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14. ABSTRACT

As near-peer adversaries have gained and demonstrated technologically advanced anti-satellite capability, the US's once dominant position in space is currently being held at risk. Any future conflict involving Russia or the People's Republic of China will likely start in cyberspace and space. The US Military has been, and continues to be, heavily reliant on satellite-based communications, precision, navigation, and timing via the Global Position System constellation and on-orbit remote sensing Intelligence, Surveillance, and Reconnaissance. The government-owned and operated space assets are highly capable yet extremely expensive and not easily replaced. The growth of commercial space in the 21st century offers the US Department of Defense a unique opportunity for the warfighter to increase capability at significant cost savings. DoD leasing of large commercial satellite constellations in low earth orbit (LEO) will augment limited national security resources and provide the resiliency necessary for DoD's space architecture in a contested domain.

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INTRODUCTION

Modern commercial satellite constellations provide crucial capability, flexibility, and resiliency that the US Department of Defense (DoD) requires for their assured and survivable space architecture. The US military cannot expect to fight and win wars unless it has the communications, precision navigation, and remote sensing intelligence, surveillance, and reconnaissance (ISR) assets it has become reliant on. From the fall of the Soviet Union through the Global War on Terror (GWOT), DoD did not prioritize defending space assets from attack. The high cost of innovating, building, and maintaining a space system architecture provided US space assets with sanctuary from adversaries through the early years of the 21st century.[1] The lack of prioritization on protecting DoD Space has enabled and emboldened near-peer adversaries, namely Russia and the People's Republic of China (PRC). These adversaries have become pacing threats in the space domain with ground-based and suspected on-orbit anti-satellite (ASAT). Russia and China understand that holding American national security satellites at risk is an effective strategic deterrent.[2]

In addition to ASAT, the current and future threats to US defense satellites are mostly non-kinetic. Cyber, electronic jamming, and directed energy dazzling attacks "every single day," according to Lt. Gen David Thompson, US Space Force's Vice Chief of Operations.[3] The old DoD satellite architecture of multi-billion dollar, unique satellites that were difficult to defend was adequate when the US was the dominant power in orbit. The impunity that the US had in space

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[1] Kendall Russell, "Defending US Space Assets from Foreign Attacks," *Via Satellite*, March 29, 2017, https://www.satellitetoday.com/government-military/2017/03/29/defending-us-space-assets-foreign-attacks/.
[2] Chris Bassler and Tate Nurkin, "A Comprehensive Triad for Space Resilience—More Than Just Numbers," *Space News*, May 9, 2022, https://spacenews.com/op-ed-a-comprehensive-triad-for-space-resilience-more-than-just-numbers/.
[3] Bassler and Nurkin, "A Comprehensive Triad."

superiority, "that era is over."[4] To mitigate this threat, DoD and the US Space Force are prioritizing space resiliency for US national security space assets. "True" space resiliency requires an architecture that is disaggregated, diverse, distributed, prolific, and can be reconstituted.[5] Slow bureaucratic acquisition processes and uncertain budgets make it impractical for a government-only solution. For example, it takes over seven years to build an Advanced Extremely High Frequency (AEHF) satellite. The development and procurement cycle has also suffered cost overruns and schedule delays.[6] Low Earth Orbit (LEO) commercial satellite constellations, however, meet these resiliency criteria and are essential to the future DoD space architecture.

Commercial satellite "mega-constellations" in LEO are the most cost effective and efficient way for the US to mitigate current and emerging threats to DoD space access. Commercial LEO constellations increase DoD space resiliency by augmenting satellite communications (SATCOM), leveraging unclassified Earth-imaging satellites, and providing an alternative position, navigation, and timing (PNT). These constellations consist of hundreds to thousands of small satellites that provide global coverage. The sheer number of these satellites makes it extremely difficult for an adversary to target them kinetically and non-kinetically.[7] LEO commercial satellites provide the survivability, flexibility, and cost savings crucial to the DoD space architecture.

COMMERCIAL LEO SATCOM – BETTER, FASTER, CHEAPER

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[4] Bassler and Nurkin, "A Comprehensive Triad."
[5] Bassler and Nurkin, "A Comprehensive Triad."
[6] Jeffrey Hill, "Lt. Gen. Pawlikowski: Military Will Ride Commercial Satcom for a 'Long Time'." *Satellite News* 35, no. 47 (Nov 20, 2012), https://login.usnwc.idm.oclc.org/login?qurl=https%3A%2F%2Fwww.proquest.com%2Ftrade-journals%2Flt-gen-pawlikowski-military-will-ride-commercial%2Fdocview%2F1266035959%2Fse-2%3Faccountid%3D322.
[7] Matthew Mowthorpe, "Space Resilience And The Importance Of Multiple Orbits," *The Space Review*, January 3, 2023, https://www.thespacereview.com/article/4504/1.

