety through the adoption of relevant international standards, guidelines and practices, and the development of more effective space safety guidelines and best practices."[105] Its definition of space safety "includes physical safety, communications safety (radio frequency interference events), and space weather awareness. Physical safety includes avoiding launch and on-orbit collisions, minimization of human casualty from spacecraft or debris reentry, and the long-term sustainability of the space operations environment."[106]

Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) is a commercial collaboration started in 2016 with funding from the Defense Advanced Research Projects Agency (DARPA). The startup organization is intended to provide a self-sustaining, and independent industry forum. The objective is to collaborate with industry partners and the US government to address policy and technical issues for on-orbit servicing, assembly, and manufacturing (OSAM).

There is a concept in the space-launch industry called "The Tyranny of Launch." This idea reflects the reality that the limitations of launch vehicles also constrain that which can be deployed in space. OSAM seeks to remove those limitations.

> Launch from Earth imposes significant limitations on the size, volume, and design of spacecraft: spacecraft need to be accommodated as a payload in the fairing of a single launch vehicle, the volume of which may restrict the size and number of instruments that can be included for science and national security missions; components must be ruggedized to withstand the harsh launch environment, which imposes penalties in terms of mass and size, limiting payload capabilities and increasing complexity, test time, and cost; and backups and redundancies must be included to provide contingencies against damage during launch or failure on orbit. The limitations associated with spacecraft architectures where components are fully assembled on Earth can thus constrain the design, capabilities, lifespan, and products of space systems. Additionally, once an asset is in space, it typically cannot be refreshed or improved (e.g., its sensors cannot be replaced with new technology to increase its capabilities).[107]

OSAM technologies, most famously employed in the construction of the ISS and other space stations, could also benefit the small-satellite sector if regulatory and other hurdles could be overcome. A wide variety of space missions could benefit from these technologies. Technical challenges, a lack of global standards, and the surrounding policy framework, however, restrict the growth of these activities.[108]

For the small satellite, there are challenges to developing and implementing OSAM new technologies and operations. They primarily center around establishing standards and practices. For example, the value propositions for OSAM activities are unknown. There is also a culture of single-launch, single-use missions, and a need for yet-to-be-implemented common interfaces, and remote verification and validation. Effectively implementing OSAM activities also requires changes in policy and regulations, as well as a means to meet international obligations. Significant issues limiting OSAM commercial operations from expanding include:

103 "Space Data Association," Space Data Association, https://www.space-data.org/sda/.

104 Ibid.

105 "Space Safety Coalition," Space Safety Coalition, 2020, https://spacesafety.org/.

106 Ibid.

107 Sara A. Carioscia, Benjamin A. Corbin, and Bhavya Lal, "Roundtable Proceedings: Ways Forward for On-Orbit Servicing, Assembly, and Manufacturing (OSAM) of Spacecraft," Institute for Defense Analysis, Science and Technology Institute, July 2018, https://www.ida.org/-/media/feature/publications/r/ro/roundtable-proceedings-ways-forward-for-on-orbit-servicing/d-10445.ashx.

108 Ibid.

- the lack of coordination in the United States, within government and between government and other stakeholders, and domestically and globally;
- the absence of a timely and effective system to establish and adopt standards; and
- the lack of a clear regulatory environment for future technologies and approaches.[109]

There were two successful OSAM missions (Mission Extension Vehicles) in 2020. Northrop Grumman Corporation provided life-extension services for commercial communication satellites. The company's MEV-1 successfully docked to the Intelsat 901 satellite in February 2020 and moved the satellite back into service. MEV-2 docked with IS-10-02 in its operational geosynchronous orbital location. The MEV-2 satellite refueled Intelsat's IS-10-2 communications vehicle. NGC states its MEVs are compatible with 80 percent of operational satellites.[110] Also in 2021, Astroscale conducted a technology demonstration, validating its magnetic-capture system by successfully docking with its own end-of-life servicing vehicle in LEO.[111]

