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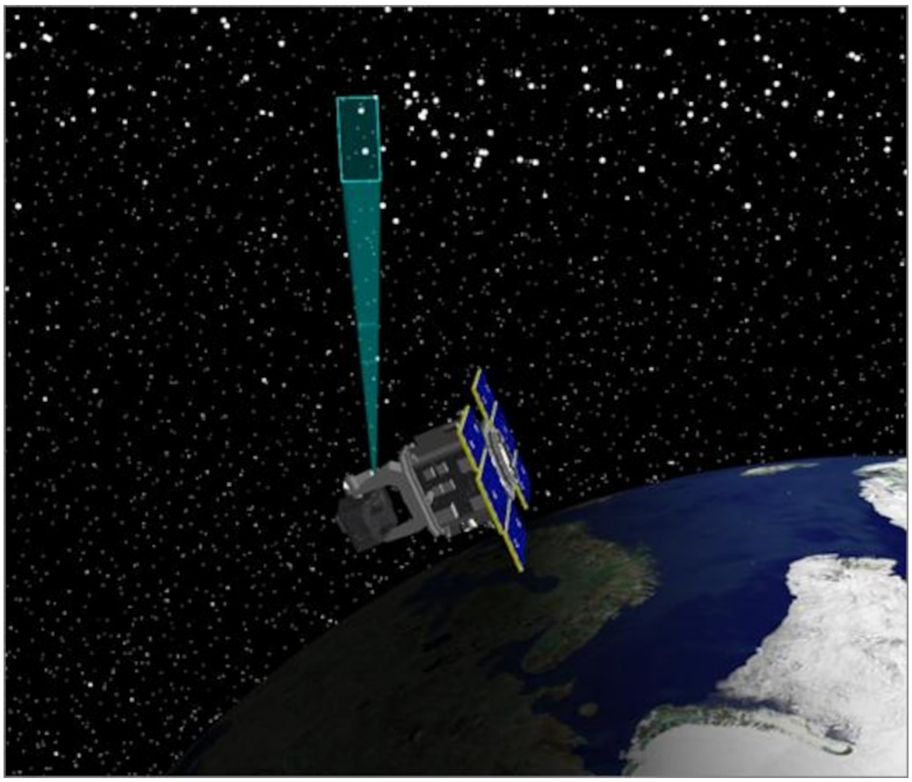
Space Domain Awareness as a Strategic Counterweight



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Executive Summary

This paper examines the role of space domain awareness (SDA) as a strategic counterweight to potential adversary and competitor actions in space. It argues that awareness of the space environment is fundamental to maintaining and protecting U.S. interests in outer space. The U.S., however, has been slow in developing a SDA capability and must now hasten the transition from a more passive peacetime capability to a system that can provide commanders with timely knowledge to predict adversary actions in potentially hostile environments.

Key findings

This study finds that effective SDA can be a strategic counterweight to possible adversary and competitor actions in space in five ways:

- **SDA enhances deterrence and reduces inadvertent escalation.** During peacetime, effective SDA can provide real-time situational awareness that can help deter gray zone activities against U.S. military and commercial interests. During a crisis or prelude to war, SDA can identify mobilization activities related to space, such as prepositioning satellites in certain orbits and deploying counterspace capabilities. During war, SDA can better inform decisions to escalate by determining whether an attack is limited or all out.
- **SDA enables warfighting.** SDA is fundamental to establishing an effective sensor-to shooter kill chain. SDA allows commanders to determine friendly and hostile actions within actionable timeframes. In the event of an attack, it allows commanders to determine whether to take passive or active countermeasures to defend space assets.
- **SDA can help develop and protect norms and regulations for space activity.** The governance of outer space remains largely undeveloped. Laying the groundwork for the establishment of widely agreed-upon norms and laws, and subsequent enforcement measures, requires an understanding of the activities taking place in outer space so that norms can be identified, their effects analyzed, and their compliance monitored.
- **SDA can help maintain space sustainability.** Orbital debris remains a major concern affecting the sustainability of space. Increased SDA capabilities will bring improved understanding of the collision threat and the necessity to deconflict orbits to ensure the sustainability of the space environment for long-term use.
- **SDA can enhance the U.S.'s influence and role in space.** Maintaining space sustainability through improved SDA capabilities could enhance the global reputation of the U.S. by allowing it to continue its role as the primary source of information on space activities, and solidify its position as the provider of "common goods" in space for allies and partners in a military context and for other countries in a civilian context.