Commercial space's low costs significantly contribute to DoD space resilience. The past ten years have seen a remarkable lowering in the price to launch due in part to innovation in commercial rockets and the decrease in the size and mass of satellites. The use of reusable boosters by SpaceX has reduced the launch price to $62M, whereas the cost to launch on the US Space Shuttle was $450M. The reduction in satellite size and weight, with an improvement in capability, has enabled rockets to rideshare to hundreds of smallsats to orbit. Weight and size reduction has been dramatic. By comparison, the first Earth-observing satellite launched by NASA in 1972 was the size of a garbage truck and weighed 1800kg. A smallsat is typically no heavier than 12kg. The combination of low launch cost and size reduction of satellites has contributed significantly to the growth of commercial space and smallsat mega-constellations.[8] This growth has been and will continue to be vital for DoD's need for global, assured communications.

The US military can also take advantage of commercial space's increased data transmission capability. Market demand for global high-speed broadband data rates with low latency has propelled the growth in commercial LEO satellite communications capacity.[9] LEO-based satellites are tremendously more effective at transmitting large data streams than the wideband broadcast satellites operating out of geosynchronous orbit (GEO). Starlink has demonstrated download speeds averaging about 62.5Mbps and upload speeds of 7.2Mbps. A GEO wideband satellite offers only 25Mbps download and 3 Mbps upload.[10] Its LEO altitude provides a much lower latency rate than a satellite in GEO- 48ms vs. 600+ms, which reduces the chance of a delayed or lost

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[8] Caitlin Macleod, "How The Explosive Growth In Satellites Could Impact Life On Earth," *The Hustle*, August 8, 2021, https://thehustle.co/the-explosive-growth-of-the-satellite-business/.

[9] Debra Werner, "U.S. Army's Satcom Demand Set To Soar As Smartphones Go to War," *Defense News* (Springfield, Va.) 26, no. 34 (2011): 41–.

[10] Paul Trey, "Best Satellite Internet Providers of 2023," *CNET*, December 2, 2022, https://login.usnwc.idm.oclc.org/login?qurl=https%3A%2F%2Fwww.proquest.com%2Fmagazines%2Ftweet-sour%2Fdocview%2F2722670409%2Fse-2%3Faccountid%3D322.

connection.[11] With the high data rate and low latency, coupled with reduced ground station infrastructure, LEO Commercial SATCOM is necessary for DoD's satellite communications architecture.

Government-owned military SATCOM (MILSATCOM) cannot meet the demand for global, continuous coverage by itself. Since Desert Storm, DoD's appetite for passing large amounts of data has grown exponentially. Assured command and control, remotely piloted aircraft (RPA) video feeds, imagery, Secure Internet Protocol Router Network (SIPRNet), and Non-classified Internet Protocol Router Network (NIPRNet) require significant bandwidth that exceeds the capacity of US government-owned SATCOM. For example, the total SATCOM Mpbs used per 5,000 military members from 1990 to 2001 increased from one Mbps to 68.1 Mbps. While the rate of increase is unknown, it will continue to grow.[12] The cost to meet this demand exceeds what a government-owned and operated satellite architecture can provide.[13] Planning for DoD SATCOM is rigid and inflexible, with space acquisition programs taking 10 to 15 years to develop and operate.[14] The cost of designing and building the Wideband Global Satcom (WGS) constellation is $1.3bn.[15] The Advanced Extremely High Frequency (AEHF) satellites cost $1.3bn per asset,[16] "take seven years to build, and its development has suffered from costs overruns and

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[11] Jon Brodkin, "Starlink Is Getting A Lot Slower As More People Use It, Speed Tests Show," *Ars Technica*, September 23, 2022, https://arstechnica.com/tech-policy/2022/09/ookla-starlinks-median-us-download-speed-fell-nearly-30mbps-in-q2-2022/.

[12] Patrick Rayermann, "Exploiting Commercial SATCOM: A Better Way," 2003.

[13] Tim Bonds, "Employing Commercial Satellite Communications Wideband Investment Options for the Department of Defense," *Rand*, 2000, xvii.

[14] Hill, "Lt. Gen. Pawlikowski: Military Will Ride Commercial Satcom for a 'Long Time'."

[15] "Wideband Global SATCOM (WGS) satellites," *Aerospace technology*, Accessed on January 17, 2023, https://www.aerospace-technology.com/projects/wgs-satellite/.

[16] Sandra Erwin, "Is The Cost Of Military Space Programs Going Up Or Down? Depends On How You Count," *SpaceNews.com*, March 19, 2018, https://spacenews.com/is-the-cost-of-military-space-programs-going-up-or-down-depends-on-how-you-count/#:~:text=For%20AEHF%2C%20the%20original%20program,%2459.6%20billion%20for%20161%20launches.

schedule delays."[17] The long lead times to plan, build, and fly these large, expensive, and unique satellites mean they do not have any surge capacity for crises. While highly capable, the limited number of AEHF and WGS satellites make them "undefendable" from ASATs.[18] MILSATCOM's high costs, long latency, lack of surge capacity, and vulnerability to a kinetic attack demonstrate their inherent limited resilience in the contested space domain.