Existing DoC regulations impede development of on-orbit commercial SSA capabilities. Commercial remote-sensing licenses for non-Earth imaging (e.g., detecting, tracking, and imaging other space objects) require a license from the DoC. These licenses include significant restrictions for non-Earth imaging. Non-Earth imaging capabilities are necessary to service, assemble, and manufacture vehicles and platforms in space. Foreign governments do not usually apply these restrictions to their companies, thereby placing US companies at a disadvantage in the world market as they compete for business conducting OSAM and orbital debris-removal operations.[112]

Space Information Sharing and Analysis Center (Space ISAC)

In 2020, the Space ISAC was established as a public-private partnership. Twenty-four companies support this effort as members, and twenty-five ISACs exist across all sectors of US critical infrastructure. They are public-private partnerships recognized as necessities to ensure the security of US critical-infrastructure sectors. The Space ISAC facilitates collaboration across the global space industry to share information, enhance preparation, mitigate threats, and increase response capabilities to vulnerabilities, incidents, and threats. The organization disseminates near-real-time threat data among member entities, and provides training, certifications, tabletop exercises, and membership communities of interest to develop best practices.[113]

Public and Private Coordination

Government and private mechanisms ensuring global standards, safety, and long-term sustainability in space have been somewhat successful. However, the processes of international coordination take years, if not decades. Current international space law and treaties do little to establish a code of conduct or an agreed set of norms addressing military or international security in space. In addition, the notification mechanisms used to ensure on-orbit safety are routinely used between nations and companies, but have failed on several occasions. The current international coordination efforts and national regulatory mechanisms cannot be expected to maintain pace with quickly evolving aspects of the commercial space industry.

109 Online interview with Dr. Brian Weeden, August 24, 2021.

110 Chandraveer Mathur, "Northrop Grumman's MEV-2 Life-Extender Successfully Coupled with an Active Satellite," NewsBytes, last updated April 19, 2021, https://www.newsbytesapp.com/news/science/mev-2-life-extending-satellite-successfully-couples-with-active-satellite/story. Note that the 80-percent figure likely refers to GOE communications satellites.

111 "Astroscale's Safe Magnetic Catch in Space," SatNews, September 7, 2021, https://news.satnews.com/2021/09/07/astroscales-safe-magnetic-catch-in-space; Interview with Chris Blackbery, chief operating oofficer of Astroscale, September 14, 2021.

112 "Space Policy and Sustainability: Issue Briefing for the Biden Administration," Secure World Foundation, December 2020, 12, https://swfound.org/media/207084/swf_space_policy_issue_briefing_2020_web.pdf.

113 Telephone interview with Erin Miller, executive director, Space ISAC, July 23, 2021; "About Us," Space ISAC, 2021, https://s-isac.org/about-us/.

Chapter 5: Findings and Recommendations

Key Findings

This report explores the trends and technological developments defining the future of the space domain. In doing so, it arrives at six key conclusions.

1. The United States will most likely lose space superiority to China within the next decade.

2. The DoD and the IC are rightly taking advantage of the small-satellite revolution. The IC is increasingly investing in commercial small-satellite data to increase collection capabilities and provide military support.

3. The DoD does not generally take a "buy commercial first" approach to space services. Rather, there is an established culture that ignores legislated "commercial first" mandates, and that behavior has become increasingly detrimental to national security interests. Over the last decade, this negative culture has eroded US space superiority, and will continue to do so as the world moves toward quickly developed and deployed, low-cost commercial space systems.[114]

4. To date, no commercial small-satellite service has proven itself viable without government support. Yet, the growth of this industry will dramatically impact US national security.

5. DoD acquisition processes are designed to reduce risk and, as a result, are ill prepared for the high-speed commercial space environment. Senior DoD leaders are making efforts to speed up acquisition processes for small satellites and associated technologies. The results to date are mixed.

