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More to See and More to Hide: Forecasting the Effect of Space Technology on Nuclear Weapon Issues

Space is changing dramatically. With advances in technology and investments in capital, the technical barriers and financial costs for space operations have never been lower. Improvements in manufacturing have enabled the miniaturization of space systems: whereas satellites were previously large and custom-made, they are increasingly getting smaller and being produced in high volumes on assembly lines. As a result, satellites are cheaper, and dozens can now fit on a single rocket. Launch costs have fallen substantially. And rockets have become reusable.

This new environment is creating a democratization of space, allowing new players to participate. New companies, such as SpaceX, have emerged and are proposing megaconstellations of satellites that, if realized, would fundamentally transform the scale of activity in space. About 2,700 active satellites are currently in orbit and about 9,000 have been launched into orbit over the entire history of the space age. Reports of planned activity indicate that more than 50,000 satellites could be launched by 2030 (Mosher 2020; Peterson, Sorge, and Ailor 2018). And the new space players are not limited to private companies. As of 2019, more than 60 countries have a national space budget, about 70 countries own or operate satellites in orbit, and nine countries – plus the European Space Agency – can independently launch a satellite into orbit (UCS 2019; US Defense Intelligence Agency 2019).

Changes to the space environment — and the changes that will further affect the space environment over the next five decades — could have profound implications for nuclear weapon issues. Increasing levels of activity in space have generated large amounts of data on military activities. For instance, space-based imagery can be used to identify force deployments and weapon sites. This enhanced visibility also applies in space: more countries and companies are developing the capabilities to see space assets, including those in high orbits. Among other impacts, this trend toward transparency will affect approaches for tracking nuclear capabilities and satellites essential for nuclear operations. States have historically gone to great lengths to shroud in secrecy their nuclear weapon programs and, in some cases, the whereabouts of their nuclear-armed delivery systems and the capabilities necessary to operate nuclear weapon systems — such as nuclear command, control, and communications satellites. Increasing transparency of these nuclear activities and capabilities might force nations, including the United States, to hide or protect their capabilities in different ways, such as building redundant systems. Depending on future technological breakthroughs, this trend of increased transparency could bring both opportunities and risks for global security. It could disincentivize proliferation through greater visibility of nuclear activities and forces, but it could also undermine strategic stability and cause states to react in ways that generate greater uncertainty. The nonproliferation and broader foreign policy community should take note of this trend toward transparency because it forecasts risks and opportunities related to nuclear weapon issues in the decades to come.

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TRANSPARENCY ON EARTH

The advance and spread of space technologies is generating more transparency on activities on Earth, which poses significant implications for nuclear-weapon issues.

At the dawn of the space age, the only satellites that could capture satellite-based imagery were controlled by the United States and the Soviet Union, which often classified the imagery and rarely released it to the public. In the decades after, governments, including these major powers, lost their exclusive grip on satellite surveillance. In April 1986, after Moscow quieted rumors of a leak at its Chernobyl nuclear facility, news outlets broadcast imagery of the disaster taken from a US civilian satellite and from a French commercial satellite (Nova 2007). The coverage signaled that “the age of total government monopoly on high-tech surveillance was over” (Kaspar 2001).

Three and a half decades after the Chernobyl incident, the number of reconnaissance and remote-sensing satellites has jumped considerably. According to a 2018 report from the Air Force, 38 countries have intelligence, surveillance, reconnaissance, and remote-sensing satellites, and 666 such systems are in orbit. The report notes that a decade ago, non-US reconnaissance and remote-sensing satellites totaled nearly 100 — a number that tripled by the middle of 2018 (National Air and Space Intelligence Center 2018). Further, more and more companies are operating satellites that offer imagery products for modest charges and, in some cases, free of charge. Using Google Maps, for example, anyone can access overhead images of a city, street, or building. The new space environment has transformed the quantity, availability, and quality of satellite-based imagery of activity on Earth. Nongovernmental customers are accessing imagery that used to be reserved for major governments, and major governments are leveraging promising new technologies and new sources of information.