The Russian invasion of Ukraine is a real-world live case study for the inherent value of the capability and resilience of LEO-based commercial communications. As Russia has repeatedly targeted Ukrainian infrastructure, it has been unsuccessful in denying or significantly degrading Ukrainian troops' ability to communicate, relay targeting information, and upload videos from the front line.[19] The crucial technology behind Ukraine's communication resiliency is Starlink. While Russia has demonstrated and proven ASAT capability in its Nudol program, it has not been employed against Starlink assets over the course of the conflict.[20] Having over 2900 satellites currently on orbit, combined with the rapid reconstitution capability provided by SpaceX, has rendered a direct-ascent kinetic attack pointless. Additionally, Starlink has proven to be extremely resistant to Russian non-kinetic effects. Despite calling the LEO constellation a legitimate military target, it has been unable to jam or hack the system. Since the start of the conflict, Starlink-equipped Ukrainian forces have continued to maintain unimpeded communications. With a price tag of $100M,[21] which is considerably less than MILSATCOM, the capability and resiliency of

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[17] Hill, "Lt. Gen. Pawlikowski: Military Will Ride Commercial Satcom for a 'Long Time'."
[18] Hitchens, "Space Force Targets 2027."
[19] Internet from the sky, (2023, Jan 07), *The Economist*, 446, 9-10, https://login.usnwc.idm.oclc.org/login?qurl=https%3A%2F%2Fwww.proquest.com%2Fmagazines%2Finternet-sky%2Fdocview%2F2761511762%2Fse-2%3Faccountid%3D322.
[20] Sean O'Connor, "Russia's ASAT Development Takes Aim At LEO assets." *Intelligence Review*, July 18, 2018, https://customer.janes.com/Janes/Display/FG_962143-JIR.
[21] Internet from the sky.

Starlink-enabled communications demonstrate the cost-benefit value of commercial LEO constellations.

THE COMMERCIAL 'UNBLINKING EYE' FROM LOW EARTH ORBIT

"We want to leverage commercial in a significant way. It is a huge national advantage for us."[22]

Commercial remote sensing smallsat constellations will be a crucial capability added to the national security satellite infrastructure. From the 1960s through the early 2000s, earth observation satellites were highly classified government programs. Today, over 40 percent of remote sensing satellites are commercial, offering resolution from 3 meters to 50-centimeter-length scale, including hyperspectral and Synthetic Aperture Radar (SAR) imagery.[23] Rather than a threat to national security satellite systems, these commercial systems offer a reliable, resilient, cost-effective, and, most importantly, unclassified augmentation capability.

Commercial earth-imaging satellites offer increased space resilience to the limited number of on-orbit assets the US intelligence community currently has. The US government suffers from the same limitation as other government-owned and operated space assets—they are limited in number, high cost, and cannot be readily replaced. The PlanetScope constellation uses over 200 satellites; SkySat has a constellation of 21 smallsats.[24] While an adversary could dazzle a smallsat, the effects would be minimal due to the number of satellites that would need to be blinded simultaneously and the high revisit rate (between 25 seconds to 24 hours, depending on location).[25] The high revisit rate is also a significant advantage over traditional national security satellites,

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[22] Gen. John W. Jay Raymond, CSO, USSF.
[23] Thomas Taverney, "The Evolution of Space-Based ISR," *Air Force Magazine* 105, no. 8 (2022): 94–.
[24] Natasha Bajema, "Commercial Satellites Are National Security's Next Frontier," *IEEE Spectrum*, June 8, 2022, https://spectrum.ieee.org/commercial-satellite-imagery-national-security162.
[25] David Roy, Haiyan Huang, Rasmus Houborg, and Vitor Martins, "A Global Analysis Of The Temporal Availability Of PlanetScope High Spatial Resolution Multi-Spectral Imagery. Remote Sensing of Environment," *Researchgate.net*, 2021, https://www.researchgate.net/publication/353200245_A_global_analysis_of_the_temporal_availability_of_PlanetScope_high_spatial_resolution_multi-spectral_imagery.

which have limited worldwide persistence due to limited numbers.[26] The commercial LEO imagery also possesses inherent resilience over the typical spy satellite. Just as the Russians have not used their ASAT capability against Starlink, the same reason applies to commercial imagery; the satellites are small, cheap, and can be easily reconstituted.[27] The high resolution, large numbers, and low costs make commercial imagery smallsats survivable and highly resilient to adversary kinetic and non-kinetic attacks.