Introduction

This paper examines the essential role that space domain awareness (SDA) plays as a strategic counterweight to potential adversary and competitor actions in space.[1] The U.S. Space Force considers outer space a warfighting domain on par with the land, air, sea, and cyber domains.[2]
The rapid growth in the number of objects in space places increasing pressure on the ability of the U.S. military to locate, identify, and track objects in Earth's orbit to maintain the safety and security of U.S. interests in space. The greater risk of collisions in this domain, and the threat of attacks against U.S. satellites, highlights the growing need for a robust capability not only to monitor but also to analyze and predict threats to U.S. space assets. SDA is an important component of maintaining U.S. access to and use of space in this increasingly congested, contested, and competitive environment. As outlined in the following sections, an effective SDA capability can help deter adversaries and reduce the risk of inadvertent escalation, enable warfighting, develop and protect norms, maintain space sustainability, and enhance the U.S.'s global influence and role in space.

Space domain awareness is fundamental to space operations

The U.S. Space Force defines SDA as the "effective identification, characterization, and understanding of any factor associated with the space domain that could affect space operations."[3] SDA is focused primarily on understanding the disposition of friendly, adversary, and third-party actors in space and the physical environment of space. However, it can also include understanding actions on Earth that affect space-based capabilities or the provision of space support, such as the employment of ground-based anti-satellite systems.[4]

SDA helps commanders identify threats and hazards, detect deceit, determine adversary intentions, and act within an adversary's decision cycle.[5] SDA provides "the actionable knowledge required to predict, avoid, deter, operate through, [and] recover from…the loss and/or degradation of space capabilities and services."[6] It is also intended to provide information on the missions, intentions, system capabilities, patterns of life, and the status of spacecraft consumables and expendables, such as propellants. In its complete form, SDA also includes intelligence on the decision-making processes, biases, cultural values, and psychological tendencies of space actors, as well as information on space weather, lighting conditions, and gravitational topology.[7]

The U.S. Space Force makes a difference between SDA and space situational awareness (SSA). According to a Presidential Memorandum, SSA is "the knowledge and characterization of space objects and their operational environment to support safe, stable, and sustainable space activities."[8] Like SDA, SSA is also intended to detect, track, and identify objects in space. However, SSA lacks a commitment to an awareness of the full range of factors and actors, described above, that can affect space as a warfighting domain.[9] In this respect, the Space Force now considers SSA useful in civilian space traffic management as a tool to deconflict the orbits of cooperative objects in a benign space environment; much like air traffic control systems manage air travel. Reflecting the bifurcation of SDA and SSA missions, the military has signaled its willingness to hand over the SSA mission to a civilian entity for space traffic management. The Trump administration, in its 2018 Space Presidential Directive-3, proposed that the responsibility for SSA be transferred from the Department of Defense (DOD) to the Department of Commerce.[10]

Space domain awareness as a strategic counterweight

SDA is fundamental to maintaining U.S. military and economic security in the outer space domain. It establishes a foundation for enhancing space deterrence, enabling warfighting, developing norms and regulations, maintaining the sustainability of the space environment, and enhancing U.S. global influence and role in space.

Enhancing deterrence and reducing inadvertent escalation

Deterrence rests, in part, on the awareness of the activities of competitors and adversaries. Activities in space can suffer from an attribution problem, however. According to one analysis, "In an era where competitors desire to hold U.S. space capabilities and, as a result, national power projection at risk, it has become far more difficult to anticipate satellite activity."[11] Without a comprehensive SDA capability, these activities can go undetected. Eve when they are detected, determining attribution can be difficult. SDA's commitment to identifying and predicting threats is intended to resolve this challenge.

