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Impacts of Anti-Access/Area Denial Measures on Space Systems: Issues and Implications for Army and Joint Forces

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Comments pertaining to this report are invited and should be forwarded to: Director, Strategic Studies Institute and U.S. Army War College Press, U.S. Army War College, 47 Ashburn Drive, Carlisle, PA 17013-5238.

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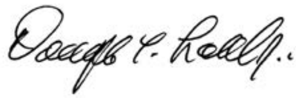
FOREWORD

In the 2018 *National Defense Strategy*, U.S. Secretary of Defense James Mattis stated that his department "will prioritize investments in resilience, reconstitution, and operations to assure our space capabilities."[1] In March 2018, U.S. President Donald Trump upheld these defense priorities in his *National Space Strategy* that focuses on the protection of "our vital interest in space—to ensure unfettered access to, and freedom to operate in space, in order to advance America's security, economic prosperity, and scientific knowledge."[2] Four months later, President Trump directed the Department of Defense (DoD) to lay the foundation for a military Space Force on par with the existing Air Force. While this directive still must clear Congress, one thing is certain—military space operations remain an essential part of joint operations.

In this monograph, Mr. Jeffrey Caton explores challenges to these space-related U.S. security priorities posed by the anti-access/area denial (A2/AD) efforts of potential adversaries. He argues that Russia and China pose the most viable A2/AD threat to U.S. space assets and contends that these nations see space activities as an integral part of their military operations and national prestige. To address possible mitigation of A2/AD efforts in the space domain, Mr. Caton provides recommendations in the areas of realistic expectations for space support, cyberspace considerations in space systems, natural space hazards, and the potential of unintentional escalation. This monograph should inform the ongoing activities of U.S. Strategic Command (USSTRATCOM) as well as individual service space organizations.



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ENDNOTES - FOREWORD

1. Department of Defense (DoD), *Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge*, Washington, DC: U.S. Department of Defense, p. 6, available from *https://www.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf*.

2. "Fact Sheet: President Donald J. Trump is Unveiling an America First National Space Strategy," Washington, DC: The White House, March 23, 2018, available from *https://www.whitehouse.gov/briefings-statements/president-donald-j-trump-unveiling-america-first-national-space-strategy/*.

ABOUT THE AUTHOR

JEFFREY L. CATON is president of Kepler Strategies LLC, Carlisle, Pennsylvania, a veteran-owned small business specializing in national security, cyberspace theory, and aerospace technology. He is also an intermittent professor of program management with Defense Acquisition University. From 2007 to 2012, Mr. Caton served on the U.S. Army War College (USAWC) faculty, including as an associate professor of cyberspace operations and defense transformation chair. Over the past 9 years, he has presented lectures on cyberspace and space issues related to international security in the United States, Sweden, the United Kingdom, Estonia, Kazakhstan, and the Czech Republic, supporting programs such as the Partnership for Peace Consortium and the North Atlantic Treaty Organization Cooperative Cyber Defence Center of Excellence. His current work includes research examining the recent elevation of U.S. Cyber Command to be a unified command as well as the evolving role of the U.S. Army with nuclear operations as part of the External Research Associates Program of the Strategic Studies Institute (SSI). Mr. Caton is also a member of the Editorial Board for *Parameters* magazine. He served 28 years in the U.S. Air Force working in engineering, space operations, joint operations, and foreign military sales including command at the squadron and group level. Mr. Caton holds a bachelor's degree in chemical engineering from the University of Virginia, a master's degree in aeronautical engineering from the Air Force Institute of Technology, and a master's degree in strategic studies from the Air War College.

SUMMARY

In January 2012, former President Barack Obama and Secretary of Defense Leon Panetta published new strategic guidance for 21st century defense. Third among the document's 10 primary missions of U.S. Armed Forces is the call to "project power despite anti-access/area denial [A2/AD] challenges," which included the charge to continue "efforts to enhance the resiliency and effectiveness of critical space-based capabilities."[1] Further, the fifth mission is to "operate effectively in cyberspace and space" potentially against "a range of threats that may degrade, disrupt, or destroy assets."[2] The 2018 *National Defense Strategy* and *National Space Strategy* both reaffirm the vital interests that the United States has in the domain of space.

The utilization of space-based capabilities is an established part of modern military operations. The first live test of a Chinese anti-satellite (ASAT) system in 2007 forever changed how the world operates in space. In one event, the People's Liberation Army (PLA) created over 2,000 pieces of debris that increased the number of manmade objects in space by 20 percent, which increased the likelihood of collisions by 37 percent. During the Cold War, the Soviet Union maintained ASAT capabilities that included direct ascent, co-orbital, and directed energy systems; many of these could be reconstituted by Russia. The technologies required for A2/AD of space satellites were proven and some were even operationalized decades ago and it is reasonable to consider that future rivals may utilize such systems. In short, space operations are becoming inherently more hazardous and vulnerable to disruption, denial, or destruction.

This monograph explores what might happen if an adversary applied such measures to U.S. space systems and how this might affect Army and joint operations. To accomplish this goal, this research focuses on the central question: What are ways for the Army to assure the success of its space-dependent warfighting functions in an A2/AD environment where space systems are degraded for significant periods of time? After providing some necessary background information on space systems, this monograph addresses this question in three parts. First, it analyzes the space capabilities of potential adversaries as well as the technologies required and the nations that possess such capabilities. Second, it explores the strategic implications of such attacks and their potential effects on elements of national power, and then it concentrates on operational effects if space systems were degraded or made unavailable to the Army and other joint warfighters. Third, it examines current measures that may mitigate the negative effects of adversary A2/AD activities as well as possible alternative space capabilities under development. Finally, it makes recommendations for U.S. defense leadership with regard to strategic and operational opportunities to enhance A2/AD mitigation activities and the effectiveness of U.S. space power writ large.

The vision of outer space as a vast and tranquil sea is but an illusion; space is an inherently hostile environment that has become congested, contested, and competitive among the nations—and this trend shows no sign of abatement. However, as with the land, sea, and air commons, the peaceful pursuit of economic, diplomatic, and informational ends in space often requires the support of a capable and restrained military space force. The continued preeminence of U.S.

military space capabilities depends on deliberate efforts to ensure access to and freedom of movement within the space domain.

ENDNOTES - SUMMARY

1. Department of Defense (DoD), *Sustaining U.S. Global Leadership: Priorities for 21st Century Defense*, Washington, DC: U.S. Department of Defense, January 2012, pp. 4-5, available from *http://archive.defense.gov/news/Defense_Strategic_Guidance.pdf*, accessed August 11, 2017.

2. Ibid., p. 5.

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BACKGROUND

> Space forces support the semi-independent execution of cross-domain maneuver and integrated security operations through space-based intelligence, surveillance, and reconnaissance [ISR]; satellite communications [SATCOM]; PNT [position, navigation, and timing]; environmental monitoring; and missile warning. Space operations enable movement and maneuver within the operational environment via joint friendly force tracking, navigation warfare, alternate compensatory control measures, and special technical operations. Space forces

protect the use of space-based capabilities and space domain freedom of maneuver through offensive and defensive space control.[3]

The utilization of space-based capabilities is an established part of modern military operations. Before examining specific space-related A2/AD threats and responses, it is necessary to provide a brief background on what comprises a space system as well as how space systems are employed in joint operations.

Three Segments of Space Systems

Space systems are comprised of three segments: ground, space, and link. Ground segments include space launch centers; telemetry, tracking, and command facilities; radar sites; and user application devices, such as a global positioning system (GPS) navigation aid. Space segments are items in Earth orbit such as satellites, space stations, and reusable launch vehicles. Link segments are the intentional electromagnetic emissions between space and ground segments to transmit data or energy.[4]

The current joint definition of A2/AD can be simplified as adversary efforts to deny long-range access to, or freedom of movement within, a given area of operations.[5] Adversary A2/AD efforts against space systems can target any one of the three segments to be effective. Ground segments can be attacked by ground troops or precision fires, but the ground segments that support the space segment will likely be located outside the operational area. The link segment can be attacked by jamming the command signals to the space segment (uplink jamming) or by jamming the data transmission from the space segment to a user device (downlink jamming). In very sophisticated attacks, the uplink may be captured, modified, and retransmitted to "spoof" the space segment into performing unintended functions. The space segment can be attacked using means that do not cause permanent damage, such as the dazzling of optical sensors by low-power lasers. They can also be attacked with methods designed to disable or destroy the space segment, such as kinetic energy or explosive ASAT missiles, directed energy weapons, electromagnetic pulse devices, or even cyberspace malware inserted into the uplink.[6] Given the importance of space capabilities for joint operations, it is prudent for U.S. military planners to anticipate that future adversaries will attack space systems.[7]

Space Mission Areas

Joint and Army doctrine organize space into five mission areas that this monograph uses as a framework for the analysis of space-related A2/AD threats and mitigation measures. They are defined as:

> **space situational awareness.** Cognizance of the requisite current and predictive knowledge of the space environment and the operational environment upon which space operations depend [emphasis in original].
>
> **space force enhancement.** Combat support operations and force-multiplying capabilities delivered from space systems to improve the effectiveness of military forces as well as support other intelligence, civil, and commercial users [emphasis in original].
>
> **space control.** Operations to ensure freedom of action in space for the United States and its allies and, when directed, deny an adversary freedom of action in space [emphasis in original].

> **space support.** Launching and deploying space vehicles, maintaining and sustaining spacecraft on-orbit, rendezvous and proximity operations, disposing of (including deorbiting and recovering) space capabilities, and reconstitution of space forces, if required [emphasis in original].
>
> **space force application.** Combat operations in, through, and from space to influence the course and outcome of conflict by holding terrestrial targets at risk [emphasis in original].[8]

Each of these mission areas are divided into functional capabilities that can be correlated to Army warfighting functions, as depicted in this monograph's appendix. Further details of U.S. space doctrine are available to the reader in existing publications and will not be repeated here.[9] Having established a common lexicon for discussion, let us examine potential A2/AD threats to U.S. space operations.

SPACE A2/AD THREATS

The 2011 *National Security Space Strategy* posits, "The current and future strategic environment is driven by three trends—space is becoming increasingly *congested*, *contested*, and *competitive* [italics in original]."[10] If competition leads to conflict, what countries currently possess or are working to develop specific space capabilities that could be used to achieve A2/AD against the United States?

Potential Adversaries in Space

In his April 2017 Congressional as Commander, U.S. Strategic Command (USSTRATCOM), General John Hyten named four countries of particular concern to his command: Russia, China, North Korea, and Iran.[11] However, do these countries have viable space A2/AD capabilities that could significantly affect U.S. military operations? To answer this question, we need to examine each country's progress in major milestones related to military space power, their current presence in space, and their current capability to perform the five joint space missions.

Table 1 provides a historical timeframe for each of these countries of key space-related milestones that indicate progression in the development of advanced space capabilities. Driven by Cold War motivations, the United States and Russia followed the same evolutionary path of space-related technology and system development: atomic weapons, large rockets capable of orbiting satellites, missiles with intercontinental range coupled with payloads that can survive reentry to Earth, rockets and life support systems that enable human spaceflight, and ASAT systems with intercept and kinetic kill capabilities. China traveled a similar path over a decade later and they have made great strides in their space power during the 21st century.

Milestone	Country				
	United States	Union of Soviet Socialist Republics/Russia	China	North Korea	Iran
Atomic Bomb Test	1945	1949	1964	2006	—
Satellite Launch	1958	1957	1970	2012	2005
Intercontinental Ballistic Missile	1959	1957	1971	2017	—
Manned Orbital Flight	1962	1961	2003	—	—
Anti-Satellite Test	1960s	1960s	2007	—	—

Table 1. Significant Space-Related Milestones

Iran successfully launched its first satellite on October 27, 2005. Although it has plans to develop military reconnaissance and communications satellites, Iran currently has only one satellite in orbit. Much of the success of their missile development is credited to Russian technical assistance, which has steadily increased since Vladimir Putin became President.[12] Some analysts contend that Iran is "developing boosters for what it claims are space purposes that create the potential to deploy a future ICBM [intercontinental ballistic missile]."[13] Regardless, Iran is still a fledging space power at best.

North Korea launched its first satellite on December 12, 2012, and its current active orbital inventory is a single satellite. Analysts from India's National Institute of Advanced Studies who reconstructed the 2012 satellite launch concluded that "**North Korea is somewhat more advanced than either Iran or Pakistan in space and missile technologies and products** [emphasis in original]" and that "**the actual performance of**

the Unha launcher as a missile, must be a source of considerable concern to North Korea's immediate neighbours as well as the United States [emphasis in original]."[14] The North Korean missile force is estimated to have approximately 200 Nodong medium-range ballistic missiles and 100 Musudan intermediate-range ballistic missiles.[15] North Korea has regularly pushed the limits of international patience with its defiant missile tests in the Pacific Ocean. In July 2017, they achieved the first two successful test flights of an ICBM.[16] Even with such advances in their force application capability, North Korea, like Iran, is a very immature space power.

Table 2 depicts the current space object inventories for countries based on the National Aeronautics and Space Administration's (NASA) orbital "box score" for August 2017. The United States has the preponderance of active payloads in space, which number over twice that of Russia and China combined. However, not all space mission areas require assets in space; for example, many space situational awareness systems are ground-based radars.

Country/ Organization	National Aeronautics and Space Administration		CelesTrak		Union of Concerned Scientists
	Total Payloads	Total Objects	Total Payloads	Active Payloads	Active Payloads
United States	1,529	6,218	1,508	722	593
Commonwealth of Independent States (Russia)	1,509	6,506	1,500	147	135
China	250	3,844	249	205	192
Japan	162	258	165	84	*
India	82	197	83	54	*
European Space Agency	75	133	75	44	*
France	63	545	62	23	*
North Korea	*	*	2	1	*
Iran	*	*	1	1	*
Other	825	939	952	597	539
Totals	**4,495**	**18,640**	**4,597**	**1,878**	**1,459**
* value not available or discernible from source information					

Table 2. Space Objects Count for Selected Countries[17]

Table 3 provides a qualitative assessment of the space force capabilities of Russia, China, Iran, and North Korea organized by the five joint space mission areas. From this, it is reasonable to classify the overall Russian and Chinese military space capability as near peers to that of the United States.

Joint Space Operations Mission Areas	Potential Adversaries			
	Russia	**China**	**Iran**	**North Korea**
Space Situational Awareness				
Detect, Track, and Identify	OP ▲	OP ▲	—	—
Threat Warning and Assessment	OP ▲	OP ▲	—	—
Characterization	OP	OP ▲	—	—
Data Integration and Exploitation	OP	OP ▲	—	—
Space Force Enhancement				
Intelligence, Surveillance, and Reconnaissance (ISR)	OP	OP ▲	—	—
Launch Detection	OP	OP ▲	—	—
Missile Tracking	OP	OP ▲	—	—
Environmental Monitoring	OP	OP	—	—
Satellite Communications (SATCOM)	OP	OP	—	—
Positioning, Navigation, and Timing (PNT)	OP	▲	—	—
Navigation Warfare	OP	OP	—	—
Space Supports				
Spacelift	OP ▲	OP ▲	DEMO	DEMO
Satellite Operations	OP	OP	DEMO	DEMO
Reconstitution of Space Forces	OP	OP	—	—
Space Control				
Offensive Space Control	OP ▲	DEMO ▲	—	—
Defensive Space Control	OP	DEMO ▲	—	—
Space Force Application				
Ballistic Missile Defense	OP	DEMO ▲	—	—
Intercontinental Ballistic Missiles (ICBM)	OP ▲	OP ▲	DEMO	DEMO

Legend:

OP = mature operational capability

DEMO = demonstrated/developmental capability

▲ = actively improving capability

— = no known capability

Table 3. Overview of Space Capabilities for Russia, China, Iran, and North Korea

While many countries may be able to exercise some forms of A2/ AD measures against U.S. space systems, the remainder of this monograph will focus on Russia and China as the most capable adversaries. Let us examine the current and projected capabilities areas with some examples of specific systems in the Russian and Chinese space forces.

Near Peer Space A2/AD Capabilities

Russia

A 2013 Marshall Institute report provided some historical background on Russian military space operations, noting, "The Soviet Union viewed outer space as a theater where a war would be fought sooner or later; consequently, it made preparations to fight a war in space."[18] The Union of Soviet Socialist Republics (USSR) developed sophisticated apparatus such as co-orbital and direct assent ASAT systems and a Fractional Orbital Bombardment System, and ICBMs that would travel to the United States over the South Pole. Soviet space systems were largely considered to be of poorer quality than those of the United States, although there were significant exceptions in areas such as rocket engine design.[19] Regardless, the remains of the Soviet space capabilities formed the backbone of the Russian space force, although substantial space infrastructure had to be integrated through agreements with former Soviet republics such as Ukraine and Kazakhstan.

The Defense Intelligence Agency (DIA) 2017 report *Russia Military Power* states that Russia has over 130 civilian and military satellites performing a variety of terrestrial support functions. The report characterizes this space fleet as "both formidable and in a state of rebuilding" and noted there are efforts underway to "prioritize the modernization of its existing communications, navigation, and earth observation systems, while continuing to rebuild its electronic intelligence and early warning system constellations."[20] Let us examine some details of this force in each of the five space mission areas.