Imagery from commercial remote-sensing satellites has created opportunities for open-source analysis that did not previously exist. The imagery is usually generated electro-optically (pictures from a camera, essentially) or with radar (pictures created by bouncing radio waves off a target). Planet, a remote-sensing-satellite company focused on electro-optical imagery, achieved a roughly 150-satellite architecture in 2018 that has enabled it to produce an image of the entire Earth each day (Schingler 2017). Capella Space offers radar remote sensing that can produce high spatial resolution through all weather conditions, day and night (Capella Space). Maxar is developing its next generation of satellites that will reportedly be able to revisit some locations on Earth up to 40 times per day (Morin and Wilson 2020). With these types of resources, nongovernmental actors can conduct analysis of military activity that was formerly reserved to governments. Nonproliferation experts outside of government, for instance, can now use commercial satellite imagery to identify weapon sites, track maritime activity, and monitor missile movements. In 2019, major news outlets reported on nuclear or missile activity in North Korea, Iran, and Saudi Arabia in which nongovernmental experts – using satellite imagery – served as the primary source (Brumfiel and Welna 2020; *Guardian* 2019; Associated Press 2019). A 2019 Aerospace Corporation report notes that trends in remote-sensing satellites, among other factors, are pushing toward a "[Geospatial Intelligence] Singularity," a scenario in which ubiquitous intelligence is available to the general public in real time (Koller 2019).

The benefits in new remote-sensing systems are not limited to nongovernmental customers. Governments are also leveraging the explosion of imagery data from private companies; the US National Geospatial-Intelligence Agency, for example, signed a five-year cooperative research agreement with Planet in 2018 (Marcus 2018). Countries without their own remote-sensing systems could look to commercial providers for their needs. Governments could also try to exploit commercial technologies and models for their own systems (Morin and Wilson 2020).

Remote-sensing imagery is becoming not just more widespread and more available, but also more sophisticated. One example is hyperspectral imagery, the next big development in remote sensing. Unlike conventional optical or radar sensors, hyperspectral sensors can use spectrometry to facilitate the determination of chemical composition. The June 2019 issue of the *IEEE Geoscience & Remote Sensing Magazine* says, "Hyperspectral captures chemical composition of materials, able to simultaneously capture the spectral and spatial content with excellent spectral and spatial resolution." Materials have diagnostic signatures that can be detected. The journal adds that "[t]he detailed spectral information thus captured allows for detailed examination of the scene, especially with regard to identifying particular materials in the scene by their unique spectral 'fingerprints.'" An analysis by Los Alamos National Laboratory says that hyperspectral imaging data supports a variety of materially focused analyses including classification, change detection, anomaly detection, and target detection (Ziemann and Theiler 2016). Such sensors can identify elements at a mining operation, distinguish different gases in plumes, and discriminate camouflage from its surroundings. For example, the imagery could, in principle, easily pick out a camouflage canopy covering military equipment or materiel.

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Creating an operational hyperspectral satellite system with meaningful spatial and spectral resolution has proven to be a challenge because it requires significant power, data processing, and analysis resources. However, steady progress in the development of technological solutions to resolve these constraints has resulted in a number of viable systems now in the planning stage in both the United States and Europe (Tratt 2020). At least for the next 5-10 years, the number of satellites carrying high-resolution hyperspectral imagers is likely to remain limited. Although some of these will be US government systems, the European Space Agency and several companies are also planning to deploy hyperspectral sensors (Green et al. 2019; Strese and Maresi 2019; Keith 2019). For example, in the commercial sector, HyperSat LLC, a US company, and Montreal-based NorthStar Earth & Space have both announced plans for hyperspectral satellite constellations. HyperSat LLC states that it will use an orbiting spectrometer that will allow it to identify the signatures of objects, materials, and processes (HyperSat, n.d.; Werner 2018).

POTENTIAL IMPLICATIONS FOR NUCLEAR WEAPON ISSUES

With more and better remote-sensing satellites comes more transparency regarding military activity. A 2018 US Defense Intelligence Agency report on space threats says that remote-sensing capabilities will continue "reducing the ability of all countries to remain undetected while performing sensitive testing and evaluation activities or military exercises and operations." According to another 2018 report, of the 666 intelligence, surveillance, reconnaissance, and remote-sensing satellites in orbit, 353 are US systems, 122 are Chinese, and 23 are Russian. For China, for example, the report notes that these satellites can be used to monitor US forces and maintain awareness of regional rivals, such as India and Japan, and potential regional flashpoints, such as the Korean Peninsula, Taiwan, and the East and South China Seas (National Air and Space Intelligence Center 2018).