Commercial LEO satellites will be invaluable as augments to the US ISR capabilities due to their unclassified data. Exquisite imagery from sophisticated US national security systems is classified and meant for strategic purposes; they are not easily shared with allies and partner nations. There are no information-sharing limitations on commercial ISR products. NATO allies have demonstrated the importance of unclassified commercial space-based ISR by providing imagery support to the Ukrainians following Russia's invasion. This current battlefield use in Eastern Europe has applications down to the tactical user, which was not possible before commercial satellite imagery. Utilizing multiple commercial space ISR vendors gives warfighters "over the hill" intelligence and can help reduce targeting timelines from hours to minutes. Combined with national assets, commercial space imagery constellations will provide a considerable advantage for the US military by reducing financial costs, increasing persistent imaging capability, and improving ISR survivability.

AUGMENTING POSITION NAVIGATION AND TIMING

Commercial LEO satellites are a viable technical solution as an alternate signal source for position, navigation, and timing (PNT). The US Global Position System (GPS) is the lynchpin of

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[26] Taverney, Thomas. "The Evolution of Space-Based ISR."
[27] Mowthorpe, "Space Resilience."

global navigation systems. The 24 satellites that make up the GPS constellation provide the PNT used by every aspect of the civilian and defense sectors. While the constellation has performed reliably for over 33 years, vulnerabilities have become more apparent.[28] The system is vulnerable to kinetic attack from on-orbit or direct assent ASATs. The GPS signal is relatively weak and can be easily jammed, interfered with, or spoofed by adversaries. Friendly interference commonly affects GPS signal reception. GPS signal hardening does not solve the interference concerns. The most effective way to provide assured PNT is to provide an alternative navigation solution that compliments and augments the GPS. The solution points towards using commercial LEO satellite constellations as an alternate signal for assured PNT (APNT).[29]

Commercial LEO communication satellites such as Iridium, OneWeb, and Starlink are ideally situated to augment PNT. The required characteristics for APNT are availability and data integrity, which these companies possess. LEO constellation signals are much higher power than the GPS signal, which makes them very difficult to jam. As communication satellites, data integrity is integral to these constellations, so they are resistant to spoofing. Commercial LEO satellites provide persistent, global coverage with powerful downlinks that can be used as signals of opportunity (SoOP) to provide a navigation fix.

Another reason why commercial LEO satellites will be effective sources for APNT is that the constellations are inherently survivable and resilient. Short of an EMP, mega-constellations "would make it extremely difficult for a threat nation" to destroy or degrade.[30] The Chinese and the Russians combined do not have enough laser or ASAT weapons to cause a significant loss of APNT capability based on the sheer numbers of these constellations. Also, the low cost of these

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[28] "GPS Overview," GPS.gov, Accessed on January 18, 2023, https://www.gps.gov/systems/gps/space/.
[29] Giles Ebbutt, "Prime Position: Industry Explores Alternative PNT Solutions," *International Defence Review*, May 18, 2022, https://customer.janes.com/Janes/Display/BSP_22123-IDR.
[30] Mowthorpe, "Space Resilience."

smallsats and their low cost to launch means that these mega-constellations can be rapidly reconstituted. For an adversary nation to effectively deny PNT in a large geographic area would require a significant degradation of both a highly resilient LEO constellation and the GPS architecture simultaneously. The only weapon that could do this would be nuclear weapons, which would cause international condemnation and a robust retaliatory response. The proliferation, global coverage, and inherent resiliency against non-nuclear threats make LEO commercial constellations a clear solution as an APNT capability.

COUNTERARGUMENT – THE WEAKNESS OF COMMERCIAL LEO

While commercial LEO constellations have high resiliency based on the large numbers of smallsats, their low launch costs, and their subsequent ease of reconstitution compared to US government-owned and operated satellites, they are particularly vulnerable to two major threats: cyber and nuclear attack. The networked nature of a LEO commercial satellite architecture provides multiple cyber access points, both on the ground and on-orbit. An adversary could take advantage of any of these access points and potentially compromise the entire constellation.[31] With their continuous coverage, GEO satellites are better suited for transmitting high data rates and secure datalinks.[32] The US government's GEO communication satellites, such as WGS and AEHF, remain the backbone of protected MILSATCOM.

Additionally, a GEO constellation with fewer satellites is at much lower risk to a nuclear detonation or an EMP due to their high altitude and the distance between satellites. A nuke detonation against a GEO target would only result in the loss of one satellite, as thousands of kilometers separate the other assets in that orbit. A nuke or EMP explosion against a mega-

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[31] Mowthorpe, "Space Resilience."
[32] Munoz, "Silver Bullet."

constellation would have a catastrophic impact, destroying or neutralizing a sizable number of close proximity smallsats with unprotected circuits.[33] In a conflict involving strategic weapons, LEO commercial satellites will not be able to provide the assured communications that the Department of Defense requires for MILSATCOM.

REBUTTAL

It is a reality that LEO commercial constellations would be highly vulnerable to nuclear weapons. However, most threats against the DoD space architecture for today and the future will not be the high-risk, low probability of nuclear armageddon. Instead, these threats will be conventional kinetic and electromagnetic means to deny the US military's use of space. The sophisticated, unique, and number-limited satellites are too easily targetable by China's DN-1 and Russia's Nudol ASAT programs. The answer to space resilience is not an 'all LEO' or an 'all GEO' approach. Instead, the future space architecture must be a hybrid combination of commercial and DoD satellites. This defense-in-depth combination provides the resilience and protection that the US military needs for assured access to SATCOM, PNT, and ISR.