Space Situational Awareness: In this mission area, Russia is largely dependent on its competent ground-based early warning systems due to delays in the modernization of its space-based detection and tracking systems. A recent report from King's College London was blunt about this current shortfall: "the space component of [an] early warning system has effectively ceased to exist,"[21] referring to the decline of the Soviet-era Oko satellite warning system. Successful launches in November 2015 and May 2017 of the next-generation missile warning system—the *Edinaya Kosmicheskaya Sistema* (EKS, translated as Unified Space System)—completes only a quarter of the system's eight-satellite constellation. Also known as Tundra, this modernization will improve the warning time since "a key improvement of the EKS system over Oko is that EKS satellites do not just detect missile launches, but can also track the path of the missile's flight."[22] Data from the space surveillance systems are fused and utilized by the Main Missile Attack Center for ballistic missile launches and by the Main Space Situation Reconnaissance Center for orbital tracking and deconfliction.[23]

Space Force Enhancement: The current DIA assessment of Russian space resources indicates it offers many capabilities to its warfighters, "including high-resolution imagery, terrestrial and space weather, communications, navigation, missile warning, electronic intelligence, and scientific observations."[24] Consistent with their military doctrine, Russian forces emphasize the need for extensive SATCOM, which have been provided by at least six types of constellations over several decades.[25] The GLONASS (*Globalnaya navigatsionnaya sputnikovaya sistema,* translated as Global Navigation Satellite System)—the Russian equivalent of GPS—reached its fully operational constellation of 24 satellites in 2011, and is being maintained regularly with new versions. The latest GLONASS put in service was a third-generation satellite launched in June 2016. The system currently has two on-orbit spares as well.[26]

Space Support: Russia has very mature space launch vehicle (SLV) systems and subsystems, as well as newer systems, some of which are based on retired ICBMs. The venerable Soyuz and Proton rockets have experienced a series of failures attributed to manufacturing and quality control issues over the past decade. These problems were serious enough to cause a gap in military launches over 11 months.[27] Current Russian space policy calls for a robust national space industry and infrastructure to meet national interests that include "the creation of a new generation of space complexes and systems to enable them to be competitive in the world market."[28] Progress toward this space infrastructure revitalization has been uneven. One notable achievement was the first launch from the new Vostochny Cosmodrome in April 2016, a complex designed to reduce dependence on the Baikonur Cosmodrome located in Kazakhstan. President Putin attended the launch and stated afterwards, "Despite all its failings, Russia remains the world leader in the number of space launches."[29] In addition to these bases, Russia has four proven launch facilities within its borders at Kapustin Yar, Plesetsk, Svobodny, and Yasny.[30]

Space Control: The Russian Federation inherited many space denial capabilities from the dissolved Soviet Union that included proven direct-ascent and co-orbital ASATs as well as developmental laser and directed energy systems.[31] Their co-orbital ASAT had, at a minimum, annual live tests from 1976 to 1982, and it remained operational until 1993.[32] The 2017 DIA *Russia Military Power* report indicates that many of these resources remain: "[Russian] Military capabilities for space deterrence include strikes against satellites or ground-based infrastructure supporting space operations."[33] Russia's electronic warfare (EW) systems include the Zhitel satellite navigation jammer as well as the Borisoglebsk-2 complex designed to jam SATCOM and radio navigation systems.[34] Russian EW systems with potential directed energy weapon abilities include the Krashukha-4, which has successfully countered U.S. radar reconnaissance satellites and claims to be able to disable electronics on low-orbiting satellites.[35] Russian space forces are actively testing a new ASAT system based on the PL-19 Nudol missile[36] with recent press reports of a fifth successful test in December 2016.[37]

Space Force Application: The Soviet Union invested heavily in land-based ICBMs as the strongest part of their nuclear forces that also included bombers and submarine-launched ballistic missiles (SLBM). Russia continues this tradition, and it has modernization programs underway, although implementation of these updates has suffered many delays. Its current force consists of Stiletto, Topol, Topol-M, Voevoda, and Yars strategic missiles, as well as the developmental Sarmat.[38] Unlike the silo-based U.S. land-based missile force, Russia deploys its ICBMs using both silo and land-mobile basing, which may include rail-mobile systems in the future.[39] Russia is also completing its new fleet of *Borey*-class ballistic missile submarines as well as the new Bulava SLBM.[40] With regard to ballistic missile defense, Russia has fielded several versions of the S-300, S-400, and S-500 anti-ballistic missile (ABM) systems, and it continues to maintain a formidable defense ring around Moscow. Additionally, these ABM forces are being augmented by modified fighter jets "used not only to gain air superiority but also to confront enemy attack means in near-Earth space."[41] Finally, Russia is developing hypersonic weapons with intercontinental range that could carry nuclear or conventional warheads, which may challenge the capabilities of the U.S. missile defense system.[42]

China

The current Army operating concept, *Win in a Complex World*, contends, "China works to negate U.S. advantages in space" in part through the development of advanced ASAT capabilities.[43] This viewpoint is reiterated in the 2017 Department of Defense (DoD) report to Congress on China, which notes that China continues to invest in "space-based ISR, satellite communication, satellite navigation, and meteorology," as well as "a variety of counter-space capabilities designed to degrade and deny the use of space-based assets by adversaries."[44] Indeed, since 2000, the Chinese orbital fleet has swelled from 10 satellites to over 200.[45] Let us examine some recent details of how China is working to improve in each of the five space mission areas.

Space Situational Awareness: The DoD assesses that China has a functional space surveillance capability, but it seeks "to utilize space systems to establish a real-time and accurate surveillance, reconnaissance and warning system."[46] In his 2016 Congressional testimony, space expert Dean Cheng provided additional insight into the Chinese efforts to build a more robust space situational awareness, noting that such improved capability is essential for the success of their ASAT systems. Also, improved space situational awareness will facilitate their space defense measures by allowing them to detect and characterize adversary orbital ASATs earlier, thus allowing them more time to plan and execute evasive maneuvers.[47]

Space Force Enhancement: China continues to make progress in the critical areas of space-based imagery, PNT support, and communications. In August 2014, China launched the Gaofen-2, its first imagery satellite with a sub-meter resolution capability that is used for government applications and commercial sales.[48] The Chinese satellite navigation system continues to grow, with four Beidou I1-S satellites added in March 2015, two in medium Earth orbit like GPS satellites and two in inclined geosynchronous (GEO) orbit. These launches demonstrated the plan to extend the Beidou network beyond regional coverage.[49] Current plans are to have global coverage with a constellation of 35 total satellites by 2020.[50] In August 2016, China significantly enhanced its capability for secure SATCOM by launching the first experimental communications that use quantum encryption technology.[51]

Space Support: Over the past 2 decades, China has built an impressive infrastructure of spacecraft manufacturing, space launch, and satellite telemetry, tracking, and command facilities. The robust family of Long March SLVs was further expanded in 2016 with the debut launches of the LM-5 medium lift SLV and LM-5 heavy lift SLV, both of which can support their growing human spaceflight program.[52] These launches were the first to occur from the new Wencheng space launch center completed on Hainan Island in 2015.[53] The Chinese are developing operationally responsive space launch capabilities designed "to augment current constellations in time of crisis and to replace lost assets in time of conflict."[54] Thus far, they have successfully developed the Kuaizhou-1A solid rocket SLV to serve this purpose; its first launch of three small satellites occurred in January 2017.[55]

Space Control: China persists in acquiring technologies for its counter-space systems that provide hard-kill and soft-kill options, to include directed-energy weapons, jammers, and ASAT missiles. In addition, they are suspected of testing dual-use capabilities, such as autonomous maneuvering, in their satellite designs that would allow them to perform counterspace tasks on orbit.[56] In what may have been a demonstration of co-orbital ASAT capability, in 2010, two small Chinese satellites performed a series of maneuvers that included a controlled conjunction. Since their infamous 2007 ASAT missile test, the PLA conducted additional missile tests in 2010, 2013, and 2014 that have ASAT applications.[57] The missile in the 2013 test had a peak altitude over 30,000 kilometers bringing it near the vulnerable GEO belt, which is at an altitude of about 36,000 kilometers. Although pressed for explanation by the United States and several international organizations, the Chinese Government has not given details of the test's purpose.[58]

Space Force Application: Although it professes a "No First Use" nuclear doctrine, China is aggressively pursuing nuclear platforms with multiple warheads and hypersonic delivery vehicles.[59] The current Chinese nuclear inventory consists of 75-100 ICBMs and 4 of the *Jin*-class ballistic submarines, each carrying up to 12 SLBMs. The PLA is developing subsystems such as decoys, chaff, jamming, and shielding to enhance the survivability of these weapons.[60]

China has developed at least one hypersonic boost-glide vehicle through a series of seven prototype flight tests since 2014. One of these tests included evasion maneuvers at speeds over Mach 10 intended to defeat U.S. missile defenses. The vehicle may be deployed in the mid-2020s with either conventional or nuclear warheads.[61]

China continues to develop a ballistic missile defense that includes kinetic energy intercept capability at atmospheric and exoatmospheric altitudes.[62] The system includes two new indigenous radar designs, one of which may be able to track multiple ballistic missiles. The viability of the system was demonstrated by successful midcourse intercept tests in 2010 and 2013.[63]

SPACE A2/AD IMPLICATIONS FOR ARMY AND JOINT OPERATIONS

What are the implications of space-related A2/AD activities for the United States, its adversaries, and other international entities? This section explores this question at both the operational military level as well as the strategic level that may include effects on other elements of national power.

Adversary View of Space Power

Strategic Level

Both Russia and China see space as a key part of their national security and their international prestige, as well as their economic, political, and informational power. They also see the opportunity that their space industries provide to access and influence other countries. For example, such efforts by China include satellite and space support infrastructure development for several Latin American countries, including Argentina, Brazil, Bolivia, Ecuador, and Venezuela.[64] Russia provides the United States with access to the International Space Station and it supports several commercial spacelift ventures, including the company Sea Launch, which has its homeport facilities in Long Beach, California.[65]

For over 2 decades, the primary space launch program for the DoD, the Evolved Expendable Launch Vehicle (EELV), has included a critical dependence on Russian RD-180 engines for the Atlas V rocket.[66] Selected on the basis of technological superiority, the agreement to purchase the engines from Russia was also influenced by the desire of the United States to help with Russia's transition from the former Soviet Union. This arrangement held until Russia's 2014 annexation of Crimea and the U.S. response of economic sanctions. Russian threats to retaliate include the possible refusal to sell any more RD-180 engines.[67] There is no immediate replacement for the RD-180 and the cost estimates for replacement with a U.S. design are over $1 billion with a time lag of at least 5 years for the development of a new design.[68]

Despite the efforts to expand their arsenals of space weapons, Russia and China are leading the effort for global acceptance of the Treaty on the Prevention of the Placement of Weapons in Outer Space—first introduced in 2008 and updated in 2014. The crux of the treaty is found in its Article II, which states in part, "States Parties to this Treaty shall not place any weapons in outer space; [and] not resort to the threat or use of force against outer space objects of States Parties."[69] The official U.S. position is that:

> the 2014 draft . . . [Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force Against Outer Space Objects] is fundamentally flawed. The scope of the proposal, absence of working definitions, lack of verification mechanisms and failure to address terrestrial-based ASAT weapons were all issues for the United States.[70]

Operational Level

Like the United States, Russia and China seek to make space capabilities an integral part of their unified military operations. Further, both countries promulgate that growing their military capabilities into a strong, technologically advanced, and operationally unified defense force is necessary to meet the growing threats of the United States and its allies.

Russia views U.S. and North Atlantic Treaty Organization (NATO) space power as a viable threat, which is reflected in their 2015 National Security Strategy and 2014 Military Doctrine.[71] Specifically, these documents express concern regarding:

> U.S. missile defense systems stationed abroad, Global Strike capabilities, and 'strategic non-nuclear

> high-precision weapons,' as well as the militarization of space, all themes that came up in the military doctrine.[72]

To help address these security challenges, the 2017 DIA report, *Russia Military Power*, asserts that Russia sees counter-space operations as a way to control deterrence and escalation, especially with space-enabled adversaries such as the United States.[73]

In August 2015, Russia created the *Vozdushno-Kosmicheskiye Sily* (VKS, translated as Russian Federation Aerospace Forces) as an organization that mirrors aspects of the North American Aerospace Defense Command (NORAD).[74] In a statement announcing the reorganization, Russian Defense Minister Shoygu noted that it was "prompted by a shift in the center of gravity in combat struggle to the aerospace sphere."[75] Further, Russian leadership noted that formation of the VKS was motivated by the increased speed of operations and decreased warning times in aerospace, as well as the increased aerospace weapons development by the United States.[76] Accordingly, the VKS structure includes space forces tasked with "conducting space launches and maintaining the ballistic missile early warning system, the satellite control network, and the space object surveillance and identification network."[77]

Chinese military leaders view "the control of outer space as a natural extension of a nation's control of its territory."[78] Their careful observation of modern wars in southwest Asia cause many of these leaders to assess that "joint operations and command were so effective because of U.S. space assets."[79] The 2017 DoD report to Congress on Chinese security notes the "PLA strategists regard the ability to use space-based systems—and to deny them to adversaries—as central to enabling modern informatized warfare."[80] To exploit the potential advantages of space capabilities, the current PLA guiding thought (roughly equivalent to U.S. doctrine) emphasizes space operations in the active defense and unified operations of the military:

> Space operations must also be integrated into larger, joint campaign plans to help achieve terrestrial objectives; command and control [C2] of space operations must therefore reconcile space-related requirements, timing, and structure with those of the overarching joint campaign.[81]

In late 2015, China established the Strategic Support Force to combine China's military, space, cyber, and EW missions. President Xi described the force as a "new-type combat force to maintain national security and an important growth point for the PLA's combat capabilities."[82] To unify their military forces further, in February 2016, the PLA established five theater commands (Eastern, Southern, Western, Northern, and Central) followed in April 2016 by the formation of their Joint Operations Command Center.[83]

Operational Space Links for U.S. Forces

Joint Operations

Space forces play a prominent role in current U.S. joint operational concepts. *The Capstone Concept for Joint Operations: Joint Force 2020* (CCJO) views the space domain's importance to globally integrated military operations in a manner similar to that of Russia and China:

> Space and cyberspace will play a particularly important role in the years ahead. As these domains figure more prominently in the projection of military power,

> operations in them will become both a precursor to and integral part of armed combat in the land, maritime and air domains.[84]

The CCJO also notes the "dramatic increases in the ability for adversaries to disrupt, degrade or destroy cyberspace and space systems" and thus the need to design U.S. systems that can operate in such degraded environments.[85] Further, the CCJO includes two explicit space-related force development initiatives: "continue to improve defensive space capabilities" and "integrate missile defense systems."[86] Finally, the CCJO acknowledges the realities of defense acquisition and admits, "such technologies, especially in a time of restricted budgets, may prove prohibitively expensive to develop and deploy."[87]

The 2012 *Joint Operational Access Concept* (JOAC) was written to provide a vision for the joint force to address the challenges posed by emerging adversary A2/AD capabilities. The JOAC bases this guidance on three major trends: growth of A2/AD capabilities, change in U.S. overseas basing, and conflict in space and cyberspace. It also envisions a significant increase in the role of space and cyberspace forces in traditional air-sea-land operations.[88] To counter this operational synergy, the JOAC anticipates that "enemies may try to disrupt U.S. use of space and cyberspace—commercial as well as governmental—well before the onset of lethal combat."[89] Accordingly, 1 of the 11 operational access precepts that enable the JOAC's primary goal is to "protect space and cyber assets while attacking the enemy's cyber and space capabilities."[90]

The 2014 *Joint Concept for Entry Operations* "establishes a common intellectual framework for the challenge of entry in advanced A2/AD environments."[91]

It emphasizes the integration of forces across domains and notes "regardless of the type of maneuver, mobility and flexibility are critical and enhanced when fully integrated with cyberspace and space capabilities."[92] Consistent with current joint doctrine, the responsibility to incorporate space forces into a joint force—the space coordinating authority—may fall upon the joint force land component commander, if so designated.[93]

Army Operations and Multi-Domain Battle

The U.S. Army Training and Doctrine Command (TRADOC) publishes the 525-series of pamphlets to describe "how future Army forces will prevent conflict, shape security environments, and win wars while operating as part of our Joint Force and working with multiple partners."[94] TRADOC Pamphlet 525-3-1, *The U.S. Army Operating Concept: Win in a Complex World, 2020-2040*, echoes the themes of joint operational access and discusses A2/AD challenges, which include those related to space systems. This document explicitly states that Landpower planners and leaders should expect potential enemies to utilize "space capabilities such as anti-satellite [ASAT] weapons to disrupt U.S. communications and freedom of maneuver," and offers the example that adversary GPS jamming could degrade the accuracy of precision fires.[95] *Win in a Complex World* also notes the active role of Army forces in protecting U.S. space systems "through reconnaissance, offensive operations or raids to destroy land-based enemy space and cyberspace capabilities."[96]

TRADOC pamphlets that complement *Win in a Complex World* include documents that describe future Army warfighting function concepts and amplify the relevant space-based support needed for future mission command, movement and maneuver, intelligence, fires, sustainment, and maneuver support.[97] These concepts explicitly state that space warfighters facilitate multi-domain battle and that such support will likely involve:

> Maneuver forces leverage space-based capabilities through organic and embedded space professionals and cadre within the formation. Space support elements, Army space support teams and other specialized teams combine to plan, coordinate, synchronize, and integrate the human and technical elements of space operations to support maneuver forces across joint, interorganizational, and multinational partners.[98]

The most recent TRADOC *Concept Capability Plan* for space operations precedes the CCJO by 6 years, but it contains the key themes of an increased integration of space capabilities into Army operations, in parallel with increased counter-space capabilities by adversaries. One of its explicit imperatives calls for the Army to "systematically and deliberately evolve Army space support operations over time to provide dedicated, responsive theater focused support to operational and tactical commanders."[99] A significant feature of such theater support is the incorporation of the systems that operate in a high altitude environment to augment orbital assets, noting that "a high altitude long-loiter system can provide long duration coverage of up to an 850-mile diameter field of view."[100]

Presently, the Army, working with the Marine Corps, is focused on the development of the Multi-Domain Battle concept of combined arms, which addresses the A2/AD challenges identified in joint concepts and includes a greater emphasis on space and other contested domains.[101] The concept envisions future adversaries, such as Russia and China, that emphasize the use of long-range precision strike capabilities protected by integrated air defense networks that would force the joint forces to operate from dispersed locations. The Multi-Domain Battle concept has three major components: "creating and exploiting temporary windows of advantage; restoring capability balance and building flexible, resilient formations in the Joint Force; and altering force posture to enhance deterrence."[102] To aid in the concept development as well as its eventual mission command, TRADOC offers a draft battlefield framework that expands the three physical spaces of AirLand Battle (rear, close, and deep) to six physical spaces (strategic support, operational support, support, close, deep, and deep fires areas).[103] In the current framework version, space capabilities have a presence in all of these physical spaces:

> It is important that even virtual locations are tied to physical locations within this framework. Space, cyberspace, and information are often cited as exclusive virtual domains or dimensions, but that attribution is inaccurate. Achieving a physical effect requires a physical location of a delivery mechanism, supporting points to facilitate delivery, and the point of the intended effect.[104]

Given the importance of this crucial dependence on space forces, what ongoing world activities might affect the future application of U.S. space power?

