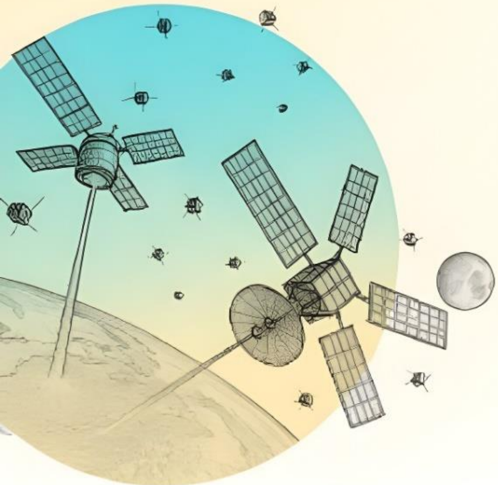
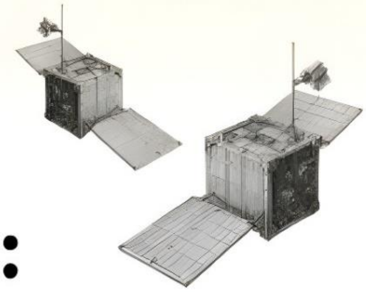
CENTRE for AEROSPACE & SECURITY STUDIES





Militarised NanoSats: Democratising Space Power and Disrupting Deterrence Paradigms

Mustafa Bilal

Research Assistant

Working Paper

President
Air Marshal Javaid Ahmed (Retd)

Edited by:
Sarah Siddiq Aneel

Proofreading and Reference Standardisation
Mashal Shahid

Layout
Hira Mumtaz

All correspondence pertaining to this publication should be addressed to CASS, Islamabad, through post or email at the following address:

Centre for Aerospace & Security Studies

+92 51 5405011
cass.thinkers@casstt.com
cass.thinkers
cassthinkers
@CassThinkers
Centre for Aerospace & Security Studies

Old Airport Road, Islamabad, Pakistan www.casstt.com

CENTRE for AEROSPACE & SECURITY STUDIES

Militarised NanoSats: Democratising Space Power and Disrupting Deterrence Paradigms

Working Paper

Mustafa Bilal

Research Assistant

TABLE OF CONTENTS

Abstract

This paper examines the militarisation of NanoSats and applies the U.S. Space Force's Competitive Endurance framework to explore their potential military utility for space-based Intelligence, Surveillance, and Reconnaissance (ISR), Earth Observation (EO) and terrestrial tactical responsiveness. While military NanoSats could offer redundancy in case of adversarial attacks, their dual-use ambiguity and proliferation rate challenge traditional deterrence paradigms. This complicates attribution and managing escalation control. Moreover, military utility of NanoSats is constrained compared to larger satellites as commercial-off-the-shelf (COTS) components in military NanoSat development risk cyberattacks, radiation vulnerabilities, diminish sensor ability, and decrease operational life. This highlights the fundamental trade-off of military NanoSats: affordability and modularity enable rapid deployment but expose them to adversarial exploitation. The United States military and aerospace firms have spearheaded the militarisation of NanoSats. Meanwhile, the military NanoSat programmes in several other states highlight how they can democratise space power. Military-commercial collaboration in NanoSat development further blurs the boundaries between civilian and military space operations. Therefore, proliferated deployment of military NanoSat constellations risks exacerbating orbital congestion and crisis misperception. This underscores the imperative of reconciling military innovation in NanoSat development with collective space sustainability, urging stakeholders to balance military advantages of NanoSat constellations with the risk of destabilising Earth's orbit.