CONCLUSION

Commercial LEO constellations will majorly contribute to the survivability of the future DoD space architecture. The low latency, high data rate, significant resistance to interference, large numbers, and low cost of commercial satellites make them highly effective in improving space resilience and lowering the US military's vulnerability in the space domain. As the first Chief of Space Operations has clearly stated, DoD must "leverage commercial in a significant way. It is a huge national advantage for us."[34]

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[33] Mowthorpe, "Space Resilience."
[34] Taverney, Thomas. "The Evolution of Space-Based ISR."

BIBLIOGRAPHY

A Path to an Integrated DoD Satellite Architecture via Commercial Satcom-as-a-Service. Potomac: Access Intelligence, LLC, 2020.

"ASAT." Weapons: Strategic. August 1, 2022. https://customer.janes.com/Janes/Display/JSWS9047-JSWS.

Baghal, Lisa A. "SATCOM Supply Versus Demand and the Impact on Remotely Piloted Aircraft ISR," 2016.

Bajema, Natasha. "Commercial Satellites are National Security's Next Frontier." IEEE Spectrum. June 8, 2022. https://spectrum.ieee.org/commercial-satellite-imagery-national-security162.

Bassler, Chris and Tate Nurkin. "A comprehensive triad for space resilience – more than just numbers." Space News. May 9, 2022. https://spacenews.com/op-ed-a-comprehensive-triad-for-space-resilience-more-than-just-numbers/.

Bonds, Tim. Employing Commercial Satellite Communications Wideband Investment Options for the Department of Defense. Santa Monica, CA: Rand, 2000.

Brodkin, Jon. "Starlink is getting a lot slower as more people use it, speed tests show." Ars Technica. September 23, 2022. https://arstechnica.com/tech-policy/2022/09/ookla-starlinks-median-us-download-speed-fell-nearly-30mbps-in-q2-2022/.

Console, Andrea. "Space Resilience – Why and How?" Joint Air Power Competence Centre. Edition 27, Autumn / Winter 2018. https://www.japcc.org/wp-content/uploads/JAPCC_J27_screen.pdf.

"Control and Communications - Elisra StarLink." All the World's Aircraft: Unmanned 48, no. 48 (2021).

DoD Directive 3100.10, "Space Policy," August 30, 2022. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/310010p.PDF.

Ebbutt, Giles. "Prime position: Industry explores alternative PNT solutions." International Defence Review. May 18, 2022. https://customer.janes.com/Janes/Display/BSP_22123-IDR.

Erwin, Sandra. "Is the cost of military space programs going up or down? Depends on how you count." SpaceNews.com. March 19, 2018. https://spacenews.com/is-the-cost-of-military-space-programs-going-up-or-down-depends-on-how-you-count/#:~:text=For%20AEHF%2C%20the%20original%20program,%2459.6%20billion%20for%20161%20launches.

Fabey, Michael. "USCG to test LEO communications in Arctic." Navy International. July 29, 2022. https://customer.janes.com/Janes/Display/BSP_31782-JNI.

"GPS Overview." GPS.gov. Accessed on January 18, 2023. https://www.gps.gov/systems/gps/space/.

Harrison, Todd. 2022. "Commercial Space Remote Sensing and Its Role in National Security." Center for Strategic & International Studies. February 2, 2022. https://www.csis.org/analysis/commercial-space-remote-sensing-and-its-role-national-security.

Hill, Jeffrey. "Lt. Gen. Pawlikowski: Military Will Ride Commercial Satcom for a 'Long Time'." Satellite News 35, no. 47 (Nov 20, 2012). https://login.usnwc.idm.oclc.org/login?qurl=https%3A%2F%2Fwww.proquest.com%2Ftrade-journals%2Flt-gen-pawlikowski-military-will-ride-commercial%2Fdocview%2F1266035959%2Fse-2%3Faccountid%3D322.

Hitchens, Theresa. "Space Force targets 2027 for resilient on-orbit posture initial capability." Breaking Defense. May 17, 2022. https://breakingdefense.com/2022/05/space-force-targets-2027-for-resilient-on-orbit-posture-initial-capability/.

"Information Assurance: The US Military's Growing Need for What Commercial SATCOM Providers Offer." Space Daily, 2017.

Internet from the sky. (2023, Jan 07). *The Economist, 446*, 9-10. Retrieved from https://login.usnwc.idm.oclc.org/login?qurl=https%3A%2F%2Fwww.proquest.com%2Fmagazines%2Finternet-sky%2Fdocview%2F2761511762%2Fse-2%3Faccountid%3D322.

Macleod, Caitlin. "How the explosive growth in satellites could impact life on Earth." The Hustle. August 8, 2021. https://thehustle.co/the-explosive-growth-of-the-satellite-business/.