International Efforts

While space-based operations may occur in a near vacuum environment, their effects and implications, intentional or not, are rarely isolated to this domain. Thus, with the United States, Russia, and China all pursuing highly integrated military operations across multiple domains, the possibility of unintentional escalation is a prudent consideration. Vincent Manzo of the National Defense University argues for the development of a common framework for interpreting cross-domain operations "that would give decision-makers a better sense of which actions and responses are expected and accepted in real-world scenarios and which would cross thresholds that escalate the situation."[105] He presents a vignette where China interferes with a U.S. satellite during a military crisis, but does not damage it. The U.S. response uses cyberspace operations to interfere with the belligerent Chinese system, but does not damage it. Is the U.S. response proportional because it is in direct response to the initial aggression, or is it escalatory because it crosses domains? The predicament is that different officials in different governments may interpret such events in dissimilar manners. Thus, the development of common frameworks for space operations may decrease the potential for unintended escalation of hostility that could be sparked by counter-space activities.

The topic of weapons in space has garnered significant international attention, including from several organizations within the United Nations (UN) such as its Institute for Disarmament Research (UNIDIR) and The Committee on the Peaceful Uses of Outer Space within the Office for Outer Space Affairs (UNOOSA). Building upon the foundation of the Outer Space Treaty of 1967, these venues facilitate several noteworthy endeavors amongst nations to better define the security environment of space, such as the No First Place of Arms in Outer Space initiative and the 2013 UN Group of Government Experts on Transparency and Confidence-Building Measures (TCBMs) in Outer Space Activities.[106] The report of the 2016 UNIDIR Space Security Conference notes that "the United States is committed to implementing norms of behavior from the 2013 UN . . . [Group of Government Experts] on space TCBMs report" and that it encourages other nations to do the same.[107] A detailed analysis of these ongoing efforts is worthy of its own monograph.[108]

The European Union (EU) continues to champion the adoption of an International Code of Conduct for Outer Space Activities, a proposal that has been met with mixed reviews from other countries.[109] In October 2016, the European Commission formally proposed a Space Strategy for Europe focused on four strategic goals. The third goal, "Reinforcing Europe's Autonomy in Accessing and Using Space in a Secure and Safe Environment," clearly establishes the priority for EU Member States to maintain autonomous access to space and related radio frequencies as well as to protect European space infrastructure.[110] Part of the ways intended to achieve these ends is to leverage the inherent synergies between military and defense space systems, which include their Copernicus Earth observation capabilities and the Galileo navigation constellation.[111]

SPACE A2/AD MITIGATION MEASURES

The *Joint Operating Environment 2035* (JOE 2035) predicts, "Competition in orbit (even during peacetime) will be intense" involving a variety of counter-space activities.[112] What current Army and joint measures may mitigate the negative effects of adversary A2/AD activities and what space systems under development may provide alternative capabilities for such mitigation? This section addresses this question by providing examples of how the Army, joint forces, and coalition members are working to address space-related A2/AD concerns.

Army Measures

During his June 2017 testimony before Congress, Lieutenant General James Dickinson, Commanding General, U.S. Army Space and Missile Defense Command (USASMDC)/Army Forces Strategic Command (ARSTRAT) and Joint Functional Component Command for Integrated Missile Defense, addressed the challenges facing U.S. ballistic missile defense and noted the essential role that space-enabled capabilities provide. Progress in the emplacement of ground-based interceptors at Fort Greeley, Alaska, as well as the establishment of an inflight interceptor communications system data terminal at Fort Drum, New York, have greatly increased the capability to defend the United States against ICBM attacks from Iran and North Korea.[113]

Earlier Congressional testimony by four Army generals representing the areas of operations and planning, force management, capability development, and acquisition addressed the results of the Army's first Strategic Portfolio Analysis Review. Capability gaps identified by the review included air and missile defense (AMD); assured PNT; EW; and assured communications.[114] Fortunately, the described ongoing Army programs are addressing some of these shortfalls.

Resilient Space Systems

In its assessment of the technological needs for the future joint force, JOE 2035 notes that systems other than traditional large satellite constellations—such as microsatellites or nanosatellites and near space platforms—may provide more responsive and resilient space support.[115] The USASMDC/ARSTRAT Technical

Center recently completed an important milestone in its Kestrel Eye technology demonstrator to provide space-based imagery augmentation directly to theater warfighters at the brigade combat team level. On August 14, 2017, the first Kestrel Eye was launched on SpaceX Falcon 9 where it will be transferred to the International Space Station for final orbital insertion.[116] Once established in orbit, the microsatellite (about 50 kilograms) will go through a series of exercises by U.S. Pacific Command to assess the system's operational utility. If the demonstration is successful, then the Army may opt to build a constellation of the satellites.[117] If so, the aim for production versions of the satellite is to cost less than $2 million each and have an operational life of at least 1 year.[118]

The Army is also pursuing resilient SATCOM through the Space and Missile Defense Command Nanosatellite Program (SNaP) as an effort "to be a cost-effective and responsive satellite technology to mitigate the impact from the loss or disruption of national space capabilities."[119] The concept is similar to "a cellphone tower in space, except . . . for Army radios" that provide voice and data SATCOM using nanosatellites (about 5.5 kilograms) that can hitch a ride to orbit on larger space launches.[120] Warfighters in U.S. Southern Command have helped to assess the operational utility of some of the earlier SNaP demonstrations.[121]

Other areas of ongoing Army development include high altitude and near space systems, navigation warfare, and high-energy lasers. High altitude systems have the potential to augment and extend tactical communications as well as help provide PNT capabilities in degraded environments.[122] The USASMDC/ARSTRAT Future Warfare Center is developing the concepts and required capabilities to characterize the tactical PNT environment, assure friendly force use of PNT, and deny adversary use of PNT.[123] Various high-energy laser demonstrators are being developed and tested by USASMDC/ARSTRAT as part of a Maneuver and Fire Integration Experiment (MFIX) series. Two mobile lasers testbeds successfully contributed to MFIX 2016 at Fort Sill, Oklahoma, and they demonstrated lethality against simulated threats. The lasers also serve as platforms for warfighter familiarization and tactics, techniques, and procedures development.[124] The current lasers operate with up to 10 kilowatts of power; the development goal is to increase the capability to 50 kilowatts by 2018 and 100 kilowatts by 2022.[125]

Training and Exercises for Theater Forces

To support the advancement of Multi-Domain Battle concepts, USASMDC/ARSTRAT is creating a multi-domain task force that "will integrate space effects at the tactical level to support maneuver elements of the operational Army."[126] The task force is planned to grow to a strength of 1,500 Soldiers and its effectiveness can be enhanced through increased awareness of space capabilities within the Army writ large. Toward this end, the USASMDC/ARSTRAT Future Warfare Center's Directorate of Training and Doctrine trained more than 8,750 Soldiers and civilians during fiscal year (FY) 2016 in over 30 different courses that covered various aspects of the 5 space mission areas. Many of the courses are open to members of other services.[127] Also, the ARSTRAT G-3 Training and Exercise Division (TREX) is developing field training events to demonstrate the effects of electromagnetic interference on GPS receivers—something that Soldiers should expect to encounter in a contested space environment.[128] To help instill space capability awareness at the beginning of an officer's career, USASMDC/ARSTRAT is partnering with West Point for their Space and Missile Defense program that was established in 2015, with a stand-alone major created in 2017.[129]

Army forces help to spread the benefits of U.S. space capabilities to other militaries around the world. In May 2014, ARSTRAT TREX demonstrated space kits to members of U.S. Army Africa that focused on space-enabled force tracking and GPS jamming awareness;[130] similar training was provided to Soldiers in U.S. Army South earlier that year.[131] In May 2016, USASMDC/ARSTRAT teamed with the California National Guard to provide space operations training to Ukrainian soldiers in their country to help them deal with degraded space support they experienced during their conflict with Russian separatists.[132] Additionally, in June 2016, Army Space Support Teams supported NATO exercise Anakonda-16 in Poland—a 10-day event that involved more than 30,000 troops from 24 countries.[133]

Joint and Coalition Measures

In April 2016, the U.S. Air Force Space Command announced its new Space Enterprise Vision to provide an integrated approach that spans the five space mission areas and "enhances U.S. space forces' ability to deter others from interference and attack, defend our space systems if deterrence fails and contribute to the defense of allied space systems."[134] Let us examine some specific examples in each space mission area of ongoing efforts to increase the resilience of U.S. forces in a contested space environment.

Space Situational Awareness

During a January 2017 presentation at Stanford University, USSTRATCOM Commander General John Hyten discussed the formerly classified Geosynchronous Space Situational Awareness Program (GSSAP), calling the four-satellite constellation "basically a neighborhood watch program for everything that goes on in that high-value orbit."[135] The Air Force declared the initial operational capability of GSSAP in September 2015.[136] To provide a more holistic approach to space situational awareness, USSTRATCOM established the Joint Interagency Combined Space Operations Center (JICSpOC) in October 2015 at Schriever Air Force Base, Colorado. JICSpOC's mission was to facilitate the fusion of space data amongst USSTRATCOM, the National Reconnaissance Office, the Air Force Space Command, the Air Force Research Laboratory, as well as to members of the intelligence community and commercial data providers.[137] In April 2017, the JICSpOC was renamed the National Space Defense Center to better match its mission as well as to avoid it from being confused with the Joint Space Operations Center (JSpOC) at Vandenberg Air Force Base, California.[138]

Several DoD programs seek to improve space object detection and data processing for space force C2. In February 2015, officials broke ground at Kwajalein Atoll for construction of the Space Fence, an improved replacement for the aged Air Force Space Surveillance System. The system provides unprompted detection data to the JSpOC for space objects as small as 10 centimeters.[139] The Space Fence is on track for an initial operating capability by 2019, and its future capability may be expanded to a second site in Australia.[140] Space

C2 is also being improved through the JSpOC Mission System modernization of hardware and software, to handle the increased volume of space situational awareness.[141] The Defense Advanced Research Projects Agency (DARPA) is exploring future space situational awareness capabilities such as OrbitOutlook, a program to provide automated synthesis of diverse sets of orbital data that may "improve the capability of the U.S. military and the global space community to make decisions about potentially hazardous space objects in near real time."[142]

Space Force Enhancement

Modernization efforts continue for several constellations of satellites that provide crucial force enhancement to warfighters in the areas of PNT, communication, missile warning, weather, and imagery. In addition to the acquisition of the next-generation GPS III satellites starting in 2017, the procurement of the GPS Next Generation Operational Control System ground control system will "provide enhanced cybersecurity, precision, reliability, and integrity."[143] In addition, the Air Force is developing the Military GPS User Equipment receiver for joint warfighters that will improve PNT capabilities and resistance to emerging counter-space measures such as jamming.[144]

Ongoing SATCOM improvements include the upcoming launch of the fourth Advanced Extremely High Frequency satellite system, part of a four-satellite constellation that "provides survivable, anti-jam, low probability of detection/intercept, worldwide secure communications for tactical and strategic users," as well as nuclear effects-hardened SATCOM.[145] The Enhanced Polar System will serve as a polar-orbiting extremely high frequency SATCOM adjunct to the advanced extremely high frequency system. Its second of two satellites is planned for launch in late 2017 for an operational capability achieved by mid-2018.[146]

With regard to Earth observation systems, the space-based infrared system (SBIRS) remains the mainstay for space-based launch detection and missile warning. The third GEO SBIRS satellite was launched in January 2017 and the fourth GEO SBIRS is scheduled to launch in early 2018 to complete the constellation that also includes two smaller satellites in highly elliptical orbit.[147] The Weather System Follow-on-Microwave is the DoD's third attempt to replace the Defense Meteorological Satellite Program. The weather system satellite is in the early phases of development; its system-level preliminary design review is scheduled for mid-2018. Ongoing efforts by the DoD's Defense Innovation Unit Experimental initiative include contracts for improved satellite imagery. The DoD has two contracts for the analysis of data from synthetic aperture radar micro-satellites to increase terrestrial situational awareness—one with Capella Space for the satellite imagery and one with Orbital Insight Space for analysis.

Space Support

The EELV has amassed an impressive 70 consecutive successful national security space launches as of March 2017. The current fleet is comprised of the Atlas V, Delta IV Heavy, and Falcon 9 SLVs that can compete for three planned launches for 2018.[148] The Air Force is exploring reusable spacecraft technologies using the X-37B Orbital Test Vehicle, the first vehicle since NASA's Space Shuttle to successfully fly in space, land on a runway, and return to space in a subsequent launch. The X-37B has flown four times since April 2010.[149] DARPA is also working on the most responsive space access capabilities such as the Experimental Spaceplane program formerly known as XS-1, "an entirely new class of hypersonic aircraft that would bolster national security by providing short-notice, low-cost access to space."[150] A defunct DARPA program, the Airborne Launch Assist Space Access, aimed "to propel 100-pound satellites into low Earth orbit . . . within 24 hours of call-up, all for less than $1 million per launch." While the program did make it to the design phase of a technology demonstrator and some subscale tests, safety concerns over its highly energetic monopropellant ended the program.

DARPA is partnering with industry to explore possible on-orbit satellite maintenance systems such as the Robotic Servicing of Geosynchronous Satellites (RSGS) designed to inspect, maintain, and repair GEO satellites.[151] The RSGS goal is to have a technology demonstrator in orbit by 2022.[152] While such a system would provide incredible new capabilities for the U.S. space fleet, the dual-use potential of RSGS may also be viewed as a weapon by potential adversaries.