6. The DoC OSC has made little progress over the last year in executing its responsibilities for STM and on-orbit mission authorities. Being subordinate to NOAA does not allow the office to function at the level required to be effective in executing its mission.

Key Recommendations

The following recommendations address areas of US space policy, the regulatory environment, coordination and cooperation with US allies, and commercial investment strategies. These recommendations have the same goals: to enhance global space security and advance the US commercial space industry. Advancing the US commercial space industry is a critical component of maintaining global space leadership and ensuring the safety and security of space systems and national security.

US Military, Government, and Civil Space

Department of Defense and Intelligence Community

1. The DoD should ensure the resilience of US space systems by using commercial systems, including responsive space launch and satellite architectures across multiple orbits, and incorporating allied space capabilities.[115]

2. Congress should direct DoD and ODNI to conduct a study to identify national security missions that can be accomplished through commercial space, related services, space communications, and SSA.

   i. Congress should earmark DoD and IC funds for the purchases of those commercial services. This action will force compliance with US law and increase commercial space services driving innovation through competition.

3. Congress and the administration must conduct rigorous oversight to ensure DoD and Intelligence Community organizations enforce policies (including their own) to "buy commercial first."

4. DoD should prototype and acquire small-satellite and related cyber capabilities using OTA and Section 804 authorities. Use of other standard acquisition processes should require a waiver.

114 For the past two decades, national policies have directed agencies to buy commercial goods and services before considering the development of a government solution. Almost all of the government and industry experts interviewed for this study believe DoD and the IC ignore those mandates for commercial space capabilities.

115 "Space Policy and Sustainability," 15.

5. The Joint Chiefs of Staff should establish a program to ensure OPSEC is integrated into doctrine and operational activities employing current awareness of commercial space remote-sensing capabilities and intelligence. This program should include training on foreign and commercial technical capabilities to defeat OPSEC. The program should also be integrated with DoD Perception Management and denial and deception efforts.

6. To ensure deterrence against hostile nations, DoD should develop, coordinate, and exercise response strategies to cyberattacks against US and allied commercial space systems. These CONOPS should be done with the IC, DHS, allies, and private industry. This activity could include the National Guard.

7. Protocols, treaties, operating rules, etc. will eventually be established by commercial companies as well as governments. The US government (particularly DoD OSD/Space Policy, Defense Threat Reduction Agency, and the Intelligence Community) should have a well-developed, well-thought-out, brilliantly designed plan for verification and compliance (sensors, networks, analysis standards, communication protocols, etc.). This plan should recognize that much of the data will necessarily be shared globally and, therefore, must be unclassified. The plan will support overall US national security and commercial space strategies.

Other US Government Actors

Department of Homeland Security

DHS plays an important role in supporting the commercial space industry in developing standards and best practices. In May 2021, DHS's Cyber and Infrastructure Security Agency (CISA) established a Space Systems Critical Infrastructure Working Group. The working group is a mix of government and industry participants developing strategies to minimize risks to space systems that support the nation's critical infrastructure.[116] CISA has also produced several cybersecurity publications and recommended standards relevant to small-satellite systems. Building upon this progress, DHS should take the following next steps:

1. DHS should lead a study to determine if space systems should be included as one of the national critical infrastructure sectors. If so, Congress should designate space systems as critical infrastructure, with the DoC as the Sector-Specific Agency.

2. DHS should continue to strongly advocate private industry's adoption of the NIST SP 800-37 Risk Management Framework for Information Systems and Organizations: A System Life Cycle Approach for Security and Privacy. This document provides a recommended cybersecurity risk-management framework for commercial satellite operators.

3. DHS should work with the Defense Counterintelligence and Security Agency to develop programs that enhance supply-chain security in the commercial space industry.

    i. Programs should include training and information sharing enabled through the Space ISAC.