Keywords: NanoSats, CubeSats, Dual-Use Technologies, Space-Based ISR, Earth Observation (EO)

Introduction

Satellite architectures like Starlink have become a tool of military power and an instrument of exerting geopolitical leverage. While such constellations comprise micro-satellites, examining the potential military applications of smaller, cheaper, and more manoeuvrable NanoSats is also of military and geopolitical significance. Any satellite weighing between 1 and 10 kilograms is classified as a NanoSatellite (NanoSat).[1] The development of NanoSats has coincided with several technological advancements in modularisation and miniaturisation in space capabilities. Miniaturisation of satellites, combined with decreasing launch costs, has contributed to an increasing frequency of launches and improved the feasibility of deploying a constellation of NanoSats. Notably, more than 120 NanoSats have been launched on a single rocket, and as of April 30, 2025, nearly 90 states have launched 2956 NanoSats, with 2730 being CubeSats, moreover, 1716 NanoSats have been launched by the United States (US), which accounts for 58% of all deployed NanoSats.[2]

Cube satellites (CubeSats) are a class of NanoSats developed according to the CubeSat Design Specification (CDS), an international dimensional standard. A 1 Unit (1U) CubeSat measures 10 centimetres on each side and weighs 1.3 kg.[3] Despite their small size, their key feature is modularity; multiple CubeSat units can be combined depending on the complexity of missions. Therefore, space enthusiasts have hailed CubeSats due to their affordability, modular architecture, and readily available commercial off-the-shelf components (COTS).[4] Developing states have also realised the promise of CubeSats. For example, Nepal, Sri Lanka and Bhutan have capitalised on the ease of CubeSat development by deploying their respective versions.[5] Pakistan has similarly launched two CubeSats for scientific and research purposes.[6]

Numerous reasons could explain why states are increasingly investing in NanoSats and CubeSats; improving communication infrastructure may serve as a primary advantage, as these miniature satellites provide economical solutions to bridge the digital divide by enhancing connections in remote or underserved regions.[7] However, while states

---

1 NASA, "What Are SmallSats and CubeSats?" Accessed January 12, 2024, https://www.nasa.gov/what-are-smallsats-and-cubesats/.

2 Erik Kulu, "NanoSats Database," *NanoSats Database*, Accessed May 4, 2025, https://www.nanosats.eu/.

3 Erik Kulu, "What is a CubeSat?" *NanoSats Database*, Accessed January 1, 2025, https://www.nanosats.eu/cubesat.

4 Mustafa Bilal, "CubeSats and Space Exploration: From Campuses to the Cosmos," *Centre for Aerospace & Security Studies*, December 9, 2024, https://casstt.com/cubesats-and-space-exploration-from-campuses-to-the-cosmos/.

5 Biplov Paneru, Bishwash Paneru and Ramhari Poudyal, "Emergence in Space Technologies with NanoSatellites, Exploring the Applications of AI in Space Development, and Future Trends," *Aerospace Engineering* 1, no. 1 (2024): 1-26, https://journal.pubmedia.id/index.php/aero/article/view/2434.

6 Bilal, "CubeSats and Space Exploration."

7 Paneru, Paneru and Poudyal, "Emergence in Space Technologies," 11.

have tried to harness the civil and commercial potential of NanoSats and CubeSats, their latent military potential has been underutilised. This is underscored by the fact that the military sector has the smallest share of NanoSats launched globally, estimated to be seven-times less than the number of NanoSats launched by universities and more than 15 times less than the commercial space sector.[8]

Even though technological innovations and declining launch costs have increased the military utility of NanoSats, they were initially considered university projects when first developed in the late 90s-early 2000s. However, since the advent of NanoSats, the US military and aerospace firms have recognised their potential in supporting terrestrial and military space operations. Over the past 15 years, they have successfully experimented with military NanoSat prototypes, each iteration being more advanced than the previous. The primary objective of the US was to utilise military NanoSats to enhance space-based Intelligence, Surveillance, and Reconnaissance (ISR) via Earth Observation (EO) to augment terrestrial military missions.

NanoSats can also execute defensive and offensive military space operations, spanning space situation awareness (SSA), tactical responsiveness, and counterspace campaigning. For defensive missions, high-value assets can be protected by several NanoSats operating in close proximity as 'guardian satellites.' In offensive applications, they can engage in Rendezvous and Proximity Operations (RPO) for tactical manoeuvring, surveillance, localised jamming, or disabling an adversarial space asset by physical interference. However, integrating NanoSats into military command, control, and communications (C3) raises operational concerns regarding cyber threats and radiation vulnerabilities because of reliance on COTS components. Furthermore, as more states become proficient in NanoSat deployment, the rapid diffusion of this technology worldwide can accelerate space militarisation by destabilising the existing offence-defence balance in global space power. Military NanoSats, in particular, could undermine space security by disrupting traditional deterrence frameworks designed during the Cold War.