Space Control

The JOE 2035 calls for the possible use of offensive space control as part of the defense of global commons as well as the need for U.S. forces to be able to respond to attempts by adversaries to create orbital debris fields.[153] In 2008, the U.S. Missile Defense Agency conducted Operation Burnt Frost at the direction of President Bush to destroy a non-functioning U.S. satellite that posed a hazard to life during an uncontrolled reentry. Although not its intended purpose, the successful operation demonstrated the low-orbit ASAT capability of the U.S. Aegis cruiser/Standard Missile-3 system.[154]

Defense counter-space forces include two Air Force squadrons of Space Aggressors tasked "to prepare joint forces and coalition partners to fight in and through contested space environments by analyzing, teaching and replicating realistic, relevant and integrated space threats."[155] Currently, the 26th and 527th Space Aggressor Squadrons focus on replicating live electronic attacks on GPS and SATCOM systems to help warfighters hone their tactics, techniques, and procedures. During the 2016 exercise Red Flag-Alaska 16-3, a Soldier from the 1st Space Battalion was integrated into the aggressor squadrons for the first time.[156]

Space Force Application

From a monetary resource viewpoint, the United States is very serious about maintaining an able space force. Ballistic missile defense systems for services are funded for $6.5 billion in the DoD FY 2018 budget request for an investment for interceptors and surveillance radars. The budget includes an additional $7.9 billion for the Missile Defense Agency and $3.7 billion for two *Arleigh Burke*-class Aegis destroyers in missile defense configuration.[157]

Members of U.S. missile defense forces continue to partner with allies in the biannual Nimble Titan missile defense experimentation campaigns sponsored by USSTRATCOM and led by the Joint Functional Component Command for Integrated Missile Defense, which is the "third hat" for USASMDC/ARSTRAT. The Nimble Titan events not only bring warfighters from different nations together, but also players who focus on policy-level lessons for their organizations.[158]

In March 2017, the Nimble Titan 18 campaign commenced with an event in the Netherlands attended by participants from 26 nations. The campaign will address missile defense interoperability and integration as well as strategic issues such as deterrence and de-escalation measures.[159]

Like Russia and China, the United States is investing heavily in the modernization of its land- and sea-based strategic ballistic missiles. The FY 2018 budget request includes $1.27 billion for the ongoing Trident II SLBM life extension that will keep the missiles as a viable deterrent through 2042, as well as $1.89 billion for work on the *Columbia*-class fleet ballistic missile submarine, which is set to begin replacing *Ohio*-class submarines in 2028.[160] The Ground-Based Strategic Deterrent program aims to provide a modern replacement for the venerable Minuteman III ICBM fleet. Still in its earlier stages, the program will incorporate technologies necessary to address the projected threats through 2075. It is currently funded for $215 million in FY 2018, with deployment planned for the late 2020s.[161]

NATO Space Capabilities

NATO doctrine for space operations is included as chapter 5 of Allied Joint Publication-3.3, *Allied Joint Doctrine for Air and Space Operations*. It focuses on three of the Joint Publication 3-14, *Space Operations*, mission areas: space situational awareness, space force enhancement, and space control, which includes defensive space control operations to protect friendly space systems and recover from adversary disruptions and attacks. Allied Joint Publication-3.3 also identifies the roles of space in the planning and execution of NATO operations as well as how to accomplish space support coordination at the strategic and operational levels.[162]

While NATO has conducted space operations since 1970, it relies on its member nations to provide military space capabilities. In a 2014 Marshall Center paper, Colonel Paul Tombarge argues for the establishment of a NATO Center of Excellence for space operations. To support his case, he presents a detailed compilation of existing NATO member space assets and the existing space-related positions in NATO's command structure as well as recommended changes to improve the integration of these space capabilities.[163]

The recent Trident Junction 2016 included the "first integration of Space in a major NATO exercise as it involved incorporation, synchronization, integration and exploitation of Space-based products and services into Joint Task Force . . . operations."[164] Participants included space experts from USASMDC/ARSTRAT, as well as ones from France, Canada, Germany, and Italy. The current plan is to build on this success by establishing such space operations participation in future Trident Junction exercises.[165]

RECOMMENDATIONS

With the most capable space systems in the world, U.S. space forces are alluring targets for adversaries who wish to diminish the effectiveness of joint forces that depend upon space capabilities. Based on the material discussed in this monograph, the following recommendations identify opportunities for improvement at the operational and strategic levels to build a more coherent and effective military space force that supports all elements of national power.

Operational Opportunities

Awareness and Realistic Expectations for Space Support

Space operations typically receive short shrift in the core curriculum of intermediate and senior service schools, often crammed into a single lesson that covers the entirety of USSTRATCOM missions. This relegation of priority may propagate ignorance of the wealth of opportunities available from space forces, and thus hamper the full integration of space operations into new paradigms, such as Multi-Domain Battle.

In contrast, the DoD and the U.S. Army should be cautious not to over-promise and under-deliver on space capabilities. Publicly accessible USASMDC videos, such as "Army Space Power 2035," border on fantasy in their depiction of Army space capabilities that might be available in less than 2 decades. The video "SMDC2017" is a more realistic depiction of Army space operation, albeit somewhat overdramatic.[166]

Aerospace as the Center of Gravity

The creation of the VKS (Aerospace Force) is a huge change for the Russian military, driven in part by the perceived "shift in center of gravity in combat struggle to the aerosphere," as noted by Defense Minister Shoyu.[167] Current Army activities often focus disproportionately on Landpower first and add in generic (vice integrated) inputs from aerospace sources. Instead, Army training, education, and planning should actively consider and possibly embrace the Russian view of aerospace as the center of gravity of the future, with land and sea forces as rapid maneuver elements. Such a shift in perspective can help to inform how the Army should evolve to remain the world's preeminent Landpower force.

"Space-Cyberspace-Electromagnetic Spectrum" Confusion

Military operations that involve space, cyberspace, or the electromagnetic spectrum are probably the least understood by those who plan and execute them. The DoD and the joint staff should actively promulgate the development of coherent military theory for these areas as a foundation for doctrine and concept development.[168] In an August 2017 article, then-TRADOC commander General David Perkins noted that, "integrating space and cyberspace domains and the electromagnetic spectrum for how Army units and joint forces will fight is something the Department of Defense [DoD] is just now beginning to understand."[169] As such, many Army and joint guidance documents simply lump these three spheres of operation together. This current muddled approach to doctrine and concepts works against the achievement of unified action and it will become more of an issue now that U.S. Cyber Command will become a unified command separate from and equal to USSTRATCOM.[170]

Cyberspace Consideration in Space System Designs

The DoD should fully explore the role of cyberspace forces in protecting the link segments to space-based assets since it is possible for malware to be inserted in uplinks and distributed via downlinks. Moreover, builders of satellites and space support facilities should implement cybersecurity features as integral design elements. Such features should emphasize mission resilience of the overall space system vice mere protection of individual system assets.[171]

Consideration of Natural Space Hazards

Outer space is an inherently hostile environment driven by solar weather with volatile effects that can disrupt space links and damage spacecraft. Significant solar weather events can also degrade the effectiveness of space surveillance, warning sensors, and terrestrial communications. Although not discussed in this monograph, planning and execution of space operations need to consider the naturally hostile space environment itself fully, especially when assessing and attributing damage to on-orbit assets during crises or conflict.

Strategic Opportunities

Unintentional Escalation Potential

The DoD should thoroughly and proactively assess the escalation potential associated with the means and effects of space-related A2/AD activities in increasing levels of crisis and conflict. This assessment should avoid egocentrism in assigning value to various elements of a space force, but must clearly articulate the threshold bounds for attacks on certain crucial U.S. space systems (such as ICBM early warning and nuclear C2). These thresholds should be communicated by means of diplomatic and informational national power using venues such as the bilateral agreements and UN fora.

Hypersonic Weapons

In her assessment of the status of hypersonic weapon development around the world, Department of Energy technical analyst Rachel Wiener noted, "The totality of Russian and Chinese advancements has a potentially destabilizing effect for U.S. nuclear deterrence posture and presents complex strategic choices for U.S. policymakers."[172] The DoD should continue to ensure that development of future U.S. missile defense addresses the unique operational profiles presented by such weapon platforms. In addition, as the U.S. deterrent force is revitalized, USSTRATCOM and the DoD should continue to assess the role of hypersonic systems in deterrence—which may include delivery of nuclear warheads—and provide the necessary resources for success.

Whole-of-Government Approach

The DoD space organizations should continue to develop and maintain vehicles like the National Space Defense Center to facilitate unity of national space power but also to create synergy for approaching new challenges. A recent opportunity for such activities is found in the revival of the National Space Council on June 30, 2017, which marks the return of this venue since it ceased operation in 1993. Upon signing the Executive Order, President Trump declared, "The National Space Council will be a central hub guiding space policy within the Administration."[173]

Partnering with Industry

The DoD should continue to partner with U.S. aerospace industry and other private sector technology organizations to pursue innovative and cost-effective approaches to future space operations. In addition to the ongoing Defense Innovation Unit Experimental initiative, both USASMDC and the Air Force Space and Missile Systems Center released Broad Agency Announcements to the public this year to solicit new technologies and concepts for the DoD space enterprise.[174]

Stewardship of Technology

The DoD as well as the Departments of State and Commerce should continue their vigilance with regard to the export of technology, especially space-related technologies that can be dual tasked (for example, an autonomous maintenance satellite that could be used as an ASAT). The DoD should examine the RD-180 Russian engine situation for lessons learned regarding the dependence on imported technology for critical aspects of U.S. space systems. Finally, when deliberating the proper balance of investment across diverse technologies, the DoD should consider the advice offered in JOE 2035 that "the fascination with small and cheap must be balanced against an appreciation for capital-intensive weapons and industrial technologies with the potential to dramatically alter the strategic landscape."[175]

Role of Humans in Space-Based Operations

Russia and China, as well as much of the world, consider their active capability for human space flight to be a matter of great national prestige. In contrast, the United States willingly abdicated its ability to launch astronauts. Since 2011, NASA has been paying the Russian Government to provide the United States access to the International Space Station, a spacecraft in which the United States has invested over $50 billion. It may be a prudent measure for the DoD and NASA to carefully examine how human space flight contributes to all elements of U.S. national power and to develop a long-range strategy based on the path that would best benefit the United States writ large.

CONCLUDING REMARKS

The vision of outer space as a vast and tranquil sea is but an illusion; space is an inherently hostile environment that has become congested, contested, and competitive among the nations—and this trend shows no sign of abatement. However, as with the land, sea, and air commons, the peaceful pursuit of economic, diplomatic, and informational ends in space often requires the support of a capable and restrained military space force. The continued preeminence of U.S. military space capabilities depends on the continued efforts to ensure access to and freedom of movement within the space domain.

ENDNOTES

1. Department of Defense (DoD), *Sustaining U.S. Global Leadership: Priorities for 21st Century Defense*, Washington, DC: U.S. Department of Defense, January 2012, pp. 4-5, available from *http://archive.defense.gov/news/Defense_Strategic_Guidance.pdf*, accessed August 11, 2017.

2. Ibid., p. 5. The full description of the mission is:

> **Operate Effectively in Cyberspace and Space.** Modern armed forces cannot conduct high-tempo, effective operations without reliable information and communication networks and assured access to cyberspace and space. Today space systems and their supporting infrastructure face a range of threats that may degrade, disrupt, or destroy assets. *Accordingly, DoD will continue to work with domestic and international allies and partners and invest in advanced capabilities to defend its networks, operational capability, and resiliency in cyberspace and space* [emphasis and italics in original].

3. Training and Doctrine Command (TRADOC), Department of the Army, *The U.S. Army Functional Concept for Movement and Maneuver, 2020-2040*, TRADOC Pamphlet 525-3-6, Washington, DC: U.S. Government Printing Office, February 2017, p. 29, hereafter, TRADOC Pamphlet 525-3-6.

4. Brian Garino and Jane Gibson, "Space System Threats," in Air Command and Staff College Space Research Electives Seminars, *AU-18 Space Primer*, Maxwell Air Force Base, AL: Air University Press, September 2009, available from *http://www.au.af.mil/au/awc/space/au-18-2009/index.htm*, accessed August 2, 2017.

5. DoD, *Joint Operational Access Concept*, Version 1.0, Washington, DC: U.S. Department of Defense, January 17, 2012, p. 6, available from *http://defense.gov/Portals/1/Documents/pubs/JOAC_Jan%202012_Signed.pdf*, accessed August 11, 2017. The *Joint Operational Access Concept* (JOAC) definition for anti-access/area denial (A2/AD) is:

> As used in this paper [JOAC], *antiaccess* [A2] refers to those actions and capabilities, usually long-range, designed to prevent an opposing force from entering an operational area. Antiaccess actions tend to target forces approaching by air and sea predominantly, but also can target the cyber, space, and other forces that support them. *Area-denial* [AD] refers to those actions and capabilities, usually of shorter range, designed not to keep an opposing force out, but to limit its freedom of action within the operational area. Area-denial capabilities target forces in all domains, including land forces. The distinction between antiaccess and area-denial is relative rather than strict, and many capabilities can be employed for both purposes. For example, the same submarine that performs an area-denial mission in coastal waters can be an antiaccess capability when employed on distant patrol [italics in original].

6. Laura Grego, "A History of Anti-Satellite Programs," Cambridge, MA: Union of Concerned Scientists, January 2012, pp. 15-16, available from *http://www.ucsusa.org/sites/default/files/legacy/assets/documents/nwgs/a-history-of-ASAT-programs_lo-res.pdf*, accessed August 12, 2017.

7. TRADOC, Department of the Army, *The United States Army's Concept Capability Plan (CCP), Space Operations, 2015-2024,*

TRADOC Pamphlet 525-7-4, Washington, DC: U.S. Government Printing Office, November 15, 2006, p. 13. Potential attacks on U.S. space systems are summarized as follows:

> Adversaries may alter the space operations environment by interfering with spacecraft, communication links, ground stations, terminals, or the associated information infrastructure. Adversaries may employ a variety of anti-satellite [ASAT] techniques. Enemy special or conventional forces, theater missiles, electronic warfare [EW] means, cyber-attack, and terrorists all pose a threat to vulnerable ground stations, control facilities, and terminals. Future adversaries will likely not be limited to today's conventional munitions, but will likely develop both the intent and capability to employ WMDs or effects. Nuclear and non-nuclear electromagnetic pulse and directed energy weapons must also be considered. Adversaries may also attack spacecraft industrial facilities, launch sites, and even space vehicles during their ascent. The various bottlenecks associated with space systems will make unique space vehicle integration and launch facilities, and control and downlink facilities particularly valuable targets. Electronic attacks will aim to degrade satellite communications [SATCOM]; telemetry, tracking, and control links; and ground stations. Low power signals, such as those emitted by the global positioning system (GPS), are particularly susceptible to localized interference.

8. Joint Chiefs of Staff, *Space Operations*, Joint Publication 3-14, Washington, DC: U.S. Joint Chiefs of Staff, May 29, 2013, p. GL-8. See also Headquarters, Department of the Army, *Army Space Operations*, Field Manual 3-14, Washington, DC: Department of the Army, August 2014. Although Field Manual 3-14 is unclassified, its distribution is limited to the DoD and DoD contractors in order to protect certain technical data. Thus, details of its contents are not included in this monograph.

9. In addition to joint and Army space doctrine, see Jeffrey L. Caton, *Evolving Army Needs for Space-Based Support*, Carlisle, PA: Strategic Studies Institute, U.S. Army War College, April 2015, available from *http://ssi.armywarcollege.edu/pubs/display.cfm?pubID=1262*.

10. Robert M. Gates and James R. Clapper, *National Security Space Strategy: Unclassified Summary*, Washington, DC: U.S. Government Printing Office, January 2011, p. 1.

11. John E. Hyten, "Statement of John E. Hyten, Commander, United States Strategic Command, before the Senate Committee on Armed Services," 115th Cong., 1st sess., April 4, 2017, available from *http://www.stratcom.mil/Portals/8/Documents/Hyten_04-04-17.pd.pdf?ver=2017-04-04-154107-750*, accessed July 8, 2017.

12. Alexandr V. Nemets and Robert W. Kurz, "The Iranian Space Program and Russian Assistance," *Journal of Slavic Military Studies*, Vol. 22, No. 1, 2009, pp. 87-96.

13. Anthony H. Cordesman, *Iran's Rocket and Missile Forces and Strategic Options*, Washington, DC: Center for Strategic and International Studies, December 2014, p. x.

14. S. Chandrashekar, N. Ramani, Rajaram Nagappa, and Soma Perumal, *North Korea's Successful Space Launch*, Report No. R20-2013, Bengaluru, India: National Institute of Advanced Studies, Indian Institute of Science Campus, April 2013, p. 1.

15. Pooja Bhatt, "North Korea's Nuclear, Ballistic Missile & Satellite Tests," Issue Brief, New Delhi, India: Indian Council of World Affairs, March 18, 2016, available from *http://icwa.in/pdfs/IB/2014/NorthKoreaNuclearBallisticMissileSatelliteIB18032016.pdf*, accessed July 5, 2017.

16. "U.S. Condemns North Korean Missile Launch," DoD News, Washington, DC: Defense Media Activity, July 4, 2017, available from *https://www.defense.gov/News/Article/Article/1236993/us-condemns-north-korean-missile-launch/*; and "Pentagon Spokesman Comments on North Korean Missile Launch," DoD News, Washington, DC: Defense Media Activity, July 28, 2017, available from *https://www.defense.gov/News/Article/Article/1261474/pentagon-spokesman-comments-on-north-korean-missile-launch/*.

17. Table data for National Aeronautics and Space Administration (NASA) values sourced from "Satellite Box Score," *Orbital Debris Quarterly News*, Vol. 21, Iss. 3, August 2017, p. 12, available from *http://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv21i3.pdf*, accessed August 9, 2017. This satellite box score is based on the objects cataloged by the U.S. space surveillance network as of

August 4, 2017. Table data for CelesTrak values sourced from T. S. Kelso, "SATCAT Boxscore," CelesTrak, current as of August 8, 2017, available from *http://celestrak.com/satcat/boxscore.asp*, accessed August 8, 2017. This satellite box score is maintained by Dr. T. S. Kelso based on open source data from the North American Aerospace Defense Command (NORAD) and is continuously updated. Table data was current as of August 8, 2017. Table data for Union of Concerned Scientists values sourced from "UCS Satellite Database," Union of Concerned Scientists, last revised November 7, 2017, available from *https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database#.WzuAISAnY-6*, accessed August 4, 2017. This satellite box score was current as of December 31, 2016. It also indicates the breakdown of the 593 U.S. satellites as: 10 civilian; 297 commercial; 136 government; and 150 military. It is important to note that this is the same database cited by the Defense Intelligence Agency (DIA) in *Russia Military Power*, see endnote 20 in this monograph.