Malenic, Marina. "US warns on Russian ASAT capabilities." Defence Weekly. June 17, 2015. https://customer.janes.com/Janes/Display/jdw58957-jdw-2015.

Mattock, Michael G, Thomas Hamilton, Tim Bonds, Carl Z Rhodes, Michael L Scheiern, Phillip M Feldman, and David et al Frelinger. "CURRENT DoD COMMUNICATIONS SATELLITES." In Employing Commercial Satellite Communications. United States: RAND Corporation, The, 2000.

McCranie, Kevin D. *Mahan, Corbett, and the Foundations of Naval Strategic Thought*. La Vergne: Naval Institute Press, 2021. Accessed January 16, 2023. ProQuest Ebook Central.

Miller, Amanda. "US Space Command Formalizes Strategy to Buy More Commercial Satellite Services." Air & Space Forces Magazine. April 5, 2022. https://www.airandspaceforces.com/us-space-command-formalizes-strategy-to-buy-more-commercial-satellite-services/.

"Measure of success - Analysing the results of China's ASAT test." Intelligence Review. April 16, 2007. https://customer.janes.com/Janes/Display/jir10154-jir-2007.

Morrar, Sam. "Using E-Band for Wideband Satcom: Opportunities and Challenges." Microwave Journal 64, no. 8 (08, 2021): 22-22,24,26,28,30,32. https://login.usnwc.idm.oclc.org/login?qurl=https%3A%2F%2Fwww.proquest.com%2Ftrade-journals%2Fusing-e-band-wideband-satcom-opportunities%2Fdocview%2F2564180816%2Fse-2%3Faccountid%3D322.

Mowthorpe, Matthew. "Space resilience and the importance of multiple orbits.' The Space Review. January 3, 2023. https://www.thespacereview.com/article/4504/1.

Munoz, Carl. "DoD sees LEO, MEO satellites as future of US missile defence." International Defence Review. July 25, 2022. https://customer.janes.com/Janes/Display/BSP_31485-IDR.

Munoz, Carl. "Silver bullet: Low Earth Orbit and the future of satellite communications." International Defence Review. July 21, 2021. https://customer.janes.com/Janes/Display/BSP_1631-IDR.

"National Security Space: Actions Needed to Better Use Commercial Satellite Imagery and Analytics." U. S. Government Accountability Office. Accessed January 15, 2023. https://www.gao.gov/products/gao-22-106106.

O'Connor, Sean. "Russia's ASAT development takes aim at LEO assets." Intelligence Review. July 18, 2018. https://customer.janes.com/Janes/Display/FG_962143-JIR.

Pultarova, Tereza and Elizabeth Howell. "Starlink satellites: Everything you need to know about the controversial internet megaconstellation." November 23, 2022. https://www.space.com/spacex-starlink-satellites.html.

Radley, Charles F, and Thomas M Eubanks. "GNSS with Satcom Networks to Dramatically Improve Space Situational Awareness." Journal of Space Safety Engineering 7, no. 3 (2020): 307–11. https://doi.org/10.1016/j.jsse.2020.08.005.

Rayermann, Patrick. "Exploiting Commercial SATCOM: A Better Way," 2003.

Rohret, David and Jonathan Holston. *Exploitation of Blue Team SATCOM and MILSAT Assets for Red Team Covert Exploitation and Back-Channel Communications*. Reading: Academic Conferences International Limited, 2010. https://login.usnwc.idm.oclc.org/login?qurl=https%3A%2F%2Fwww.proquest.com%2Fc

onference-papers-proceedings%2Fexploitation-blue-team-satcom-milsat-assets-red%2Fdocview%2F869617319%2Fse-2%3Faccountid%3D322.

Roy, David, Haiyan Huang, Rasmus Houborg, and Vitor Martins. "A global analysis of the temporal availability of PlanetScope high spatial resolution multi-spectral imagery. Remote Sensing of Environment." 2021. https://www.researchgate.net/publication/353200245_A_global_analysis_of_the_temporal_availability_of_PlanetScope_high_spatial_resolution_multi-spectral_imagery.

Russell, Kendall. "Defending US Space Assets from Foreign Attacks." Via Satellite. March 29, 2017. https://www.satellitetoday.com/government-military/2017/03/29/defending-us-space-assets-foreign-attacks/.

"Satcoms from a Tablet-Sized Device?" Military Technology 43, no. 9 (2019): 12–.

Savage, Olivia. "Commercial space: Industry steps up to deliver satellite-based capabilities." International Defence Review. December 8, 2022. https://customer.janes.com/Janes/Display/BSP_50828-IDR.