This paper addresses these issues by examining the central research problem: How does the militarisation of NanoSats and CubeSats support terrestrial military operations and augment military space capabilities, and what are the accompanying geopolitical, normative, and technological implications? The analysis is focused mainly on a case study of the US. Still, the paper also examines military NanoSat development beyond the US and how the proliferation of these systems could democratise space power by enabling states worldwide to acquire asymmetric space capabilities.

8 Erik Kulu, *NanoSats Database*, Accessed January 1, 2025, figure 'Nanosatellites by Organisations', https://www.nanosats.eu/img/fig/Nanosats_organisations_black_2024-12-31.png.

Considering the topic, the research utilises qualitative methodology and relies on an analytical framework which is grounded in the following:

- Academic literature on NanoSat technologies and military space strategy,
- Astropolitical theory and deterrence stability,
- Official publications and reports from defence agencies,
- Industry white papers and think tank analyses, and,
- Military magazines and online defence platforms.

Full-text assessments ensured that each publication explicitly addressed the research problem. Key themes, such as military utility and applications of NanoSats and CubeSats, were systematically extracted from the texts. The extracted data were analysed qualitatively to shed light on the under-explored military potential of NanoSats. This framework facilitates nuanced examination of military NanoSat development. It also provides a basis for understanding how the military-technical characteristics of NanoSats and CubeSats intersect with evolving space security and deterrence dynamics. The framework is also aligned with the primary research objective of the paper: examining the military utility of NanoSats and CubeSats.

As noted in the introduction, the US dominates global NanoSat deployment, launching 58% of all NanoSats and CubeSats as of April 30, 2025. Its dominant position in global NanoSat development and its relatively transparent ecosystem of military-commercial collaboration qualified the US as the main case study in this paper. The US-centric analysis offers constructive insights and draws pertinent implications for other space actors. The study also briefly examines militarisation of NanoSats beyond the US. The analysis thus situates the militarisation of NanoSats within a broader astropolitical landscape by analysing their impact on the global balance of space power and its implications for space security and deterrence dynamics.

To this end, the paper adds a novel contribution to existing literature by:

- Exploring the NanoSats and CubeSats' military applications in terrestrial and military space operations.
- Identifying technical risks such as cyber threats, COTS vulnerabilities, and radiation exposure accompanying military NanoSat development.
- Examining initiatives by the US and other states to harness the military potential of NanoSats.
- Analysing the theoretical implications for deterrence and space security.

Section I examines the latent military potential of NanoSats, while Section II outlines the study's theoretical framework. Section III explores commercial NanoSat development and their potential military applications. Section IV focuses on the US militarisation of NanoSats, highlighting key developments and initiatives. Sections V and VI address military NanoSat advancements beyond the US, and proliferation of military NanoSats and their implications for space security, respectively.

The study addresses these multifaceted dimensions to bridge the gap between technical discourse, military, and geopolitical analysis. It offers a forward-looking perspective on NanoSats' evolving role in supporting terrestrial and military space operations.

Latent Military Potential of NanoSats

Historical accounts of CubeSat development have labelled it a purely civilian academic endeavour. For example, Bob Twiggs, co-founder of the CubeSat, stated in a 2014 interview that these satellites attracted no interest or funding from military organisations, and critics wrote them off as toys and the 'dumbest idea'.[9] However, US defence organisations did not consider miniature satellites dumb or toys. As far back as 2000, Stanford University (which pioneered the development of CubeSats) had developed four PicoSatellites (PicoSats) for the US Defense Advanced Research Projects Agency (DARPA), which were even smaller than NanoSats and weighed less than one kilogram.[10]