18. Jana Honkova, *The Russian Federation's Approach to Military Space and Its Military Space Capabilities*, Policy Outlook, Arlington, VA: George C. Marshall Institute, November 2013, p. 8, available from *http://studylib.net/doc/8138846/the-russian-federation-s-approach-to-military-space-and*, accessed July 5, 2017.

19. Ibid., p. 8.

20. DIA, *Russia Military Power: Building a Military to Support Great Power Aspirations*, Washington, DC: Defense Intelligence Agency, 2017, p. 35, available from *http://www.dia.mil/Military-Power-Publications/*, accessed July 10, 2017.

21. Pavel Baev, "The Nuclear Dimension of Russian Military Power," in Natasha Kuhrt and Valentina Feklyunina, eds., *Assessing Russia's Power: A Report*, London, UK: King's College London and Newcastle University, 2017, p. 14, available from *http://www.bisa.ac.uk/files/working%20groups/Assessing_Russias_Power_Report_2017.pdf*, accessed July 5, 2017.

22. William Graham, "Soyuz 2-1B launches Tundra missile detection spacecraft," NASASpaceFlight.com, May 25, 2017, available from *https://www.nasaspaceflight.com/2017/05/soyuz-2-1b-launches-tundra-missile-detection-spacecraft/*, accessed August 10, 2017.

23. Timothy L. Thomas, *Russia Military Strategy: Impacting 21st Century Reform and Geopolitics*, Fort Leavenworth, KS: Foreign Military Studies Office, 2015, p. 188, available from *https://community.apan.org/wg/tradoc-g2/fmso/m/fmso-books/195605/download*, accessed July 5, 2017. Thomas summarizes the details of these command centers as follows:

> The Space Command Troops include the Main Missile Attack Warning Center, whose space echelon monitors the launch of ballistic missiles of other nations and whose ground echelon monitors their flight. A Unified Space System is supporting the space echelon, while new Voronezh-type radars are active components of the ground echelon. Near Moscow the Don 2N radar system performs missions in support of missile defense. The Main Space Situation Reconnaissance Center is responsible for warning about foreign objects that might impact the International Space Station. Finally the Main Space Systems Test Center is developing both the space and ground echelons. Outside of Russia the Volga and Dnepr radars are located in Belarus and Kazakhstan, respectively, and the Okno space surveillance system is located in Tajikistan.

24. DIA, p. 35.

25. Honkova, pp. 25-31. The families of Russian communications satellites include Raduga, Molniya, Meridian, Strela, and Gonets, as well as the Geizer and Garpun relay satellites.

26. "The Current Status and Further Development of the GLONASS Orbital Grouping in Support of Multi-Constellation GNSS Implementation," Working Paper A39-WP/452, presented by the Russian Federation, Montreal, Canada: International Civil Aviation Organization, September 20, 2016, p. 2, available from *http://www.icao.int/Meetings/a39/Documents/WP/wp_452_en.pdf*, accessed August 10, 2017. The presentation includes the following status of the GLONASS (*Globalnaya navigatsionnaya sputnikovaya sistema,* translated as Global Navigation Satellite System) constellation:

> 2.1.1 In recent years, GLONASS has been maintained at the optimal level of 24 satellites, and it has been significantly modernized. As of July 2016, the GLONASS system, in line with its intended use, included 24 satellites, 23 of which

> were second generation (GLONASS-M) space vehicles . . . , and one third-generation (GLONASS-K). However, one GLONASS-M space vehicle (successful launch conducted on 29 May 2016), was put into service on 27 June 2016, two . . . [space vehicles] are being held in orbital reserve, and another GLONASS-K space vehicle is undergoing flight tests.

27. Graham. This article provides these details on the gap in Russian military space launch:

> Thursday's [May 15, 2017] mission was Russia's first military launch since 4 June last year—one of the longest gaps between Russian, or formerly Soviet, launches in history. A reported budget squeeze, coupled with reliability concerns and manufacturing problems has seen Russia's launch rate—usually the highest in the world—drop significantly over the last twelve months.
>
> The lull in activity has in part been down to manufacturing defects and quality control issues affecting Russia's production of rocket engines. A contractor was found to have been using cheaper materials in place of precious metals in alloys used to make parts of the engines. Seventy-one Proton engines and a number of Soyuz engines were recalled for inspection and repair.

28. Anastasia Edelkina, Oleg Karasev, and Natalia Velikanova, "Space Policy Strategies and Priorities in Russia," Basic Research Program Working Paper 37/STI/2015, Moscow, Russia: National Research University Higher School of Economics, 2015, p. 4, available from *https://publications.hse.ru/en/preprints/147513677*, accessed July 5, 2017. The authors summarize the goals of the Russian space policy related to space support as follows:

> In addition, the national space policy includes measures for the industry development of the rocket-space complex that meet national interests. These measures include the creation of a new generation of space complexes and systems to enable them to be competitive in the world market and the completion of the development of the GLONASS system; the development of satellite groups, including the creation of groups of communications satellites, ensuring the growth of the use of all forms of communications—fixed, mobile and personal; the creation of a group of meteorological satellites

> that are capable of delivering information in real time; the expansion of the Russian presence in the world space market, and finally, the modernization of ground space infrastructure and technological equipment.

29. Agence France-Presse, "Putin hails first rocket launch from new cosmodrome," *The Guardian*, April 28, 2016, available from *https://www.theguardian.com/world/2016/apr/28/putin-rocket-launch-cosmodrome-soyuz-delay-space*, accessed August 11, 2017.

30. "United Nations Register of Objects Launched into Outer Space," United Nations Office for Outer Space Affairs, n.d., available from *http://www.unoosa.org/oosa/spaceobjectregister/resources/index.html*, accessed August 4, 2017.

31. DoD, *Soviet Military Power 1990*, 9th ed., Washington, DC: U.S. Department of Defense, 1990, pp. 60-61, available from *http://www.dtic.mil/docs/citations/ADA229299*, accessed August 12, 2017. The section titled "Antisatellite (ASAT) Systems" includes the following summary of Soviet capabilities in 1990:

> The Soviets maintain a significant ASAT capability against low-earth-orbit and medium-earth-orbit satellites, but capabilities against high-altitude ones are limited. Future ASAT developments could include new directed-energy weapons or direct-ascent nonnuclear interceptors.
>
> The Soviets have additional potential ASAT capabilities exoatmospheric. ABM missiles [anti-ballistic missiles], located around Moscow and at the Sary Shagan test range, that could be used against satellites in near-earth orbit; at least one ground-based laser, also at Sary Shagan, that may have sufficient power to damage some unprotected satellites in near-earth orbits; and electronic warfare [EW] assets that probably would be used against satellites at all altitudes. Research and development of technologies applicable to more advanced ASAT systems continue at a steady pace. Areas of investigation that appear to hold promise include high energy laser, particle beam, radio frequency, and kinetic energy technologies.

32. Grego, p. 4.

33. DIA, p. 36.

34. Thomas, pp. 155-157. Technical details on the highly capable Russian Borisoglebsk-2 systems include:

> This is reportedly a multifunctional EW complex consisting of nine machines. Designed to jam mobile satellite communication and radio-navigational systems, the complex 'has electronic reconnaissance and electronic jamming facilities with an expanded frequency band, an increased speed of scanning the frequency range, reduced reaction time with regard to unknown frequencies, higher accuracy in determining the coordinates of a source of radiation, and jamming facilities with a higher throughput capacity.' It is stated that the complex can suppress over twice the frequency range than its predecessors (such as the Mandat or R-330), and it can find a signal to jam in a hundredth of the time. The Eastern Military District, Arctic, and Southern Military District have tested the complex at Tambov, with the Arctic units attempting to take into account the specific conditions of the Polar Region. It is mounted on a mobile tracked MT-LBu armored personnel carrier. The Borisoglebsk-2 was produced by the Sozvezdiye Concern. (p. 157)

35. Ibid, pp. 158-159. Technical details of the Krasukha-4 EW system relevant to space control include:

> Manufactured by the Radioelektronnyye Tekhnologii Concern, part of Rostekh, each system is comprised of two KamAZ vehicles with an operating radius of more than 300 km. The new system is fully automated and takes into consideration changes in wavebands and how the frequencies of homing-guidance heads operate as well as the algorithms of its effect. The system detects the frequencies on which reconnaissance is being conducted and initiates suppression automatically. The old Soviet systems, on the other hand, often saturated a waveband with noise and unfortunately suppressed its own equipment in the process. The system has successfully countered the US Lacrosse-class radar reconnaissance satellites. Lacrosse-class radar surveillance satellites are designed to monitor launch sites of the Topol or Yars mobile ground-based systems. The system creates a dome that is impenetrable to electromagnetic waves. It can blind and deafen AWACS-type long-range radar surveillance planes, space satellites used to guide rockets to targets, and

in tough situations, can control a high-frequency beam to 'burn out all of an airplane's electronic systems, rockets, or low-orbiting satellite.'. . . The system also can be found in the Eastern and Southern Military Districts and in the Arctic.

36. Baev, "The Nuclear Dimension," p. 14.

37. Weston Williams, "Russia launches anti-satellite weapon: A new warfront in space?" *The Christian Science Monitor*, December 22, 2016, available from *https://www.csmonitor.com/USA/Military/2016/1222/Russia-launches-anti-satellite-weapon-A-new-warfront-in-space*, accessed July 5, 2017. Few details of the Russian tests are available:

> Once more, Russia has conducted a successful test of an anti-satellite [ASAT] weapon, Pentagon officials said Thursday.
>
> It was the fifth time the weapon, a PL-19 Nudol missile, had been tested. Some military analysts have expressed concern over the test, saying that it was a provocative demonstration of Moscow's might on a relatively new military frontier: outer space. But they suggest that it's more about Russian posturing than an imminent threat.
>
> The latest test of the Nudol missile took place on December 16, an official with knowledge of the launch told The Washington Free Beacon. The launch originated from a facility near Plesetsk, about 500 miles north of Moscow, and was apparently successful, despite CNN reports that no debris was detected by US monitoring stations, meaning that no test target was destroyed.

38. Baev, "The Nuclear Dimension," p. 14.

39. Thomas, pp. 191-194. The envisioned operational advantages of a rail-mobile intercontinental ballistic missile (ICBM) system are described as follows:

> Another way that Russia has restored its missile shield is through the announcement that it will be resurrecting its rail-mobile ICBM system. This is in response to the US global strike platform. In the Soviet era the RT-23 Molodets (NATO [North Atlantic Treaty Organization] classification as the SS-24 Scalpel) was the rail-mobile combat missile complex (BZhRK). It will be replaced by the Barguzin BZhRK, which

> should become operational by 2020. The main weapon of the Barguzin will be the RS-24 Yars missile, which contains four warheads. Each Barguzin will carry six Yars. Like Molodets it can be hidden from space surveillance among "the thousands of railroad trains bustling throughout the expanses of an enormous country daily." It took less than three minutes for the Molodets to receive an order and execute it by launching the first missile. Whether such parameters are available for the Barguzin is not known. (p. 194)

40. Baev, "The Nuclear Dimension," pp. 13-14.

41. Thomas, pp. 181-187. This book includes a concise overview of Russian ABM systems:

> The enhanced but yet to be produced S-300VM/VMK is capable of intercepting ballistic missiles with a range of 2,500 km and re-entry speeds of 4.5 km/s, whereas the S-400 is claimed to be capable of intercepting ballistic missiles with a range of 3,500 km, which equates to re-entry speeds of 4.8 to 5 km/s. A system designed to intercept warheads at 5 km/s has the ability to act as a point system against simple ICBM warheads, which have a typical re-entry speed of 7 km/s. Apart from the main Moscow deployment, Russia has striven actively for intrinsic ABM capabilities of its late model . . . [surface-to-air missile] systems.
>
> The S-500 (and the S-400) most likely will use the 77N6-N and the 77N6-N1 missiles. They were reported to be capable of direct engagement with targets flying at hypersonic speeds (seven kilometers per second). However, it is not clear when the 77N6-N and the 77N6-N1 will enter service. The S-500 is expected to use the following radars: the 91N6A (M) acquisition and battle management radar, the revised 96L6-TsP acquisition radar, and the new 76T6 multimode engagement and 77T6 ABM engagement radars. Further, the Aerospace Forces have in their inventory some 125 aerodromes. About 80 percent require upgrades, and the repair will last until about 2020. (pp. 186-187)

42. Vladimir Dvorkin, "Hypersonic Threats: The Need for a Realistic Assessment," Carnegie Moscow Center, August 9, 2016, available from *http://carnegie.ru/2016/08/09/hypersonic-threats-need-for-realistic-assessment-pub-64281*, accessed August 12, 2017. The

author describes the mission profile of a possible Russian hypersonic weapon:

> According to accounts in Russian defense publications and journals, the development of such a missile complex was conducted based on government order No. 173-45, issued on February 9, 1987. The complex's development was carried out by the NPO Mashinostroenia (NPOmash) Design Bureau under the leadership of Gerbert Yefremov. In theory, the complex's design was relatively simple: At boost phase, the UR-100N UTTKh (SS-19) intercontinental ballistic missile (ICBM) would launch a so-called hypersonic gliding vehicle (HGV) to an altitude of 80 to 90 kilometers, after which the HGV would make a low-angle turn toward the earth's surface and accelerate at a descending trajectory, gliding to intercontinental range at hypersonic speed, or five times the speed of sound. An HGV armed with a nuclear weapon would supposedly make rapid cross-range maneuvers to circumvent ground-based U.S. missile defenses.

43. TRADOC, Department of the Army, *The U.S. Army Operating Concept: Win in a Complex World, 2020-2040*, TRADOC Pamphlet 525-3-1, Washington, DC: U.S. Government Printing Office, October 31, 2014, p. 13, hereafter, TRADOC Pamphlet 525-3-1. This document certainly views China as a potential adversary in space:

> China works to negate U.S. advantages in space and cyberspace. China is developing significant anti-satellite [ASAT] capabilities, integrating cyber into all aspects of military operations, and developing sophisticated missiles and air defenses as part of an effort to challenge United States' ability to project power.

44. DoD, *Military and Security Developments Involving the People's Republic of China 2017, Annual Report to Congress*, Washington, DC: Office of the Secretary of Defense, May 15, 2017, p. 34, available from *http://www.defense.gov/Portals/1/Documents/pubs/2017_China_Military_Power_Report.PDF?ver=2017-06-06-141328-770*, accessed July 29, 2017.

45. Anthony H. Cordesman and Joseph Kendall, "How China Plans to Utilize Space for A2/AD in the Pacific," The Buzz, blog of *The National Interest*, August 17, 2016, available from

http://nationalinterest.org/blog/the-buzz/how-china-plans-utilize-space-a2-ad-the-pacific-17383, accessed June 19, 2017.

46. DoD, *Military and Security Developments Involving the People's Republic of China 2016, Annual Report to Congress*, Washington, DC: Office of the Secretary of Defense, April 26, 2016, p. 61, available from *http://defense.gov/Portals/1/Documents/pubs/2016%20China%20Military%20Power%20Report.pdf*, accessed July 29, 2017.

47. Dean Cheng, *U.S.-China Competition in Space, Testimony before Subcommittee on Space, Committee on Science, Space, and Technology before the U.S. House of Representatives on September 27, 2016*, Washington, DC: The Heritage Foundation, September 27, 2016, available from *https://www.heritage.org/node/159801/print-display*, accessed June 19, 2017.

48. DoD, *Military and Security Developments Involving the People's Republic of China 2015, Annual Report to Congress*, Washington, DC: Office of the Secretary of Defense, April 7, 2015, p. 13, available from *http://defense.gov/Portals/1/Documents/pubs/2015_China_Military_Power_Report.pdf*, accessed July 29, 2017.

49. DoD, *Military and Security Developments Involving the People's Republic of China 2016*, p. 36.

50. Cordesman and Kendall.

51. DoD, *Military and Security Developments Involving the People's Republic of China 2017*, p. 34.

52. Ibid.

53. DoD, *Military and Security Developments Involving the People's Republic of China 2015*, p. 14.

54. Cheng, *U.S.-China Competition in Space*, p. 13.

55. Rui C. Barbosa, "Chinese Kuaizhou-1A rocket launches several small satellites," NASASpaceflight.com, January 9, 2017, available from *https://www.nasaspaceflight.com/2017/01/chinese-kuaizhou-1a-launches-several-small-satellites/*, accessed August 17, 2017. This monograph's author notes with some irony that the name of one of the satellites was "Caton-1."

56. DoD, *Military and Security Developments Involving the People's Republic of China 2017*, p. 35.

57. Dean Cheng, *The PLA's Interest in Space Dominance, Testimony before U.S.-China Economic and Security Review Commission on February 18, 2015*, Washington, DC: The Heritage Foundation, February 24, 2015, available from *https://www.heritage.org/node/163551/print-display*, accessed June 19, 2017.