Department of Commerce

The DoC plays a significant role in regulating, overseeing, and advancing the US commercial small-satellite industry. It also has a critical function in establishing US leadership in global STM. The DoC should take the following next steps:

1. The DoC should purchase commercial SSA data and services, to the maximum extent possible, and secure international data-sharing agreements. DoC should incentivize the private sector to develop innovative analytical tools and advanced services to conduct STM.

2. Move the Office of Space Commerce out from under NOAA. OSC's recently expanded responsibilities for STM and mission authorities make it a poor fit under an entity focused on oceanographic and atmospheric administration. Being buried in NOAA puts the OSC in poor position to conduct the required interagency and international coordination.

3. Congress should affirm that the DoC Office of Space Commerce has the requisite on-orbit authorities to allow it to promulgate regulations for on-orbit mission operations that fall outside the current licensing and supervision framework.

4. DoC requested $88 million in its fiscal year 2023 (FY23) budget to conduct the STM mission and develop new data tools.[117] Congress should support this request and ensure DoC executes it with a "commercial first" approach.

116 "Space Systems Critical Infrastructure Working Group," Cyber and Infrastructure Security Agency, May 13, 2021, https://www.cisa.gov/news/2021/05/13/cisa-launches-space-systems-critical-infrastructure-working-group.

117 "Budget of the U.S. Government Fiscal Year 2023," US Office of Management and Budget, 2022, 50, https://www.whitehouse.gov/wp-content/uploads/2022/03/budget_fy2023.pdf.

5. OSC should fully embrace commercial SSA providers through contracts. It is imperative that this office live up to the requirement to "buy commercial first".

6. The OSC should provide clear, deliberate direction to acquire, prioritize, implement, and deploy existing commercial SSA and STM services.

Commercial Space Actors

One of the challenges facing the small-satellite industry is educating and helping to reorient the DoD and IC. For generations, the US defense and intelligence communities had little concern for economic security and advancing domestic commercial industries. A hostile and competitive rising China has altered the global situation, necessitating closer cooperation between the US national security community and commercial space providers.

1. Small-satellite and related industry associations should enhance and coordinate efforts to educate relevant government departments on capabilities, emerging technologies, and the market case for commercial satellites.

US Allies and Partners

The US faces many foreign policy challenges, including a rising hostile authoritarian China and aggressive military actions from Russia. Space security is a foundational element of ensuring peace with these strategic competitors. The United States must expand its efforts in space diplomacy to ensure coordinated action with allies and establish global standards with partners:

1. The Department of State, DoD Office of Space Policy, and Department of Commerce should enhance space diplomatic efforts with the following goals:

   i. Increase the urgency to establish behavioral norms for space systems, particularly:

      1. rendezvous and proximity operations;

      2. notifications and guidelines;

      3. orbital debris and guidelines; and

      4. cybersecurity standards.

   ii. Support commercial space industry efforts to enhance Track 2 international collaboration and coordination.

   iii. Establish the United States as the global leader and provider of STM.

      1. Develop an interagency process for unclassified and classified STM and SSA data to be used in international forums.

Conclusion

This growth of the global commercial small-satellite industry is quickly changing the paradigm of how the United States and its allies must act to ensure space security. If the United States is to guarantee safety and security in space, then public-private partnerships and the use of commercial small-satellite capabilities must evolve to be the cornerstone of national security space. The traditional DoD technology development and acquisition processes are simply not capable of maintaining parity with commercial industries that field advanced software in weeks and satellites in months. The DoC must also accelerate its processes to field commercial data-driven solutions for STM. DoD will have to act in the immediate future if the United States is to maintain security and its global leadership in space.

The commercial space industry is fast and, over the next decade, will accelerate its technology development and manufacturing processes even more. These advances will not be the sole domain of US industry, but will be realized worldwide. Competitor and hostile nations are empowering their companies to compete with the US commercial space industry. By providing national-level support and a friendly regulatory environment, China has already caught up to, and in some cases surpassed, the United States in select aspects of space technology. There is no reason that China could not do the same in the commercial small-satellite market. If the United States is to ensure security in space, then the US government must adapt to a new operating environment.