Seck, Hope Hodge. "Space Force Woos Industry as Ukraine Highlights Commercial Partnerships." Air & Space Forces Magazine. April 7, 2022. https://www.airandspaceforces.com/space-force-woos-industry-as-ukraine-highlights-commercial-partnerships%ef%bf%bc/

Seffers, George I. "Fight SATCOM Concept Grows Closer to Reality." Signal 74, no. 9 (05, 2020): 36-37. https://login.usnwc.idm.oclc.org/login?qurl=https%3A%2F%2Fwww.proquest.com%2Ftrade-journals%2Ffight-satcom-concept-grows-closer-reality%2Fdocview%2F2406319537%2Fse-2%3Faccountid%3D322.

Starlink. "HOW STARLINK WORKS." Accessed January 16, 2023. https://www.starlink.com/technology.

Taverney, Thomas. "The Evolution of Space-Based ISR." Air Force Magazine 105, no. 8 (2022): 94–.

"Trend: Demand for Bandwidth Drives Commercial Satcom." Broadcast & CableSat, 2012.

Trey, Paul. "Best Satellite Internet Providers of 2023." CNET. December 2, 2022. https://www.cnet.com/home/internet/best-satellite-internet/.

Tweet and sour. (2022, Oct 08). *The Economist, 445*, 26. Retrieved from https://login.usnwc.idm.oclc.org/login?qurl=https%3A%2F%2Fwww.proquest.com%2Fmagazines%2Ftweet-sour%2Fdocview%2F2722670409%2Fse-2%3Faccountid%3D322.

"USMC explores operational use of low Earth orbit satcom." Jane's. August 9, 2022. https://customer.janes.com/Janes/Display/BSP_32577-IDR.

ViaSat Demonstrates Commercial Satcom Over JTRS Network. Vol. 9. Potomac: Access Intelligence, LLC, 2010.

Wang, B. (2022). *Over 2900 SpaceX starlink satellites*. Moffett Field: Newstex. Retrieved from https://login.usnwc.idm.oclc.org/login?qurl=https%3A%2F%2Fwww.proquest.com%2Fblogs-podcasts-websites%2Fover-2900-spacex-starlink-satellites%2Fdocview%2F2708279159%2Fse-2%3Faccountid%3D322.

Werner, Debra. "US Army's Satcom Demand Set to Soar as Smartphones Go to War." Defense News (Springfield, Va.) 26, no. 34 (2011): 41–.

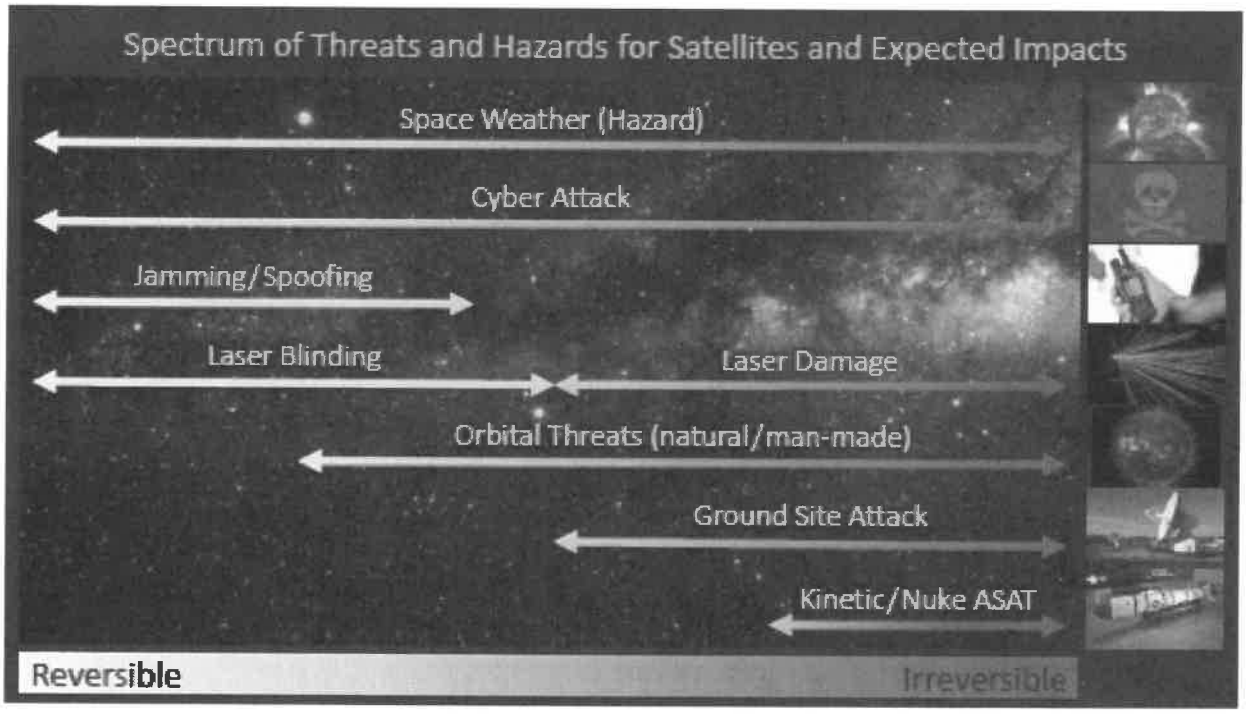
White, Andrew. "USSOCOM to launch LEO satellite for Special Reconnaissance missions." International Defence Review. May 23, 2022. https://customer.janes.com/Janes/Display/BSP_23445-IDR.