58. DoD, *Military and Security Developments Involving the People's Republic of China 2015*, p. 14.

59. Hyten, p. 3.

60. DoD, *Military and Security Developments Involving the People's Republic of China 2015*, p. 60.

61. Rachel Wiener, "The Impact of Hypersonic Glide, Boost-Glide, and Air-Breathing Technologies on Nuclear Deterrence," in Mark F. Cancian, ed., *Project on Nuclear Issues: A Collection of Papers from the 2016 Nuclear Scholars Initiative and PONI Conference Series*, Washington, DC: Center for Strategic and International Studies, May 1, 2017, pp. 136-160, available from *https://www.csis.org/analysis/project-nuclear-issues-2*, accessed August 8, 2017.

62. DoD, *Military and Security Developments Involving the People's Republic of China 2017*, pp. 49-50.

63. DoD, *Military and Security Developments Involving the People's Republic of China 2015*, p. 34.

64. R. Evan Ellis, *Indian and Chinese Engagement in Latin America and the Caribbean: A Comparative Assessment,* Carlisle, PA: Strategic Studies Institute, U.S. Army War College, March 13, 2017, p. 33, available from *http://ssi.armywarcollege.edu/pubs/display.cfm?pubID=1346*. The author summarizes China's recent space-related efforts in Latin America:

> In space services, China's National Space Administration and its space services provider, Great Wall Industries, have developed and launched four satellites for Brazil, two for Venezuela, and one for Bolivia, as well as the launch of the Pegasus microsatellite for Ecuador. Such projects have included Chinese construction of space-ground-control

> infrastructure for both Venezuela and Bolivia, and the training of personnel for both newly created space programs in the PRC. The PRC has also built a deep space radar tracking facility in a remote part of Neuquén, Argentina, as a laser range-finding capability at Argentina's San Juan Observatory, and has tried unsuccessfully to win contracts to develop and launch satellites for Chile and Argentina.

65. Sea Launch has been acquired by S7 Space since the writing of this monograph. Their former website, archived with Internet Archive, included information about the heritage of the company, see "History," Sea Launch, n.d., available from *https://web.archive.org/web/20170812073104/http://www.sea-launch.com:80/about/11129*, accessed July 3, 2018:

> The concept for Sea Launch originated in the early 1990's, when numerous commercial voice, data and broadband satellite constellations were being planned for launch. After the dissolution of the Union of Soviet Socialist Republics (USSR), RSC Energia looking to utilize their wealth of space expertise, in conjunction with The Boeing Company, Kvaerner, Yuzhmash and Yuzhnoye agreed to do conceptual studies on what an ocean-based Zenit-3SL launch system would look like.
>
> Since its inception in 1995, and its first demonstration flight in 1999, Sea Launch has carved out a niche as one of the industry's premier launch providers that has brought innovation, competition, diversity of supply and service to the world's satellite operators.

66. "Russian Rocket Engines used by the United States," Fact Sheet, Colorado Springs, CO: Space Foundation, August 8, 2016, p. 2, available from *https://www.spacefoundation.org/sites/default/files/reports/RussianRocketEnginesUsedByTheUnitedStates.pdf*, accessed July 13, 2017. This document includes a brief history of how the Russia RD-180 rocket engine came into the U.S. space launch supply chain:

> The RD-180 is based on the RD-170/RD-171 engines. The RD-170 was used in the Soviet-era Energia launch vehicle—which had only two launches. The RD-171 engines are still in service on various versions of the Ukrainian/Russian Zenit rockets; these are used by Russia for some government

launches and also by the Sea Launch and Land Launch companies that perform commercial satellite launches. General Dynamics' Convair Division originally developed the Atlas rockets and that division was acquired by Martin Marietta in 1994, which in turn merged with Lockheed Corporation to form Lockheed Martin. The company negotiated the rights to use the RD-180 as a first stage engine for the Atlas rocket—initially to launch commercial satellites and later as part of the Department of Defense's [DoD] Evolved Expendable Launch Vehicle (EELV) program. The original intent was for the RD-180 to be produced by NPO Energomash for commercial satellite launches and by Pratt & Whitney (a subsidiary of United Technologies Corp.) for U.S. Government launches, but to date all engines have been produced in Russia.

67. Todd Harrison, Andrew Hunter, Kaitlyn Johnson, Evan Linck, and Thomas Roberts, *Beyond the RD-180*, Washington, DC: Center for Strategic and International Studies, March 21, 2017, available from *https://www.csis.org/analysis/beyond-rd-180*, accessed August 3, 2017.

68. "Russian Rocket Engines used by the United States," p. 5. This document summarizes the challenges associated with eliminating the Russia rocket engines from the U.S. Atlas V design:

> The U.S. Government and industry have invested approximately $300M over the last 20 years in technology associated with . . . [the oxygen-rich staged combustion] engines. The Department of Defense [DoD] estimates it would need $1 billion over five years to establish production of an RD-180 class engine on U.S. soil. Meanwhile, if the supply is interrupted, some missions could be offloaded to the Delta IV while Pentagon officials prioritize what missions need to be flown on the Atlas V. (The Delta IV uses the RS-68 engine, manufactured by Aerojet Rocketdyne; the RS-68 is a U.S. engine, develops 663,000 pounds of thrust at sea level, and uses Liquid Hydrogen . . . and . . . [liquid oxygen] for fuel.)

69. "Draft Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects," Geneva, Switzerland, United Nations Conference on Disarmament, June 12, 2014, p. 3, available from

https://documents-dds-ny.un.org/doc/UNDOC/GEN/G14/050/66/pdf/G1405066.pdf?OpenElement, accessed August 15, 2017. The full text of Article II is:

The States Parties to this Treaty undertake:

- Not to place any weapons in outer space;
- Not to resort to the threat or use of force against outer space objects of States Parties to the Treaty;
- Not to engage, as part of international cooperation, in outer space activities that are inconsistent with the object and purpose of this Treaty;
- Not to assist or induce other States, groups of States, international, intergovernmental or non-governmental organizations, including non-governmental legal entities established, registered or located in territory under their jurisdiction and/or their control, to participate in activities inconsistent with the object and purpose of this Treaty.

70. Daniel Golston, *UNIDIR Space Security Conference 2016: Sustaining the Momentum: the Current Status of Space Security*, Conference Report 28-29 April 2016, Geneva, Switzerland: United Nations Institute for Disarmament Research, 2016, p. 50, available from *http://www.unidir.org/files/publications/pdfs/space-security-2016-en-654.pdf,* accessed August 4, 2017.

71. Isabelle Facon, *Russia's national security strategy and military doctrine and their implications for the EU*, Brussels, Belgium: European Parliament's Sub-Committee on Security and Defence, European Parliament, February 1, 2017, p. 9, available from *http://www.europarl.europa.eu/RegData/etudes/IDAN/2017/578016/EXPO_IDA(2017)578016_EN.pdf,* accessed July 5, 2017. The European Union (EU) assessment of current Russian security strategies include:

All Russian security documents explicitly single out the challenges that the policies of Western states supposedly create for Russian security (with particularly harsh words in the Security strategy). Grievances connected to what Russia sees as 'systemic problems in the Euro-Atlantic region' (Foreign policy concept), the enlargement of NATO, the location of its military infrastructure close to Russian borders, its 'offensive capabilities' and the trend towards the Alliance acquiring 'global functions', the 'symptoms' of the U.S. efforts to retain absolute military supremacy (the global antimissile system, Global Strike capabilities, militarization of space)—all these problems were mentioned in the previous versions of these doctrines.

72. Olga Oliker, "Unpacking Russia's New National Security Strategy," Center for Strategic and International Studies, January 7, 2016, available from *https://www.csis.org/analysis/unpacking-russias-new-national-security-strategy*, accessed July 5, 2017. See also Thomas, pp. 179-181; details on the U.S. systems that concern Russia include:

> In June 2014 nearly 200 scientists took part in the 17th All-Russia Scientific and Practical Conference on Defense and Security in Saint Petersburg. The discussion began with a presentation by the President of the Russian Academy of Missile and Artillery Sciences, Vasiliy Burenok, who listed six 21st century military-technical threats to Russia, four of which turned out to be aerospace-related: the US and Chinese missile defense systems; the US's adoption of hypersonic cruise missiles; NATO's development of high-speed kinetic weapons, laser systems, and weapon control systems; and space technology developments, such as the use of mini- and nano-satellites. (pp. 179-180)

73. DIA, p. 36. Reasons why the Russian military desires to increase its space power include:

> The Russian General Staff argues for pursuing in wartime such strategies as disrupting foreign military C2 [command and control] or information support because they are so critical to the fast-paced, high-technology conflicts characteristic of modern warfare. Russia believes that having the military capabilities to counter space operations will deter aggression by space-enabled adversaries and enable Russia to control escalation of conflict if deterrence fails. Military capabilities for space deterrence include strikes against satellites or ground-based infrastructure supporting space operations.

74. Thomas, pp. 174-175. The *Vozdushno-Kosmicheskiye Sily* (VKS, translated as Russian Federation Aerospace Forces) is now one of four services in the Russian military forces:

> The Air Force and those forces currently belonging to the . . . [Russian Aerospace Defense Forces] have now been integrated into one service. The Air Force will cease to exist as a separate service; only the Ground Forces, Navy, Strategic Rocket Forces, and VKS will remain. One source noted that the VKS will include an aerospace attack reconnaissance and warning system, an aerospace attack deterrence system, a unified control system, and a comprehensive support system. (p. 174)

75. Ibid., p. 198.

76. Ibid., p. 199. More details regarding the Russian motivation for forming the VKS include:

> Russia's military offered three reasons for the reorganization effort. Primarily, defense in aerospace is very different from other defense postures. Aerospace defense systems are defending against attacks launched at them at super-high speeds from hundreds of kilometers away, which makes warning times extremely short and the destruction potentially significant, depending on the target chosen and the destructive force of the incoming projectile/wave. Secondly, as Deputy Commander of Aerospace Defense Troops Major General Kirill Makarov asserted in April 2015 (and repeated by Shoygu in August), since the end of the last century the . . . [center of gravity] of warfare has shifted to the aerospace sphere. Finally, Russia's military sees an aerospace threat from the US in the form of the Prompt Global Strike concept, which, according to Makarov, "presupposes an instantaneous strike against any state which the US considers the enemy within a short space of time, from 40 minutes to two and a half hours." The threat could include cruise or intercontinental missiles, as well as hypersonic aerial vehicles.

77. DIA, p. 37.

78. Larry M. Wortzel, *The Chinese People's Liberation Army and Space Warfare: Emerging United States-China Military*

Competition, Washington, DC: American Enterprise Institute, October 17, 2007, p. 4, available from *http://www.aei.org/wp-content/uploads/2011/10/20071017_SpaceWarfare.pdf*, accessed August 16, 2017.

79. Ibid., p. 2.

80. DoD, *Military and Security Developments Involving the People's Republic of China 2017*, p. 50.

81. Cheng, *U.S.-China Competition in Space*, p. 7.

82. DoD, *Military and Security Developments Involving the People's Republic of China 2017*, p. 34.

83. Ibid., pp. 1-2.

84. Joint Chiefs of Staff, *Capstone Concept for Joint Operations: Joint Force 2020*, Washington, DC: U.S. Joint Chiefs of Staff, September 10, 2012, p. 2.

85. Ibid., p. 9.

86. Ibid., p. 12. The full context of the two space-related force development initiatives is:

> Continue to improve defensive space capabilities. Given the heavy reliance of Joint Forces on space systems and the rapidly increasing proliferation of counter-space systems, it is essential that Joint Forces be able to protect friendly space capabilities, including defensive space control and space situational awareness capabilities.
>
> Integrate missile defense systems. As missile technology improves and proliferates, missiles will become a major threat to deployed and deploying forces and even to forces in the homeland. A concept predicated on global agility requires the ability to protect against such a threat. Integrating existing capabilities into a comprehensive defensive system will be as important as developing new capabilities.

87. Ibid., p. 14.

88. DoD, *Joint Operational Access Concept*, Foreword.

89. Ibid., p. 26.

90. Ibid., pp. iii, 9. One of the seven key anti-access capabilities identified in the JOAC is "Kinetic and nonkinetic antisatellite weapons that can disable space systems vital to U.S. force projection." (p. 9)

91. Joint Chiefs of Staff, *Joint Concept for Entry Operations*, Washington, DC: U.S. Joint Chiefs of Staff, April 7, 2014, pp. iii, v, available from *http://www.jcs.mil/Portals/36/Documents/Doctrine/concepts/jceo.pdf?ver=2017-12-28-162000-837*, accessed August 11, 2017.

92. Ibid., p. 20.

93. Joint Chiefs of Staff, *Command and Control for Joint Land Operations*, Joint Publication 3-31, Washington, DC: U.S. Joint Chiefs of Staff, February 24, 2014, p. II-3. The possible joint force land component commander role of integrating space forces into the joint force is described as:

> Performing the duties of the space coordinating authority (SCA), if designated. The individual designated to be the . . . [joint force land component commander] may also be designated to be the SCA within a joint force to coordinate joint space operations and integrate space capabilities. The SCA has primary responsibility for joint space operations planning, to include ascertaining space requirements within the joint force. The SCA gathers operational requirements that may be satisfied by space capabilities and facilitates the use of established processes by joint force staffs to plan and conduct space operations.

94. TRADOC Pamphlet 525-3-1, p. i.

95. Ibid., pp. 11-12.

96. Ibid., p. 12.

97. The following TRADOC Pamphlets describe U.S. Army functional concepts for warfighting functions. TRADOC, Department of the Army, *The U.S. Army Functional Concept for Intelligence, 2020-2040*, TRADOC Pamphlet 525-2-1, Washington, DC: U.S. Government Printing Office, February 2017, available from

http://adminpubs.tradoc.army.mil/pamphlets.html, accessed June 29, 2018; TRADOC, Department of the Army, *The U.S. Army Functional Concept for Mission Command, 2020-2040*, TRADOC Pamphlet 525-3-3, Washington, DC: U.S. Government Printing Office, February 2017, available from *http://adminpubs.tradoc.army.mil/pamphlets.html*, accessed June 29, 2018; TRADOC, Department of the Army, *The U.S. Army Functional Concept for Fires, 2020-2040*, TRADOC Pamphlet 525-3-4, Washington, DC: U.S. Government Printing Office, February 2017, available from *http://adminpubs.tradoc.army.mil/pamphlets.html*, accessed June 29, 2018; TRADOC, Department of the Army, *The U.S. Army Functional Concept for Maneuver Support, 2020-2040*, TRADOC Pamphlet 525-3-5, Washington, DC: U.S. Government Printing Office, February 2017, available from *http://adminpubs.tradoc.army.mil/pamphlets.html*, accessed June 29, 2018; TRADOC Pamphlet 525-3-6; TRADOC, Department of the Army, *The U.S. Army Functional Concept for Sustainment, 2020-2040*, TRADOC Pamphlet 525-4-1, Washington, DC: U.S. Government Printing Office, February 2017, available from *http://adminpubs.tradoc.army.mil/pamphlets.html*, accessed June 29, 2018.

98. TRADOC Pamphlet 525-3-6, p. 29.

99. TRADOC, Department of the Army, *The United States Army's Concept Capability Plan (CCP), Space Operations, 2015-2024,* TRADOC Pamphlet 525-7-4, ver. 1.0, Washington, DC: U.S. Government Printing Office, November 15, 2006, pp. ii, 19, available from *http://adminpubs.tradoc.army.mil/pamphlets.html*, accessed June 29, 2018.

100. Ibid., p. 12. Details of the high altitude environment and its contribution to future Army space operations include:

> The high altitude region can supplement orbital space capabilities and integrate additional high altitude long-loiter capabilities to support the joint force commander in a theater with emphasis at the operational and tactical levels. Systems operating in the high altitude region have the potential to provide rapid, on demand, dedicated capabilities augmenting strategic space assets.
>
> The proximity of high altitude long-loiter systems over orbital space systems can provide improved performance

> in support of certain Army operations. A high altitude long-loiter system can provide long duration coverage of up to an 850-mile diameter field of view. Operations in this region allow for flexibility, augmentation to existing air and space systems, and tailorable, recoverable packages that can be reconfigured to meet changing operational needs. In addition, high altitude long-loiter assets have the potential to reduce the operational tail and airspace management issues associated with the aerial layer. The combination of orbital space and high altitude long-loiter capabilities is a critical enabler for implementation of the fundamental principles of the future Modular Force concepts, particularly with respect to achieving information superiority, creating situational understanding, and operating within the high tempo, non-contiguous, simultaneous framework of distributed operations.