About the Author

Nicholas Eftimiades is a nonresident senior fellow at the *Forward* Defense practice of the Atlantic Council's Scowcroft Center for Strategy and Security. Eftimiades currently holds an appointment with the Office of the Director of National Intelligence, National Intelligence Council, and has held appointments with the Defense Science Board and the Homeland Security Advisory Council's Subcommittee on Economic Security. He is also a professor at the Penn State University Homeland Security Programs and is a member of the graduate faculty teaching homeland security, intelligence, and national security policy. He conducts research on China's economic espionage and emerging space threats.

Eftimiades retired from a thirty-four-year government career, including employment at the US Central Intelligence Agency, the Department of State, Diplomatic Security Service, and Defense Intelligence Agency. He is widely regarded for his expertise on China and national security space issues. As a subject-matter expert, he has testified before congressional committees and briefed numerous senior US and foreign officials, members of Congress, and staff.

Eftimiades has an MS in strategic intelligence from the National Defense Intelligence College and a BA in East Asian Studies from George Washington University. He lived and studied in China and Japan. He was a senior research fellow at the King's College Department of War Studies in London. Eftimiades has authored books, reports, and articles on China's intelligence methodology, national security space issues, and emerging technology. His book *Chinese Intelligence Operations* is an examination of the structure, operations, and methodology of the Chinese intelligence services. It is widely regarded as the seminal work in the field.

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- **Kari Bingen**, *chief strategy officer*, HawkEye 360
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- **Dr. Nate Dailey**, *principal architect*, *Space Engineering*, MITRE
- **Dr. Thomas W. Cooley**, *chief scientist*, *Space Vehicles Directorate*, Air Force Research Laboratory
- **James Cooper**, *senior system engineer*, *SSA Solutions*, COMSPOC
- **Debra D. Facktor**, *head of U.S. space systems*, Airbus U.S. Space & Defense, Inc.
- **Col Eric J. Felt, USAF**, *commander*, Phillips Research Site; *director*, *Space Vehicles Directorate*, Air Force Research Laboratory
- **Yasuhito Fukushima**, *senior research fellow*, *Policy Studies Department*, Japan National Institute for Defense Studies
- **Dr. William C. Greenwalt**, *nonresident senior fellow*, American Enterprise Institute
- **Dr. Kelly A. Grieco**, *senior fellow*, *New American Engagement Initiative*, *Scowcroft Center for Strategy and Security*, Atlantic Council
- **Stephen L. Kitay**, *senior director*, *Azure Space*, Microsoft
- **Dr. Fred G. Kennedy**, *inaugural director*, *Space Development Agency*, *Office of the Under Secretary of Defense for Research and Engineering*, US Department of Defense
- **Axel Kloth**, *founder and chief executive officer*, Abacus Semiconductor Corporation
- **Dr. Jerry Krasner**, *consultant*, *Space Situational Awareness*, US Department of Defense
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- **Erin Miller**, *executive director*, Space Information Sharing and Analysis Center
- **Kevin O'Connell**, *founder and chief executive officer*, Space Economy Rising, LLC
- **Dr. John Olds**, *founder and chief executive officer*, SpaceWorks Enterprises, Inc.
- **Robbie Schlinger**, *co-founder and chief strategy officer*, Planet Labs
- **Scott Simmons**, *former chairman*, *Sensor Working Group*, Open Skies Treaty
- **Dr. Derek M. Tournear**, *director*, *Space Development Agency*, *Office of the Under Secretary of Defense for Research and Engineering*, US Department of Defense
- **Paula Trimble**, policy chief and director of legislative affairs, *Space Development Agency*, *Office of the Under Secretary of Defense for Research and Engineering*, US Department of Defense
- **Dr. Brian Weeden**, *director*, *program planning*, Secure World Foundation

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1030 15th Street, NW, 12th Floor, Washington, DC 20005

(202) 463-7226, www.AtlanticCouncil.org