This increased transparency presents opportunities and risks related to nuclear weapons. It can be beneficial for nonproliferation by making it harder for aspiring nuclear-armed states to hide their programs and for current nuclear-armed states to proliferate without the rest of the world knowing. More actors being able to detect illicit activities may disincentivize a country from conducting those illicit activities. But that increased transparency could also expose hidden nuclear weapon systems, which could weaken strategic stability – meant here as the condition in which countries are confident their adversaries would not be able to undermine their nuclear deterrent (Podvig 2012). If increased transparency makes a country feel as if its weapons are no longer secure, that country could respond in unpredictable and destabilizing ways.

Tracking proliferation in non-nuclear-weapon states. The history of nuclear weapon proliferation and testing is partly a history of states taking steps to conceal illicit activities from one another. Prior to its nuclear weapon test in 1974, Indian leaders maintained that their country's nuclear program was only for peaceful purposes, and they prepared for the test in secrecy. For its subsequent tests, in 1998, India also reportedly avoided test preparations that would be readily detectable by satellites and kept personnel out of view of passes by US satellites (Nuclear Weapon Archive 2001; US Central Intelligence Agency 1965; Best 1998). News reports of the 1998 Indian tests note that US satellites were covering the test site only every three days (Risen, Meyers, and Weiner 1998). Current and future developments in remote-sensing satellites would make it harder for states to hide their preparations in the same way.

In identifying nuclear weapon programs, hyperspectral systems could be particularly valuable. As a notional example of how hyperspectral sensing could be applied, Jeffrey Lewis, an expert on proliferation and satellite imagery, discussed a uranium processing plant where the by-products are released into a nearby pond: "At the low end of hyperspectral technology, you can see water turbidity, which can give you a sense of whether water is flowing in ponds and in what direction. At the high end, you can identify specific chemicals in that water. Once that happens, your ability to identify industrial processes at facilities is pretty strong" (Lewis 2020).

Nonproliferation experts have also cited the potential that hyperspectral sensors could have in verifying suspected uranium mines and mills in North Korea (Hanham et al. 2018). In 2015, NATO, the European Defence Agency, and the US Department of Defense identified detection of weapons of mass destruction as one of the most promising military applications of hyperspectral technologies. In one case study on chemical weapons, hyperspectral sensors were able to detect and classify chemical and hazardous materials (Shimoni, Haelterman, and Perneel 2019).

The plethora of systems and wide availability of constant global satellite surveillance could also lessen the likelihood that an actor could operate nuclear-weapon facilities and prepare for tests without anyone else noticing. If one state does not catch the activity, another state or interested party might. In an environment in which coverage may be ubiquitous and critical materials may be detectable, concealment becomes harder.

Tracking vertical proliferation in current nuclear-armed states. Just as it has in the past, satellite imagery will likely continue to play an important role in providing visibility into existing nuclear-weapon programs. Since the 1970s, government-controlled satellites have been recognized as a "national technical means" in that they can help verify US and Russian compliance with arms control treaties by, among other things, collecting detailed imagery of intercontinental ballistic missiles and aircraft. Verifying arms levels and capabilities can give states confidence that their rival is not seeking to overwhelm their capabilities or surprise them with an attack. US President Jimmy Carter noted in 1978 that "[p]hotoreconnaissance satellites have become an important stabilizing factor in world affairs in the monitoring of arms control agreements. They make an immense contribution to the security of all nations" (Carter 1978). Onsite inspections have served as the predominant method for checking compliance, but the use of satellites has been recognized as an important verification tool (Gleason 2020).[1]

The value in satellites collecting information on strategic systems, force levels, and weapon movements could deepen if US and Russian arms control goes away.

The value in satellites collecting information on strategic systems, force levels, and weapon movements could deepen if US and Russian arms control goes away. The New Strategic Arms Reduction Treaty (New START) is the last remaining treaty between the United States and Russia that ensures both countries can conduct onsite inspections on each other's deployed warheads and delivery systems. Absent an extension, New START would expire in February 2021. In this potential scenario, more and better remote-sensing satellites could be crucial for providing insight into the countries' nuclear activities, information that could be available to governments and publics alike. Interested citizens and nongovernmental organizations would know whether governments were proliferating vertically — and if so, how. Other countries would have information on the world's two largest nuclear arsenals, those of Russia and the United States. The two countries would have some understanding of each other's nuclear developments and forces so that they could maintain strategic parity and have some assurances that the other was not preparing a nuclear strike. Of course, satellite imagery will not provide all the benefits inherent in arms control, but, in the absence of arms control, such imagery could be more important than ever (Manzo 2019).