Effective SDA enhances space deterrence and reduces inadvertent escalation by allowing the U.S. military to identify and predict actions taken by adversaries, providing the ability to deter adversaries from taking "opportunistic acts of aggression…that would result in a fait accompli."[12] During peacetime, effective SDA can provide real-time situational awareness that can deter gray zone activities against U.S. military and commercial interests. According to one analysis, space warfare simulations have indicated that gray zone activities conducted in outer space may be particularly susceptible to inadvertent escalation because of the lack of knowledge of the adversary's intent and type of attack.[13]

The Gray Zone of Space

Gray zone activities in space, as in other domains, challenge effective responses by falling below the threshold of war. Space gray zone activities can include jamming or spoofing communication and satellite navigation signals, conducting unwelcome proximity operations against another country's satellite, or even occupying and preventing access to parts of the lunar surface.

During a crisis or prelude to war, effective SDA can also identify mobilization activities related to space, such as prepositioning satellites in certain orbits and deploying counterspace capabilities. During war, SDA can better inform decisions to escalate by determining whether an attack is limited.[14] The intelligence provided by SDA in these situations can identify attribution, determine the nature of the threat, and provide information that can be used to publicize activities and provide options to decision-makers to forestall an adversary's intended actions.

Enabling warfighting

Awareness is a fundamental component of maintaining superiority in any military domain. According to one analysis, "Without being able to determine the origin or source of a hostile or malicious action, the ability to respond appropriately seems doubtful."[15] As a result, operations in the space domain require "the same type of fidelity that provides location data for friendly and adversarial forces on the ground, in the air, and on the seas."[16]

The intelligence provided by SDA allows commanders to determine friendly and hostile actions within actionable timeframes. In the event of an attack, it allows commanders to determine whether to take passive or active countermeasures to defend space assets. SDA is also critical to establishing an effective sensor-to-shooter kill chain. This includes the ability to find, fix, track, target, and engage adversary space assets and assess the results of the attack through a system of sensors, shooters, and command and control nodes.[17]

One critical aspect of SDA in warfighting is predicting adversary behavior. Indeed, U.S. Space Force director of intelligence, surveillance and reconnaissance Major General Leah Lauderback has stated that "characterizing threats" is a major challenge for the Space Force.[18] According to one analysis, one part of "space reconnaissance" is the "fusion of astrodynamics, operations, and intelligence."[19] This involves identifying potential threats, allocating intelligence, surveillance, and reconnaissance assets to monitor their activities, and then identifying courses of action to counter or preempt potential adversary actions. The goal is to "develop the flexibility to employ…assets in such a manner to quickly recognize the nature of any myriad of threats." A critical limitation to achieving this goal, however, is the limited capabilities of the U.S. Space Surveillance Network (SSN, discussed later). Thus, SDA activities will need to prioritize intelligence collections against the most likely threats.[20]

Developing and protecting norms and regulations

Despite its scientific, economic, and national security value, outer space activities remain largely devoid of international governance. Unlike activities in other domains, which are governed by international law and require states to self-regulate and enforce their provisions, no such legal framework exists for space. The domain's primary governing document, the 1967 Outer Space Treaty, provides overarching principles for conduct in space but lacks specific regulatory and enforcement measures. Moreover, the relative newness of space as a domain means that widely agreed-upon norms of behavior have not yet been established. Laying the groundwork for the establishment of international norms and laws, and subsequent enforcement measures, requires an understanding of the activities taking place in outer space so that norms can be identified, their effects analyzed, and their compliance monitored.[21]

Maintaining space sustainability

Orbital debris is a major concern affecting the sustainability of space. In 2009, an Iridium communications satellite and a derelict Russian Cosmos military satellite accidently collided, and in 2013, debris from the Chinese 2007 anti-satellite test likely collided with the Russian BLITS satellite.[22] Increased SDA capabilities will allow for an improved understanding of the collision threat and will highlight the necessity to deconflict orbits to ensure the sustainability of the space environment for long-term use. Although the U.S. military tracks more than 20,000 objects in space, it is estimated that more than 900,000 pieces of debris between 1 and 10 centimeters remain untracked.[23] Traveling at a speed of 17,500 mph, even small pieces of debris can damage satellites severely.