"Wideband Global SATCOM (WGS) satellites." Aerospace technology. Accessed on January 17, 2023. https://www.aerospace-technology.com/projects/wgs-satellite/.

Withington, Thomas. "COMMERCIAL BREAK: Despite a Reduction in US Strategic Commitments Around the World, the Commercial Satellite Communications (SATCOM) Industry Is Confident That Military Demand Will Increase as Countries Seek to Diversify Supply and Augment Nationally-Owned Capabilities." Armada International 41, no. 5 (2017): 22–.

APPENDIX A

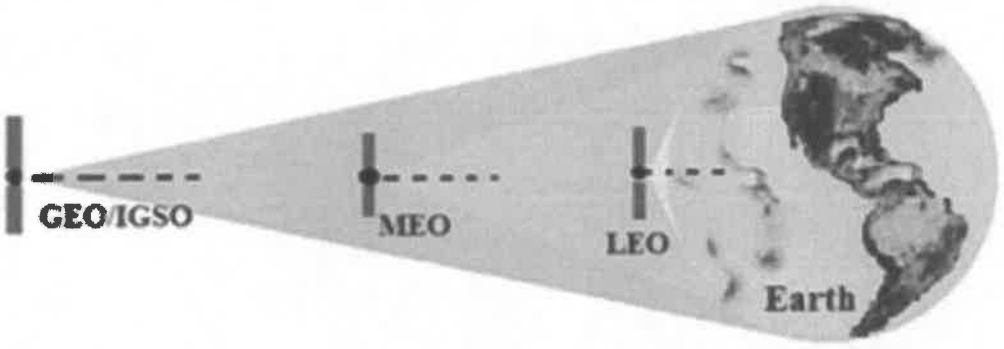
THREATS TO SATELLITES



Source: Right Column, 3rd Pic: © US Air Force, Tech. Sgt. Nicholas B. Ontiveros; 6th Pic: © ESA, C. Lezy; Any Other: © Copyrighted; Background: © NASA. https://www.japcc.org/wp-content/uploads/JAPCC_J27_screen.pdf.

APPENDIX B

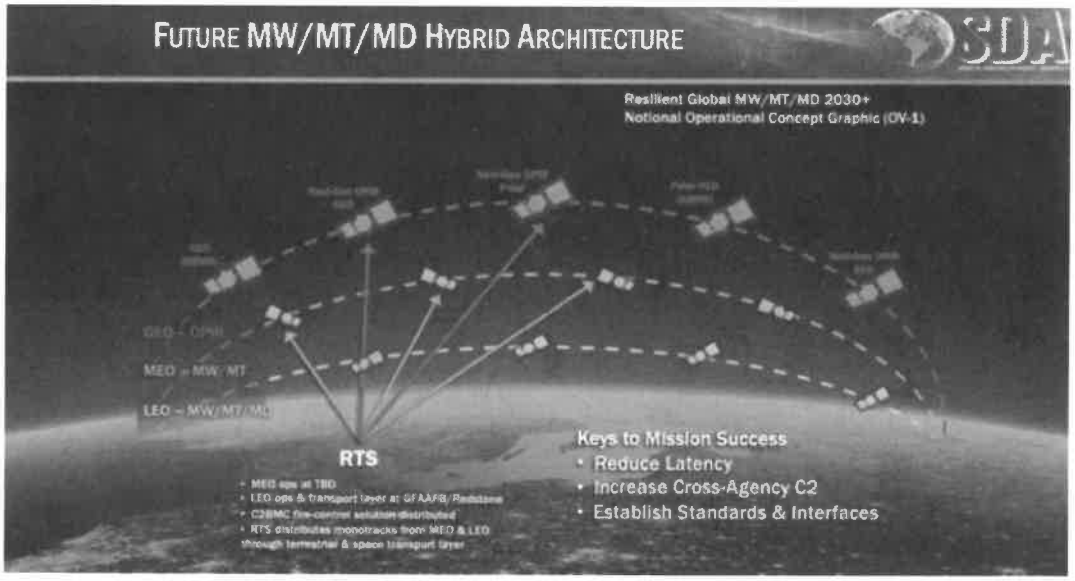
COMPARING THE FIELDS OF VIEW OF LEO, MEO, AND GEO



Source: The Space Review. January 3, 2023. https://www.thespacereview.com/article/4504/1.

APPENDIX C

FUTURE HYBRID SPACE ARCHITECTURE



Source: Space Development Agency. May 17, 2022. https://breakingdefense.com/2022/05/space-force-targets-2027-for-resilient-on-orbit-posture-initial-capability/