The role of satellites in providing insight into nuclear forces extends beyond Russia and the United States. China could use satellite imagery to look for vertical proliferation in India. And India could do the same for China, as could Pakistan for India and India for Pakistan. For these countries, as for Russia and the United States, satellite imagery can play a stabilizing role. Without the transparency they provide, worst-case planning could result.

Exposing hidden weapon systems. Although increased transparency can be a stabilizing influence among major nuclear-weapon states, enhanced visibility could also expose hidden weapon systems, worrying states that their nuclear

1. The term "national technical means" includes more than just satellites; it also encompasses sensors based on the ground, on aircraft, or even underwater. However, arms control experts consider satellites the most important type of national technical means.

deterrent might be vulnerable to attack from other states. This is less of a concern for Russia and the United States, given the size of their arsenals. China and other nuclear-armed states, however, could perceive trends in growing transparency as compromising their nuclear deterrent and thus compromising strategic stability. Increasing the numbers and quality of remote-sensing satellites could make nuclear-armed states reconsider the importance they assign to practices such as moving their nuclear forces to avoid detection.

It is worth stressing that such a development, if ever realized, is unlikely to happen anytime soon. Even in the next several years, remote-sensing satellites may not be able to sufficiently detect and track hidden and mobile weapons. And even if they could, detection and tracking would need to be coupled with other military developments, such as better data systems and prompt strike capabilities, to credibly threaten a country's nuclear deterrent. Much depends on how this trend of increasing transparency evolves – and the technologies undergirding it and developing alongside it. It is not implausible, however, that future developments in satellite capabilities – particularly within countries with advanced missile systems, such as the United States, Russia, and China – could lead some nuclear-armed states to believe that evasion and mobility may not ensure survivability in the future as effectively as they have in the past.

A critical unknown in projecting the long-term effect of remote-sensing satellites is whether satellites and their data will largely remain physically protected. If that were to fundamentally change, the implications would be much different.

How states might respond. When presented with the new circumstances created by better remote-sensing satellites, states could accept the transparency and perhaps modify their behavior, or they could take aim against the transparency – the information from the satellites and the satellites themselves.

It is possible that states, in the face of increased transparency, would be deterred from engaging in illicit proliferation behavior precisely because many – rival states, private companies, publics – have the tools to track such activities. With greater public access to information, it might be harder to discredit revelations about clandestine activities. States pursuing nuclear weapons and current nuclear-armed states considering proliferation could decide, in the face of ubiquitous sensors, that the perceived gains are not worth the likely costs.

Alternatively, states may take countermeasures to negate the advantages of overhead capabilities. Among other approaches, states could seek to weaken the credibility of satellite data. In a paper on the applications of remote sensing for arms control, Melissa Hanham and Jeffrey Lewis point to misinformation as an effective approach for an actor not wanting to be imaged: "Another tactic that has been employed with great success is simply to flood media with false or confusing imagery. In a charged political environment, it may not matter if there is 'proof' in a satellite image if another image can be offered" (Hanham and Lewis, n.d.). States could try to hide their activities by moving them underground; however, advancing satellite imagery that can penetrate belowground may lessen the efficacy of such measures (Alzeyadi, Hu, and Yu 2019). States could also seek to degrade the satellites capabilities themselves. The Aerospace Corporation paper on Geospatial Intelligence Singularity suggests military forces may seek out active measures, such as jamming sensors, jamming communication links, and using lasers against sensors to mitigate the risks of detection.

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TRANSPARENCY OF SPACE

Advances in space technology are not limited to improvements in seeing activity on Earth. Countries and companies are pursuing capabilities that enable more accessible mapping of the space environment, called space situational awareness, and concepts that require close operations between satellites, called proximity operations. These capabilities and concepts are generating more transparency of space, which – just like on Earth – has significant implications for nuclear-weapon issues.

Space situational awareness is an important and growing area. Capabilities in this area include ground-based radars, telescopes, and space-based sensors. Until recently, the United States was the only country in the world – outside, perhaps, Russia – to develop high-fidelity space situational awareness information (Lal et al. 2018). While the US capabilities continue to represent the gold standard, now more than 18 countries have or are pursuing space situational awareness systems that can help identify and track orbital objects. Companies have also developed space situational awareness products for paying customers. LeoLabs, for example, in October 2019 established a space radar in New Zealand that will allow it to track objects as small as two centimeters in low Earth orbit (LeoLabs 2019).