The problem of space debris will only become more serious. Moreover, plans to launch tens of thousands of additional satellites by commercial companies will exacerbate the problem. According to computer simulations conducted by six national space agencies, the region in LEO between 700 and 1,000 kilometers will see additional collisions similar to the Iridium-Cosmos collision every five to nine years.[24] The increased risk of collisions between spacecraft and between debris and spacecraft will raise the costs of operating in orbit because of the costs of replacement satellites and the need to over-engineer them to make them more resilient to collisions.[25]

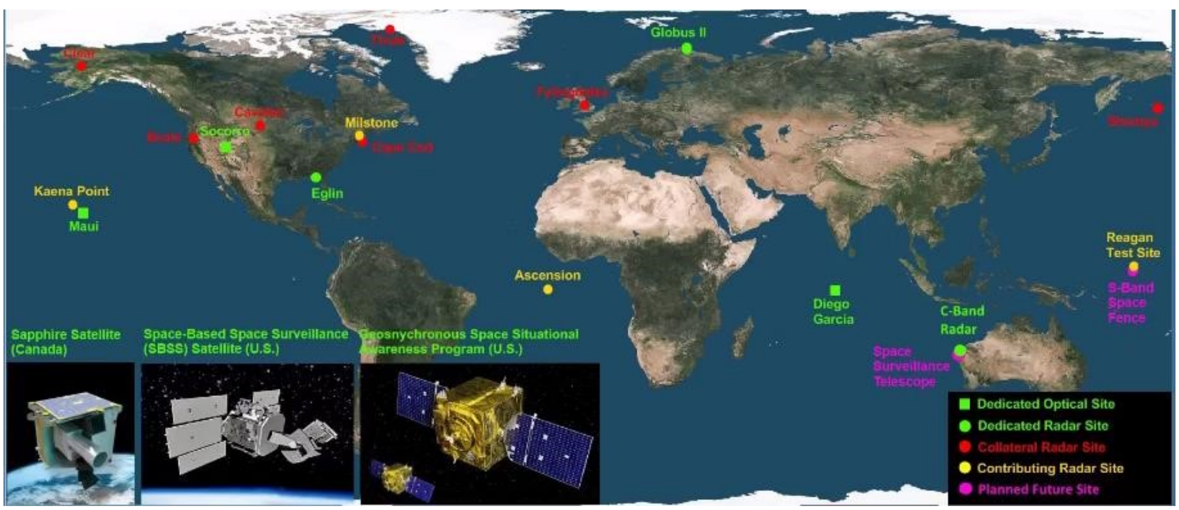
Enhancing U.S. global influence and role in space

Maintaining space sustainability through improved SDA and SSA capabilities could enhance the global reputation of the U.S. by allowing it to continue its role as the primary source of information on space activities and solidify its position as the provider of "common goods" in space for allies and partners in a military context and for other countries in a civilian context. Indeed, the U.S. Space Command maintains a space situational awareness data sharing program with more than 100 different entities with the goal of encouraging safe operations in space[26].