101. TRADOC, *Multi-Domain Battle: Combined Arms for the 21st Century*, White Paper, Fort Eustis, VA: U.S. Army Training and Doctrine Command, February 24, 2017, pp. 3-4, available from *https://web.archive.org/web/20170713102300/www.tradoc.army.mil/multidomainbattle/docs/MDB_WhitePaper.pdf*, accessed June 29, 2018. The white paper addresses anticipated A2/AD efforts by future adversaries:

> Yet the Joint Force cannot assume command and control [C2] systems fielded over two decades of assured access to space, cyberspace, and the electromagnetic spectrum will suffice now and into the future. Adversaries can challenge access to these domains with attacks that will severely degrade the synchronization critical to effective operations because the Joint Force currently possesses limited countermeasures and interdependent capabilities with few redundancies. As a result, the Joint Force should anticipate disrupted deployment and sustainment operations and degraded effectiveness of the stand-off targeting and strikes currently required to gain access and seize the initiative. (p. 3)

> Multi-Domain Battle evolves combined arms methodology to include not only those capabilities of the physical domains, but also greater emphasis on space, cyberspace, and other contested areas such as the electromagnetic spectrum, the information environment, and the cognitive dimension of warfare. (p. 4)

102. Ibid., p. 4.

103. David G. Perkins, "Multi-Domain Battle: Driving Change to Win in the Future," *Military Review*, Vol. 97, No. 4, July-August 2017, pp. 10-11. The six physical spaces of Multi-Domain Battle are summarized as:

- A deep fires area is beyond the feasible range of conventional maneuver forces, but it is where joint fires and national capabilities may be employed to operational or strategic effect. Likely within sovereign borders, it is largely denied by maneuver elements.
- A deep area contains challenges that must be defeated in order to be successful in the close area. In a deep area, maneuver forces must have the capability to converge and open temporary windows of domain superiority to seize the operational initiative.
- A close area is where the major direct fire fight unfolds. In a close area, ground forces seize and hold key terrain, maneuver to destroy enemy ground formations, and secure populations.
- A support area directly supports the forward fight. A support area enables operations in the close, deep maneuver, and deep fires areas with sustainment, fires, maneuver support, and mission command capabilities.
- An operational support area holds the central point, key capabilities, and sustainment of joint forces. An operational support area provides the location of critical joint force mission command, sustainment, and fires and strike capabilities.
- A strategic support area stretches from the homeland, along deployment lines of communication, to the initial point of entry. In detail, a strategic support area encompasses home ports and stations, strategic sea and air lines of communication, and homeland communications. Traversing through, and operating within, the strategic support area will undoubtedly require acute cross-combatant command coordination.

104. Ibid., p. 11.

105. Vincent Manzo, "Deterrence and Escalation in Cross-domain Operations: Where Do Space and Cyberspace Fit?" *Strategic Forum*, No. 272, Washington, DC: National Defense University, December 2011, p. 5, available from

http://ndupress.ndu.edu/Portals/68/Documents/stratforum/SF-272.pdf, accessed August 11, 2017.

106. Golston, pp. 1-2.

107. Ibid., p. 5.

108. Readers who wish to learn more about United Nations (UN) treaties and resolution related to outer space should consider the following document as a good starting point: UN Office of Outer Space Affairs (UNOOSA), *United Nations Treaties and Principles on Outer Space and related General Assembly resolutions*, New York: United Nations, 2008, available from *http://unoosa.org/pdf/publications/st_space_11rev2E.pdf*, accessed August 15, 2017.

109. *Draft: International Code of Conduct for Outer Space Activities*, Brussels, Belgium: European Union, March 31, 2014, available from *http://eeas.europa.eu/sites/eeas/files/space_code_conduct_draft_vers_31-march-2014_en.pdf*, accessed August 15, 2017.

110. *Space Strategy for Europe, Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions*, COM(2016) 705 final, Brussels, Belgium: European Commission, October 26, 2016, pp. 3, 5, 8, 11, available from *http://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/COM-2016-705-F1-EN-MAIN.PDF*, accessed August 4, 2017. The other three goals of the strategy are:

> 1. Maximising the Benefits of Space for Society and the EU Economy. (p. 3)
>
> 2. Fostering a Globally Competitive and Innovative European Space Sector. (p. 5)
>
> 4. Strengthening Europe's Role as a Global Actor and Promoting International Cooperation. (p. 11)

111. Ibid., p. 10. Regarding the dual use (military and civilian) of many space systems, the strategy states:

> Most space technologies, infrastructure and services can serve both civilian and defence objectives. Although some space capabilities have to remain under exclusive national and/or military control, in a number of areas synergies

> between civilian and defence can reduce costs, increase resilience and improve efficiency. The EU needs to better exploit these synergies.
>
> This will be a key theme of the European defence action plan, which is expected to highlight space's crucial enabling role for civilian and defence capabilities. The EU and Member States' institutional actors, including those providing security services to citizens, increasingly rely on satellite communication services for their missions and infrastructure, but the critical security and defence needs are not fully met today. The Commission is therefore working with the European Defence Agency and . . . [European Space Agency] to assess the demand for and feasibility of a new initiative providing resilient satellite communication services for governmental and institutional security users.
>
> It will also assess further the potential of Copernicus and Galileo/EGNOS to meet EU autonomy and security needs and improve the EU's capacity to respond to challenges related to migration, border control and maritime surveillance. To this end, the Commission will strengthen security requirements when developing these systems and will reinforce synergies with non-space observation capacities (e.g. unmanned aerial vehicles).

For more information on the Copernicus and Galileo space systems, see Vincent Reillon, "Galileo and Copernicus—EU flagship space programmes," European Parliamentary Research Service Blog, April 11, 2017, available from *https://epthinktank.eu/2017/04/11/galileo-and-copernicus-eu-flagship-space-programmes/*, accessed August 6, 2017.

112. Joint Chiefs of Staff, *Joint Operating Environment 2035: The Joint Force in a Contested and Disordered World*, Washington, DC: U.S. Joint Chiefs of Staff, July 14, 2016, pp. 32-33, available from *http://www.jcs.mil/Portals/36/Documents/Doctrine/concepts/joe_2035_july16.pdf?ver=2017-12-28-162059-917*, hereafter JOE 2035. The document describes the full context of a future contested orbital environment as:

> The space commons is the primary medium of military communication, data transmission and ISR [intelligence, surveillance, and reconnaissance]. Although the United

> States currently possesses a pronounced advantage in space-based sensors, Russia, China, and other nations have developed increasingly capable space-based C3/ISR systems. Competition in orbit (even during peacetime) will be intense, highlighted by satellites maneuvering to hinder the operations of other satellites, co-orbital jamming, and the use of ground-based lasers to dazzle or destroy imaging sensors. Future adversaries will also have the capability to deploy blockers and grapplers to impede the free operation of commercial and military satellites, and they will use ASAT weapons launched at space assets from the ground as well as from other satellites. Ultimately, this may generate space debris leading to a runaway chain reaction which destroys other satellites and threatens the integrity of many important orbits.

113. "Statement by Lieutenant General James H. Dickinson, USA, Commanding General, U.S. Army Space And Missile Defense Command/Army Forces Strategic Command and Joint Functional Component Command for Integrated Missile Defense," before the Subcommittee on Strategic Forces, Committee on Armed Services, United States House Of Representatives, 115th Cong., 1st session, June 7, 2017, available from *http://docs.house.gov/meetings/AS/AS29/20170607/106064/HHRG-115-AS29-Bio-DickinsonJ-20170607.pdf*, accessed July 30, 2017.

114. Statements by Lieutenant General John M. Murray, Lieutenant General Joseph Anderson, Major General Robert M. Dyess, Jr., and Brigadier General Robert L. Marion, before the Subcommittee on AirLand, Committee on Armed Services, United States Senate, on Army Modernization, 115th Cong., 1st sess., March 22, 2017, pp. 7-8, available from *http://armed-services.senate.gov/imo/media/doc/Murray-Anderson-Dyess-Marion_03-22-17.pdf*, accessed August 15, 2017. Descriptions of the space-related capability gaps identified by the Strategic Portfolio Analysis Review are:

> Air and Missile Defense (AMD). We lack the capability and capacity to meet the AMD demands of the combatant commanders to cover key fixed sites and provide effective AMD protection of the maneuvering forces. . . . Assured Position, Navigation, and Timing (PNT). The commercial and Military Global Positioning Systems (GPS) are susceptible

> to threat disruption (jamming) and spoofing (mimicking friendly forces). . . . Electronic Warfare (EW). The Army is unable to conduct Electronic Attack and EW Support against near-peer adversaries. . . . Assured Communications. Current communications systems are vulnerable to near-peer threat detection, disruption/denial, and exploitation.

115. JOE 2035, p. 17. The document explains how other systems can augment traditional satellite constellations:

> Emergence of micro/nano-satellites and near-space capabilities. Micro/nano-satellites, as well as ultra-high altitude aircraft and balloons, will continue to replace large satellites because they are considerably cheaper and faster to build and launch. These advances will likely lead to improved reliability, with networks of small satellites and stratospheric swarms performing the tasks previously reserved exclusively for large satellites.

116. Jason B. Cutshaw, Space and Missile Defense Command (SMDC)/Army Forces Strategic Command (ARSTRAT), "Army's Kestrel Eye hitches ride to International Space Station," U.S. Army, August 15, 2017, available from *https://www.army.mil/article/192321/armys_kestrel_eye_hitches_ride_to_international_space_station*, accessed August 16, 2017.

117. Jason B. Cutshaw, USASMDC/ARSTRAT Public Affairs, "SMDC prepares for upcoming Kestrel Eye launch," U.S. Army, August 1, 2017, available from *https://www.army.mil/article/191708/smdc_prepares_for_upcoming_kestrel_eye_launch*, accessed August 1, 2017.

118. "Kestrel Eye Visible Imagery Microsatellite Technology Demonstration," factsheet, Huntsville, AL: U.S. Army Space and Missile Defense Command, Army Forces Strategic Command, Public Affairs Office, 2017, p. 1, available from *http://www.smdc.army.mil/FactSheets/KESTRELEYE.pdf*. The factsheet overview for Kestrel Eye is:

> The Technical Center is developing Kestrel Eye as an electro-optical microsatellite-class imagery satellite for tasking by the tactical ground component Warfighter. Capable of producing tactically useful imagery, Kestrel Eye's data can be downlinked directly to the same Warfighter via a data

> relay network that is also accessible by other Warfighters in theater without any continental United States relay. The intent of Kestrel Eye is to demonstrate a tactical space-based imagery microsatellite. A Kestrel Eye satellite constellation provides dramatically lower unit cost than typical space-based assets. With this low cost, large numbers of satellites can be procured enabling the system to be dedicated to the tactical Warfighter. (p. 1)

119. "SNaP: Space and Missile Defense Command Nanosatellite Program," factsheet, Huntsville, AL: U.S. Army Space and Missile Defense Command, Army Forces Strategic Command, Public Affairs Office, 2016, p. 2, available from *http://www.smdc.army.mil/FactSheets/SNAP.pdf*, accessed August 16, 2017. The factsheet notes:

> In October 2015, three SNaP nanosatellites were launched from Vandenberg Air Force Base, California. After launch and being released from the main rocket body, the three SNaP [Space and Missile Defense Command Nanosatellite Program] satellites were diagnosed for status and functionality, and were tracked by SMDC [Space and Missile Defense Command]/ARSTRAT [Army Forces Strategic Command] ground stations.
>
> Each SNaP nanosatellite consists of three approximately 10 centimeter cubes stacked for a length a little more than 30 centimeters, weighing nearly 5.5 kilograms. Each has four deployable solar panels and four deployable . . . [radio frequency] antennas.

120. David Vergun, Army News Service, "Nanosatellites may soon communicate with Soldiers from space," U.S. Army, May 18, 2015, available from *https://www.army.mil/article/148754/Nanosatellites_may_soon_communicate_with_Soldiers_from_space/*, accessed August 2, 2017.

121. Jason B. Cutshaw, USASMDC/ARSTRAT Public Affairs, "Future Army nanosatellites to empower Soldiers," U.S. Army, July 20, 2015, available from *https://www.army.mil/article/152508/Future_Army_nanosatellites_to_empower_Soldiers/*, accessed August 2, 2017.

122. Army Capabilities Integration Center, *The United States Army Warfighters' Science and Technology Needs*, Fort Eustis, VA: U.S. Army Training and Doctrine Command, September 21, 2016, pp. 30-31.

123. James B. Johnson, "Future Warfare Center Overview to Huntsville Aerospace Marketing Association," PowerPoint briefing, Huntsville, AL: U.S. Army Space and Missile Defense Command, Army Forces Strategic Command, Future Warfare Center, August 12, 2016, slide 10, available from *http://hamaweb.org/presentations/2016/august2016jamesjohnson.pdf*, accessed July 13, 2017.

124. "Warfighter Experimentation with High Energy Lasers," factsheet, Huntsville, AL: U.S. Army Space and Missile Defense Command, Army Forces Strategic Command, Public Affairs Office, 2017, available from *http://www.smdc.army.mil/FactSheets/WEHEL.pdf*, accessed August 16, 2017.

125. David Vergun, U.S. Army News, "'Eyes in space' and more powerful lasers will soon enhance the Army's arsenal," U.S. Army, July 21, 2017, available from *https://www.army.mil/article/191197/eyes_in_space_and_more_powerful_lasers_will_soon_enhance_the_armys_arsenal*, accessed July 30, 2017.

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127. Jason B. Cutshaw, USASMDC/ARSTRAT Public Affairs, "SMDC trains record number of space Soldiers," U.S. Army, October 7, 2016, available from *https://www.army.mil/article/176524/SMDC_trains_record_number_of_space_Soldiers/*, accessed August 1, 2017.

128. John J. Abbatiello, SMDC/ARSTRAT G-3 Training and Exercise Division (TREX), "Contested space training occurs on Fort Carson," U.S. Army, December 29, 2015, available from *https://www.army.mil/article/160456/Contested_space_training_occurs_at_Fort_Carson/*, accessed August 2, 2017.

129. Jason B. Cutshaw, SMDC/ARSTRAT, "SMDC partners with military academy to develop future space officers," U.S. Army, March 23, 2017, available from *https://www.army.mil/*

article/184832/smdc_partners_with_military_academy_to_develop_future_space_officers/, accessed August 1, 2017.

130. Alexander Urosevich, SMDC G-3 TREX, "G3 TREX demonstrates space kits to support U.S. Army Africa operations, exercises, training," U.S. Army, June 16, 2014, available from *https://www.army.mil/article/128097/G3_TREX_demonstrates_space_kits_to_support_U_S__Army_Africa_operations__exercises__training/*, accessed August 2, 2017.

131. Mahlet Tesfaye, U.S. Army South Public Affairs, "U.S. Army South to increase its space capabilities for future missions," U.S. Army, April 1, 2014, available from *https://www.army.mil/article/123015/U_S__Army_South_to_increase_its_space_capabilities_for_future_missions/*, accessed August 2, 2017. Details of the space kits are:

> Space Kit 1, known as space knowledge tablets, are software programs (Android-based iSpace applications) with constantly updated positioning of satellites that Soldiers can use to locate satellites from anywhere in the world. The programs are used to predict GPS accuracy for a location on the Earth, determine ground site visibility for selected satellites, determine angles from ground site to satellite, and use augmented reality to display satellites across the sky.
>
> Space Kit 2 is a space enhancement kit used to enhance situational awareness and force protection, ideally suited to small units operating in remote locations. This kit allows GPS tracking on displayed map, text messaging, and picture uploads between Soldiers, a ground-based weather sensor that provides wind data, humidity, and lightning detection, uses networked solar powered sensors to geolocate threat and report via Wi-Fi/satellite, and also uses a seismic and motion detection sensor kit to distinguish between humans, vehicles and animals.
>
> Space Kit 3, called the Space Degradation Kit, contains a system capable of demonstrating effects of space system degradation such as GPS jamming. The kit will be used as a training tool in preparation for unit deployment.

132. Dottie K. White, USASMDC/ARSTRAT, "SMDC provides space operations training to Ukrainian soldiers," U.S. Army, May 27, 2016, available from *https://www.army.mil/article/167439/SMDC_provides_space_operations_training_to_Ukrainian_soldiers/*, accessed August 1, 2017.

133. Dottie White, USASMDC/ARSTRAT Public Affairs, "Army Space Support Team participates in Exercise Anakonda," U.S. Army, June 30, 2016, available from *https://www.army.mil/article/170786/Army_Space_Support_Team_participates_in_Exercise_Anakonda/*, accessed August 1, 2017.

134. Air Force Space Command Public Affairs, "Hyten announces Space Enterprise Vision," U.S. Air Force, April 13, 2016, available from *http://www.af.mil/News/Article-Display/Article/719941/hyten-announces-space-enterprise-vision/*, accessed July 10, 2017.

135. Cheryl Pellerin, "Hyten: Deterrence in Space Means No War Will be Fought There," DoD News, Defense Media Activity, January 26, 2017, available from *https://www.defense.gov/DesktopModules/ArticleCS/Print.aspx?PortalId=1&ModuleId=753&Article=1061833*, accessed July 8, 2017.

136. For information about the Geosynchronous Space Situational Awareness Program (GSSAP), see J. Michael Gilmore, *Director, Operational Test and Evaluation: FY 2016 Annual Report*, Washington, DC: Officer of the Director, Operational Test and Evaluation, December 2016, pp. 371-372, available from *http://www.dote.osd.mil/pub/reports/FY2016/,* accessed August 29, 2018.

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138. Phillip Swarts, "The JICSpOC is dead; Long live the National Space Defense Center," Space News, April 4, 2017, available from *http://spacenews.com/the-jicspoc-is-dead-long-live-the-national-space-defense-center/*, accessed July 10, 2017.

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140. U.S. Government Accountability Office, *Defense Acquisitions: Assessments of Selected Weapon Programs*, Report No. GAO-17-333SP, Washington, DC: U.S. Government Accountability Office, March 30, 2017, pp. 155-156, available from *https://www.gao.gov/products/GAO-17-333SP*, accessed August 17, 2017.