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ExoAnalytics can track objects in geosynchronous orbit (some 20,000 miles above the atmosphere) and maneuvers (when an object moves into a different orbit). The evolution in transparency on Earth is similar to the evolution of awareness of space. A recent report published by the Institute for Defense Analyses (Lal et al. 2018) concludes, "The world is on a path-of-no-return for the proliferation of [space situational awareness] capabilities, a trend that has significant implications for transparency in space (e.g., more actors will be increasingly able to track others' activities in space)."

In addition to helping manage space traffic, avoid collisions, and prevent debris, better mapping of the space operational environment can assist proximity operations. Proximity operations and imaging of satellites could support operational concepts that include debris tracking and removal, end-of-life disposal, and on-orbit inspection, repair, refueling, and repositioning. These concepts could be extremely important in an environment with 50,000-plus systems. But they also pose risks to critical satellites.

In early 2020, both the threat and opportunity of space proximity operations were displayed. In February, a Northrop Grumman satellite docked on an Intelsat satellite to provide life extension services. This was the first time a commercial satellite had ever docked with another commercial satellite (Henry 2020). Also in February, media reports indicated that a Russian satellite had been making orbital maneuvers near a US government satellite. General John Raymond, the commander of the US Space Force, called this Russian activity unacceptable (Erwin 2020). Experts have suggested that Russia's activity could have been a pretext to take imagery and capture detailed information of the US satellite (Gohd 2020). As reported by James A. Vedda and Peter L. Hays, taking images of space objects – non-Earth imaging, as it is often called – has made maintaining secrecy of specific systems more challenging: "In space surveillance and imaging, the diffusion of observation technology and know-how has curtailed the ability to maintain secrecy in areas once thought to be invisible to public view" (Vedda and Hays 2018).

Commercial proximity operations are still in their infancy; however, in the next decades, they could become much more prevalent, as could proximity operations among smaller states. The availability of these operations coupled with growing space situational awareness capabilities reveals a clear trend: space is becoming more transparent for major powers, smaller countries, and publics – in short, for everyone.

POTENTIAL IMPLICATIONS FOR NUCLEAR WEAPON ISSUES

Imagery and data on the satellite operational environment could also help states identify, catalog, and track critical satellites. And if they can be identified and tracked, they can be targeted. In a moment of irony, Secretary of the Air Force Heather Wilson commented in 2018 that "We built a glass house before the invention of stones" when she discussed the emerging threats to critical US space systems (Cooper and Roberts). Just in 2020, Russia has tested direct-ascent anti-satellite weapons and a space-based co-orbital weapon (U.S. Space Command 2020). Although a war in space has never occurred, the domain is becoming increasingly tense.

Among the most critical satellites are those essential to nuclear command, control, and communications. This category includes satellites that provide protected communications capabilities, such as US Advanced Extremely High Frequency and UK Skynet satellites, and early warning of adversaries' missile launches, such as the US Space Based Infrared System and Russia's Kupol satellites (Air Force Space Command 2017; Allison 2018; Air Force Space Command 2017; Dahlgren 2019). Future vulnerability of such systems could weaken strategic stability. From a threat perspective, the effect of growing transparency is not all bad, however. Increasing transparency could allow more actors to identify and attribute malign behavior in space. Much like transparency of military activities on Earth, increasing transparency of the space operational environment and of individual satellite systems presents opportunities and risks.

Tracking NC3 satellites. Much like its nuclear forces, a country's nuclear command, control, and communications (NC3) is a fundamental element of its deterrent. "When it comes to nuclear modernization, NC3 is the least expensive, yet perhaps the most critical," says a 2019 report from the Mitchell Institute and MITRE. "Possession of an effective and robust NC3 system," the report states, "is essential for deterrence since its existence will convince potential adversaries that any attempted surprise nuclear aggression will fail and will be met with a devastating response" (Deptula, LaPlante, and Haddick 2019). Nuclear scholar Paul Bracken notes the growing recognition of the importance of NC3: "An interesting feature of the global nuclear command and control system that is now developing is the recognition that the information regime around nuclear weapons is increasingly critical. It is critical for deterrence and for other aspects of nuclear governance" (Bracken 2020).