The U.S. Space Surveillance Network is incomplete

To manage the challenges inherent to the space domain, the DOD has the most comprehensive SDA capability in the world. Its Space Surveillance Network (SSN) is a global network made up of more than 30 ground-based radars and optical telescopes and satellites in orbit.[27] The SSN, however, does not provide complete coverage of the space environment. Many of its systems were originally intended for ballistic missile warning. Located on the northern borders of the U.S., they provide coverage over the Northern Hemisphere but cannot cover the Southern Hemisphere. As a result, "there are large gaps in the tracking coverage for low earth orbit space objects and sometimes significant time between tracks."[28] In recent years, the DOD has sought to increase coverage by establishing a radar and optical telescope in Australia and the S-Band radar, known as the "Space Fence," on Kwajalein Atoll.[29] The main components of the SSN are reviewed below.

Figure 1. The U.S. Space Surveillance Network



Source: Brian Weeden, "Space Situational Awareness Fact Sheet," Secure World Foundation, May 2017, https://swfound.org/media/205874/swf_ssa_fact_sheet.pdf.

Ground radar

Ground radars are the most common type of SDA technology. They can track the distance and speed of objects regardless of weather. Some, like phased-array radars, can track multiple objects simultaneously. Some radars can also detect the motion of an object and construct a representation of its shape. The main disadvantages of radars are their cost, size, and complexity.[30] U.S. radars that are part of the SSN include the following:

- *Globus II*. Globus II is a large X-band dish radar located at Vardo, Norway. It is used for tracking deep space objects and wide-band imaging. It is one of three dedicated radar sensors in the SSN.[31]
- *AN/FPS-85*. The AN/FPS-85 is the world's first large phased-array radar and is one of three dedicated radar sensors of the SSN. It is based at Eglin Air Force Base in Florida.
- *Space Fence*. The Space Fence is a solid-state S-band radar that tracks satellites and space debris, mainly in LEO. It is based on Kwajalein Atoll in the Pacific Ocean.[32]
- *Millstone/Haystack Radar (MHR)*. MHR is a large L-band dish-tracking radar located on Millstone Hill, in Westford, Massachusetts. It is used for near-earth and deep space tracking.[33]
- *ARPA Long Range Tracking and Instrumentation Radar (ALTAIR)*. ALTAIR is a large steerable dish-array radar based at the U.S. ballistic missile test range on Kwajalein Atoll in the Pacific Ocean.[34]
- *Perimeter Acquisition Radar Attack Characterization System (PARCS)*. PARCS is phased-array radar located at Cavalier Air Force Station in North Dakota. Its primary mission is missile warning.[35]
- *Cobra Dane*. Cobra Dane is a large phased-array radar located on Shemya Island in the Aleutian Island chain. Its primary mission is missile warning.[36]

Ground telescopes

Optical telescopes are also a common technology used for SDA. Telescopes used for SDA operate in the same manner as those used for observing stars and planets. In this case, they are directed at orbiting satellites. The advantage of telescopes is that they can cover a large area quickly and can observe targets above 5,000 km in altitude. They are limited, however, by light conditions and cloud cover. Space-based telescopes are not limited by these constraints.[37] Ground telescopes making up the SSN include the following:

- *Ground-based Electro-Optical Deep Space Surveillance (GEODSS)*. GEODSS is composed of 1-meter telescopes equipped with digital cameras. Each of the three GEODSS sites is made up of three telescopes. GEODSS systems can track objects as small as a basketball more than 20,000 miles away. GEODSS systems are located in Socorro, New Mexico; Maui, Hawaii; and Diego Garcia.[38]
- *Space Surveillance Telescope (SST)*. The SST is a 3.5-meter telescope used to track and identify debris in geosynchronous Earth orbit. It is based near Exmouth, Australia.[39]

Space-based systems

The DOD also operates three space-based SDA systems. They have the advantage of not being limited by weather and they can be maneuvered to provide better monitoring of space-based threats. They include the following:

- *Space Based Space Surveillance (SBSS)*. SBSS is a satellite located in LEO and equipped with a visible sensor.[40]
- *Geosynchronous Space Situational Awareness Program (GSSAP)*. The four GSSAP satellites are located in the near geosynchronous earth orbit regime. GSSAP satellites can conduct rendezvous and proximity operations that involve the maneuver of the satellite near a space object for enhanced surveillance.[41]
- *Missile early warning satellites*. The U.S. maintains a space-based missile early warning constellation made up of legacy Defense Support Program satellites and newer Space Based