141. Jerry "JD" Harris, Jr., Arnold W. Bunch, Jr., and Mark C. Nowland, "Presentation to the Senate Armed Services Committee, Subcommittee on AirLand Forces, Subject: Air Force, Force Structure and Modernization Programs," 115th Cong., 1st sess., March 29, 2017, pp. 16-17, available from *https://www.armed-services.senate.gov/download/?id=E26AA57B-172F-4ED6-B3C3-453C309EF7C6&download=1*, accessed August 15, 2017.

142. "OrbitOutlook Integrates Largest and Most Diverse Network of Space Sensors Ever to Help Avoid Collisions in Space," Arlington, VA: Defense Advanced Research Projects Agency, June 29, 2016, available from *https://www.darpa.mil/news-events/2016-06-29*, accessed August 2, 2017.

143. Harris, Jr., Bunch, Jr., and Nowland, p. 15.

144. U.S. Government Accountability Office, pp. 149-150.

145. DoD, *Program Acquisition Cost by Weapon System: United States Department of Defense Fiscal Year 2018 Budget Request*, Washington, DC: Office of the Under Secretary of Defense (Comptroller), Chief Financial Officer, May 2017, p. 7-2, available from *http://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2018/fy2018_Weapons.pdf*, accessed August 14, 2017.

146. U.S. Government Accountability Office, pp. 135-136.

147. DoD, *Program Acquisition Cost by Weapon System*, p. 7-5.

148. Ibid., p. 7-3. See also U.S. Government Accountability Office, pp. 137-138.

149. "X-37B Orbital Test Vehicle," factsheet, U.S. Air Force, April 17, 2015, available from *http://www.af.mil/About-Us/Fact-Sheets/Display/Article/104539/x-37b-orbital-test-vehicle/*, accessed August 17, 2017.

150. Scott Wierzbanowski, "Experimental Spaceplane," Arlington, VA: Defense Advanced Research Projects Agency, n.d., available from *https://www.darpa.mil/program/experimental-space-plane*, accessed June 21, 2018. The desired vehicle performance would include:

> DARPA envisions a fully reusable unmanned vehicle, roughly the size of a business jet, which would take off vertically like a rocket and fly to hypersonic speeds. The vehicle would be launched with no external boosters, powered solely by self-contained cryogenic propellants. Upon reaching a high suborbital altitude, the booster would release an expendable upper stage able to deploy a 3,000-pound satellite to polar orbit. The reusable first stage would then return to Earth, landing horizontally like an aircraft, and be prepared for the next flight, potentially within hours.

151. "DARPA Selects SSL as Commercial Partner for Revolutionary Goal of Servicing Satellites in GEO," Arlington, VA: Defense Advanced Research Projects Agency, February 9, 2017, available from *https://www.darpa.mil/news-events/2017-02-09*, accessed August 2, 2017.

152. "Program Aims to Facilitate Robotic Servicing of Geosynchronous Satellites," Arlington, VA: Defense Advanced Research Projects Agency, March 25, 2016, available from *https://www.darpa.mil/news-events/2016-03-25*, accessed August 2, 2017.

153. JOE 2035, p. 47. The full context of the potential use of offensive space control by U.S. space forces is as follows:

> The Joint Force must be prepared to conduct Global Commons Defense to disrupt the ability of adversaries to interdict the seas, air, space, and electromagnetic spectrum, or otherwise degrade an adversary's ability to operate in the commons in ways unfavorable to U.S. interests. These missions might involve the creation of forward-projected, multi-domain blockades to impede adversary use of the commons. The Joint Force will establish these area-denial zones through a flexible combination of surface and subsurface sea control capabilities, air defense measures, offensive space operations, and electronic warfare [EW]. This mission is likely to be complicated by an adversary's use of strike assets positioned on sovereign territory or

the deceptive placement of sensor systems on commercial platforms, to include space assets. Despite these challenges, the Joint Force must maintain the ability to conduct targeted command and control [C2] warfare, counter ISR operations, and discriminate sensor interdiction and spoofing in all commons. Furthermore, the Joint Force should be capable of responding to the threat of adversaries creating debris fields in important orbits. The Joint Force should explore ways to enhance operations in the commons by leveraging anticipated advances in long-range robotic and autonomous systems.

154. For the archived website information page with video, see "Aegis Ballistic Missile Defense, One-Time Mission: Operation Burnt Frost," U.S. Department of Defense, Missile Defense Agency, n.d., available from *https://web.archive.org/web/20170901154211/mda.mil/system/aegis_one_time_mission.html*, accessed August 17, 2017.

155. Darren Domingo, 50th Space Wing Public Affairs, "527 SAS, 26 SAS: Knowing your enemy," Schriever Air Force Base, July 15, 2016, available from *http://www.schriever.af.mil/News/Features/Article/841606/527-sas-26-sas-knowing-your-enemy/*, accessed July 28, 2017.

156. Shawn Nickel, 354th Fighter Wing Public Affairs, "Army, AF integrate first ever space aggressor soldier in RF-A 16-3," Eielson Air Force Base, August 9, 2016, available from *http://www.eielson.af.mil/News/Article-Display/Article/909522/army-af-integrate-first-ever-space-aggressor-soldier-in-rf-a-16-3/*, accessed August 1, 2017.

157. DoD, *Program Acquisition Cost by Weapon System*, pp. 4-1, 6-4.

158. Jason B. Cutshaw, USASMDC/ ARSTRAT Public Affairs, "NIMBLE TITAN provides multi-national cooperation for missile defense," U.S. Army, April 25, 2016, available from *https://www.army.mil/article/166716/NIMBLE_TITAN_provides_multi_national_cooperation_for_missile_defense*, accessed August 1, 2017.

159. Joint Functional Component Command for Integrated Missile Defense, Press Release, "Nimble Titan strengthens

multinational missile defense cooperation," U.S. Army, April 3, 2017, available from *https://www.army.mil/article/185351/nimble_titan_strengthens_multinational_missile_defense_cooperation/*, accessed August 1, 2017.

160. DoD, *Program Acquisition Cost by Weapon System*, pp. 5-14, 6-8.

161. Ibid., p. 5-16.

162. *Allied Joint Doctrine for Air and Space Operations*, Allied Joint Publication-3.3, Edition B, Version 1, Brussels, Belgium: North Atlantic Treaty Organization Standardization Office, April 2016, available from *http://www.japcc.org/wp-content/uploads/AJP-3.3-EDB-V1-E.pdf*, accessed August 4, 2017.

163. Paul A. Tombarge, *NATO Space Operations: The Case for a New NATO Center of Excellence*, Occasional Paper Series, No. 26, Garmisch-Partenkirchen, Germany: George C. Marshall Center, December 2014, p. 15, available from *http://www.marshallcenter.org/mcpublicweb/mcdocs/files/College/F_Publications/occPapers/occ-paper_26-en.pdf*, accessed August 4, 2017. The paper includes a concise overview of the source of NATO space capabilities:

> NATO has been active in space since 1970, beginning with the launch of its NATO I, II, III, and IV series of communications satellites. However, the 28-nation Alliance largely relies on the military and civilian capabilities of its member nations, fifteen of which are active in space (Canada, the Czech Republic, Denmark, France, Germany, Greece, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Turkey, the United Kingdom, and the United States). Although NATO does not conduct space operations, its members do, and the Alliance must understand what capabilities are available as well as plan for and ensure those space capabilities are properly integrated into NATO operations.

164. Robert Kroeger, John Patrick, and Kai Richter, "Introducing Space Support to operations," *The Three Swords Magazine*, No. 31, January 2017, pp. 74-75, available from *www.jwc.nato.int/images/stories/_news_items_/2017/SPACE.pdf*.

165. Ibid.

166. ArmySMDC, "Army Space Power 2035," September 22, 2009, ArmySMDC YouTube Channel, video file, available from *https://youtu.be/QBH61gT3Cck*, accessed August 18, 2017; and ArmySMDC, "SMDC2017," April 18, 2014, ArmySMDC YouTube Channel, video file, available from *https://youtu.be/D9mJ8PfJKOA*, accessed August 18, 2017.

167. Thomas, p. 189.

168. Jeffrey L. Caton, *The Land, Space, and Cyberspace Nexus: Evolution of the Oldest Military Operations in the Newest Military Domains*, Carlisle, PA: Strategic Studies Institute, U.S. Army War College, March 2018, available from *http://ssi.armywarcollege.edu/pubs/display.cfm?pubID=1378*.

169. Perkins, p. 12.

170. "Statement by President Donald J. Trump on the Elevation of Cyber Command," Washington, DC: The White House, August 18, 2017, available from *https://www.whitehouse.gov/briefings-statements/statement-president-donald-j-trump-elevation-cyber-command/*, accessed August 18, 2017.

171. See Jandria S. Alexander, "Achieving Mission Resilience for Space Systems," *Crosslink*, Vol. 13, No. 1, Spring 2012, pp. 30-37, available from *http://aerospace.wpengine.netdna-cdn.com/wp-content/uploads/crosslink/V13N1.pdf*.

172. Wiener, "The Impact of Hypersonic Glide," pp. 136-137. The author describes the potentially destabilizing nature of hypersonic weapons:

> At the present time, it is not possible to determine whether the configuration of a hypersonic weapon is conventional or nuclear prior to impact. Due to the extremely short time from launch to delivery to target, nuclear-armed hypersonic glide and boost-glide weapons have the potential to be used as a strategic first-strike capability. Compounding the situation, according to publicly available reports, Russian and Chinese hypersonic glide and boost-glide weapons are designed to evade U.S. antiballistic missile defense detection and interdiction.

173. "Remarks by the President Signing an Executive Order on the National Space Council," Washington, DC: The White House, June 30, 2017, available from *https://www.whitehouse.gov/briefings-statements/remarks-president-signing-executive-order-national-space-council/*, accessed August 2017. See also "President Trump Issues Executive Order on Reviving the National Space Council," Washington, DC: The White House, June 30, 2017, available from *https://www.whitehouse.gov/articles/president-trump-issues-executive-order-reviving-national-space-council/*. For the full Executive Order, see "Presidential Executive Order on Reviving the National Space Council," Washington, DC: The White House, June 30, 2017, available from *https://www.whitehouse.gov/presidential-actions/presidential-executive-order-reviving-national-space-council/*.

174. "Space Enterprise Vision Industry Study Broad Agency Announcement," Announcement Number: FA8814-17-R-0003, Los Angeles Air Force Base, CA: Space And Missile Systems Center, June 16, 2017, available from *https://www.fbo.gov/utils/view?id=81ac21c07d6ea3d8cfe96cc57323e30d*, accessed July 11, 2018. See also Jason B. Cutshaw, USASMDC/ARSTRAT Public Affairs, "SMDC seeks technologies and concepts that will enable Multi-domain Battle," U.S. Army, April 14, 2017, available from *https://www.army.mil/article/186118/smdc_seeks_technologies_and_concepts_that_will_enable_multi_domain_battle/*, accessed June 22, 2017. For the USASMDC broad agency announcement, see "New and Innovative Ideas for Air, Space and Missile Defense Technology," Broad Agency Announcement W9113M-17-R-BAA1, Redstone Arsenal, AL: U.S. Army Space and Missile Defense Command and Army Forces Strategic Command, April 6, 2017, p. 4, available from *https://www.fbo.gov/index?s=opportunity&mode=form&tab=core&id=1e0c9ee97a1d5d864db6903c158cecb8*, accessed June 22, 2017. This document solicits studies in several specific focus areas:

> 4.1 Expected technology white papers and/or proposal areas of interest reflect USASMDC/ARSTRAT emphasis for Fiscal Years (FY) 2017 and 2018, specifically in the areas as follows: Tactically Responsive Space; Space Superiority; Integrated Air and Missile Defense [AMD]/Homeland Defense; Directed Energy . . . ; High Altitude . . .; Cybersecurity; Positioning, Navigation, Timing (PNT)/Navigational

Warfare . . . ; Test, Lethality, and Survivability; and Global Satellite Communications (SATCOM).

175. JOE 2035, pp. 17-20:

- ***Proliferation of advanced radio-frequency weapons***. Advances in phased-array technology will facilitate the development of beam-focusing systems, which will permit high-powered radio frequency . . . weapons to degrade or destroy very precisely versus omnidirectional systems. This will lead to new applications for area denial, crowd control, and the destruction of a range of electronic equipment [emphasis and italics in original]. (p. 17)
- ***Availability of non-nuclear*** . . . [electromagnetic pulse]. Non-nuclear electromagnetic pulse . . . weapons will allow for the discriminate and precise targeting of a range of electronics-based systems. The next two decades will see these weapons integrated into air, ground, and surface systems providing adversaries the capability to disrupt, degrade, and disable components of U.S. and allied . . . [Command, Control, Communications, Computers/ISR] networks [emphasis and italics in original]. (pp. 17-18)
- ***Deployment of >100 KW electrical lasers.*** Electrical laser systems will become smaller, lighter, and cheaper, and the introduction of femto- and pico-second pulses will lead to novel sensors and effects. Ultra-precise, multiple shot, weaponized lasers will easily achieve >100 KW, permitting stealthy engagements at longer ranges with less dwell time required to achieve effects [emphasis and italics in original]. (p. 19)
- ***Hypersonics.*** It is probable that one or more states will field an operational hypersonic weapon system within the next two decades. Likely to achieve speeds in excess of one mile per second on non-ballistic flight paths, functional hypersonic systems will improve the range, accuracy, and lethality of offensive global strike capabilities and have the potential to disrupt portions of anti-access/area denial [A2/AD] capabilities as well as missile defense systems [emphasis and italics in original]. (p. 19)

ACRONYMS AND ABBREVIATIONS

A2/AD	anti-access/area denial
ABM	anti-ballistic missile
AMD	air and missile defense
ARSTRAT	Army Forces Strategic Command
ASAT	anti-satellite
C2	command and control
CCJO	*Capstone Concept for Joint Operations*
DARPA	Defense Advanced Research Projects Agency
DIA	Defense Intelligence Agency
DoD	Department of Defense
EELV	Evolved Expendable Launch Vehicle
EKS	*Edinaya Kosmicheskaya Sistema* (translated as Unified Space System)
EU	European Union
EW	electronic warfare
FY	fiscal year
GEO	geosynchronous
GLONASS	*Globalnaya navigatsionnaya sputnikovaya sistema* (translated as Global Navigation Satellite System)
GNSS	Global Navigation Satellite System (worldwide)
GPS	global positioning system
GSSAP	Geosynchronous Space Situational Awareness Program
HGV	hypersonic gliding vehicle

ICBM	intercontinental ballistic missile
ISR	intelligence, surveillance, and reconnaissance
JICSpOC	Joint Interagency Combined Space Operations Center
JOAC	*Joint Operational Access Concept*
JOE 2035	*Joint Operating Environment 2035*
JSpOC	Joint Space Operations Center
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NORAD	North American Aerospace Defense Command
PLA	People's Liberation Army
PNT	position, navigation, and timing
RSGS	Robotic Servicing of Geosynchronous Satellites
SATCOM	satellite communications
SBIRS	space-based infrared system
SCA	space coordinating authority
SLBM	submarine-launched ballistic missile
SLV	space launch vehicle
SMDC	Space and Missile Defense Command
SNaP	Space and Missile Defense Command Nanosatellite Program
SSI	Strategic Studies Institute
TRADOC	Training and Doctrine Command
TREX	Training and Exercise Division
UN	United Nations

UNIDIR	United Nations Institute for Disarmament Research
UNOOSA	United Nations Office for Outer Space Affairs
USASMDC	U.S. Army Space and Missile Defense Command
USAWC	U.S. Army War College
U.S.S.R.	Union of Soviet Socialist Republics
USSTRATCOM	U.S. Strategic Command
VKS	*Vozdushno-Kosmicheskiye Sily* (translated as Russian Federation Aerospace Forces)

APPENDIX

Joint Space Operations Mission Areas	Army Warfighting Functions					
	Mission Command	Movement and Maneuver	Intelligence	Fires	Sustainment	Protection
Space Situational Awareness						
Detect/Track/Identify			X			X
Threat Warning & Assessment			X			
Characterization	X	X	X	X		
Data Integration & Exploitation	X	X	X	X	X	X
Space Force Enhancement						
Intelligence, Surveillance, & Reconnaissance	X	X	X	X		X
Launch Detection	X	X	X	X		X
Missile Tracking	X	X	X	X		X
Environmental Monitoring	X	X	X	X	X	X
Satellite Communications	X	X	X	X	X	X
Positioning, Navigation, & Timing	X	X	X	X	X	X
Navigation Warfare (NAVWAR)	X	X	X	X	X	X
Space Supports						
Spacelift					X	
Satellite Operations	X	X	X	X	X	X
Reconstitution of Space Forces					X	
Space Control						
Offensive Space Control	X	X	X	X		X
Defensive Space Control	X	X	X	X	X	X
Space Force Application						
Ballistic Missile Defense	X	X	X	X	X	X
Intercontinental Ballistic Missiles						X

Table Appendix-1. Joint Space Operations Support of Army Operations[1]

ENDNOTES – APPENDIX

1. Revised table originally printed in Jeffrey L. Caton, *Evolving Army Needs for Space-Based Support*, Carlisle, PA: Strategic Studies Institute, U.S. Army War College, April 2015, p. 7.

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