NC3 satellites used to be protected in part by their obscurity in high orbit: potential adversaries did not have the means to track and collect detailed information on these systems. With space becoming more transparent, hiding may no longer be an effective approach for protecting critical capabilities. In a speech in April 2020, Christopher Ford, a senior official in the US State Department, said that China is "exploring capabilities to attack satellites in orbits such as those of our NC3 systems" (Ford 2020). If space situational awareness, proximity operations, and threat technologies mature in a way that causes states to see their NC3 systems as becoming increasingly vulnerable, the states could lose confidence in their overall nuclear deterrent. Strategic stability could suffer.

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Tracking malign activity. Just as more transparency could enable an actor to conduct malign activity in space, it also could enable other actors to see and attribute that malign activity. In the example of Russian satellites trailing a US government satellite, the initial news coverage of the Russian satellites' abnormal activity was based on the work of amateur satellite trackers

(Grush 2020). In the future, with more and better information available on the satellite operational environment, a state may not be able to surreptitiously attack another satellite without being noticed. Such detection and attribution could lessen the likelihood that the country would engage in the attack in the first place.

How states might respond. Increasing transparency of the space environment and evolving threats have prompted proposals on how states should best respond. In the United States, for example, the government in 2019 established the Space Development Agency to develop a large network of satellites. Instead of relying on a small number of large and complex systems, this approach would emphasize a high number of small and modular systems. The new agency is planning to launch dozens of satellites in 2022. Derek Tournear, the agency's director, has said that the eventual architecture could entail thousands of satellites and that this architecture would provide "resiliency via numbers." Based on today's architecture, an attack on US satellites that resulted in the loss of a couple of critical systems could be crippling; an attack that led to the loss of a few satellites in an architecture of thousands of satellites may produce little effect (Vergun 2019; Strout 2019).

Other countries may also multiply their satellites in orbit. Or they could pursue systems to threaten constellations. Russia and China could try to emulate the United States or adopt asymmetric approaches to mitigate the US advantages, focusing on countering a disaggregated architecture or pursuing new ways of making satellites systems vulnerable. Smaller states may observe these actions and reactions and respond themselves.

CONCLUSIONS

Since the beginning of the Space Age, space technologies have played an important role in exposing nuclear activities and capabilities. In 1960, a satellite that was part of the US Corona photoreconnaissance program, which was intended to identify missile launch sites and production facilities, dropped a canister of film through the atmosphere that was successfully recovered, delivering intelligence photos taken over Soviet territory (US Central Intelligence Agency 2015; US Department of Defense, n.d.).

The deepening and widening of transparency, both on Earth and in space, has a few implications in the nuclear weapons sphere. Proliferators will find it less easy to hide clandestine activities, but they may be able to draw upon space technology as well. States with established nuclear weapons programs could find a more transparent environment challenging and uncomfortable. The trend toward increasing reliance on space-based assets for command and control, particularly if conventional and nuclear forces overlap, could create instabilities. At the same time, space-based assets will continue to be critical in verifying arms control agreements to reduce nuclear weapons.

In contrast to the current nuclear weapons status quo, the space environment in the next few decades will be crowded and noisy, with few obvious advantages to the traditional big players. With a certain degree of foresight and caution, states agreed long ago not to deploy nuclear weapons in space. Looking ahead, they may need to consider steps to minimize the global risks and maximize the opportunities that emerge from interplay of developments in space and nuclear weapons. ■

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BIOGRAPHY

Robert S. Wilson is a policy analyst for the Center for Space Policy and Strategy at The Aerospace Corporation. In his role, he is responsible for leading work on international space; nuclear command, control, and communications; and missile issues. Wilson has authored papers on the impact of Brexit on UK space; Japan's shift toward space security; the future of space-based nuclear command, control, and communications; and space traffic management. He has led work for the Office of the Assistant Secretary of the Air Force for Acquisition and Integration, the Office of the Director of National Intelligence, and the Air Force Nuclear Weapons Center. As a result of his work, Wilson has testified to the House of Lords in a public hearing, discussed space issues in Track II dialogues in Moscow, guest lectured at universities, and presented on panels at think tanks in Washington, at U.S. Strategic Command, and at the Pacific Northwest National Laboratory.

Prior to joining Aerospace, Mr. Wilson served as a senior analyst in the U.S. Government Accountability Office, leading reports on nuclear command, control, and communications; strategic force structure; arms control; and U.S. nuclear forces in Europe. He has completed fellowships with the National Defense University's Program for Emerging Leaders, the Center for Strategic and International Studies Project on Nuclear Issues, the German Marshall Fund, and the Nonproliferation Policy Education Center.