Infrared System satellites equipped with infrared sensors to detect missile launches, including antisatellite direct ascent missiles.[42]

Challenges to establishing effective space domain awareness

To build an effective SSN, a number of challenges unique to the space domain must be considered. They include the following:

- *Space is big.* The large expanse of the space domain around the Earth, coupled with an increase in the number of space actors, makes monitoring activities difficult. Cislunar space, the area between the Earth and the Moon, fills a volume of approximately 2.38×10^{17} km^3![43] A comprehensive SDA monitoring system needs to be able to cover this vast expanse.
- *Space is global.* Because of orbital dynamics, most spacecraft in Earth orbit do not remain above the same spot over the Earth. Spacecraft in low earth orbit (LEO), for example, circle the Earth approximately every 90 minutes and fly over different parts of the Earth with each successive orbit. A comprehensive SDA monitoring system will need to be composed of a global sensor network to account for spacecraft throughout their orbits.
- *Space is a hostile environment.* Space is inhospitable to life and hostile to the spacecraft operating there, with no pressure, no oxygen, high radiation levels, and large fluctuations in temperatures. Thus, most spacecraft are unmanned. The lack of a human presence in space complicates the ability to inspect, maintain, and service spacecraft in orbit. The challenges to satellite inspection make determining whether spacecraft anomalies are due to malfunction, accident, or purposeful action more difficult. A comprehensive SDA monitoring system will need to be composed of space-based sensors to adequately monitor hostile satellites and inspect friendly satellites.
- *Spacecraft are fast.* Spacecraft in LEO can travel at speeds of 17,500 mph. The Secure World Foundation's Brian Weeden writes, "most objects in space move too fast for the human eye to see, and collisions will likely happen much faster than any human could possibly react to."[44] A comprehensive SDA monitoring system will need to place priority not only on tracking spacecraft but also on predicting their trajectories.

Better SDA is required to meet the challenges of space's strategic landscape

The strategic landscape of space is becoming more complicated. Outer space is increasingly congested with satellites and space debris, contested as a military domain, and competitive as a commercial endeavor More than 70 countries now have space programs; 11 can independently launch objects into space. As of June 2021, the U.S. military was tracking more than 20,000 objects in Earth's orbit, including more than 4,500 active satellites. In 2020 alone, more than 1,200 satellites were launched.[45] This number may increase. SpaceX, for example, envisions launching 12,000 small satellites by 2027 for its Starlink constellation.[46]

More countries are using space for military purposes, and denying space capabilities to an adversary is seen as an asymmetric approach to overcoming conventional military superiority. China and Russia pose the greatest threats to the U.S. in space. China is developing a robust suite of capabilities designed to threaten U.S. space assets from the ground to geosynchronous orbit, including direct-ascent kinetic kill, directed energy, and co-orbital capabilities.[47] Russia, for its part, is reinvigorating its Cold War-era space control capabilities across the spectrum of technologies.[48]

Outer space is also a domain for economic and commercial use. As the technological barriers for entry to space have decreased, the number of commercial space actors has grown. Between 2005 and 2019, the space economy grew from $179.65 billion to $423.8 billion, and the number of spacecraft serving commercial missions increased from 170 in 2018 to 251 in 2019.[49] As economic investment in space increases, the requirement to defend those interests from foreign interference will likely play a growing role in future military space missions.

The expansion of space as a military and economic domain complicates the ability to ensure the normal operation of satellites and to maintain the military, civil, and commercial capabilities they provide. As the militaries and economies of the U.S. and its allies become more dependent on the space-based capabilities, the building of an effective SDA system to act as a strategic counterweight to potential adversary and competitor actions in space will become even more critical to maintaining U.S. national interests, not only in space, but also on the Earth.

Endnotes

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