In this context, it has been argued that the 'original sin' of space technologies is that underlying military objectives spurred the development of civil and commercial space systems.[11] Civil and military space technologies, thus, have a historical inextricable linkage, often referenced as the basis for the argument that all space assets inherently have dual-use potential. Based on this assertion, in the case of miniature satellites, their original sin could be linked to DARPA's sponsorship of PicoSats. Therefore, to explore the military potential of NanoSats and CubeSats, it is first necessary to acknowledge that while the defence sector has lagged in its development, the military utility of miniature satellites was not lost on US defence organisations. This is underscored by how DARPA developed technology for improving the imaging of distant objects in space by fitting powerful space telescopes inside its own CubeSat in 2020, two decades after first funding the development of Stanford University's miniature satellites.[12]

---

9 Garret Reim, "Cubesats: How an Accidental Standard Launched a New Space Age," *Aviation Week Network,* November 8, 2023, https://aviationweek.com/space/commercial-space/cubesats-how-accidental-standard-launched-new-space-age.

10 Alice Phen, "The Realization of a Study on the Current and Future Trends of the Cost of Access to Space for CubeSat Missions," (Master's Thesis, Luleå University of Technology, Luleå, 2022), https://ltu.diva-portal.org/smash/record.jsf?pid=diva2%3A1715413&dswid=-7973.

11 Bleddyn Bowen, *Original Sin: Power, Technology and War in Outer Space* (London: Hurst Publishers, 2022), 20.

12 DARPA, "Miniature Telescope Demonstration Focuses on Sharpening View of Distant Objects in Space," *Defense Advanced Research Projects Agency*, July 28, 2020, https://www.darpa.mil/news/2020/miniature-telescope.

Theoretical Framework

The military utility of NanoSats can be explored through the U.S. Space Force (USSF)'s doctrinal construct 'Competitive Endurance.' It was discussed in March 2023 by General Chance Saltzman as a *theory of success* for the USSF.[13] Competitive Endurance is not an overly complicated theoretical framework; it is grounded in three overarching tenets: denying first-mover advantage to the adversary; avoiding operational surprise; and undertaking responsible counterspace campaigning.[14] These three tenets are interlinked and are means to the end of achieving success in military space operations. This construct was formulated against the backdrop of widespread cyberattacks on Ukraine's centralised space infrastructure, forcing the armed forces to pivot to Starlink's proliferated and resilient architecture.[15] Therefore, the theory draws pertinent lessons from the role of satellites in the Russo-Ukrainian war by emphasising transitioning from legacy space systems, which have traditionally been large, exquisite, slow, and vulnerable space assets. It advocates for establishing smaller, cost-effective, agile, proliferated, resilient space architectures. Considering that NanoSats align with all these characteristics, 'Competitive Endurance' offers a novel lens to analyse the militarisation of NanoSats and their implications for global space power and deterrence dynamics.

1. Denying First-Mover Advantage through Proliferated Space Architectures

The traditional logic of deterrence in space has been grounded in the survivability of a limited number of large, stationary satellites performing critical military functions. However, these satellites were vulnerable due to being single points of failure. To mitigate such vulnerabilities, Competitive Endurance proposes establishing decentralised space architecture. Notably, the cost efficiency and redundancy offered by NanoSats make them a suitable option to materialise such an architecture. Unlike larger satellites, NanoSats fundamentally present dilemmas, not linear problems, to adversaries. For instance, they can be deployed in large constellations, so the cost of shooting down any of these dispersed satellites would be more than its development cost, and its loss would not significantly impact the overall architecture. This would dramatically alter the adversary's targeting calculus and disincentivise preemptive military action in space. Inversion of the cost equation in space defence by potentially deploying NanoSats would depart from how traditional integrated air defence systems

---

13 Greg Hadley, "Saltzman Unveils 'Competitive Endurance' Theory to Guide Space Force," *Air & Space Forces Magazine*, March 7, 2023, https://www.airandspaceforces.com/saltzman-unveils-competitive-endurance-theory-to-guide-space-force/.

14 Office of the Chief of Space Operations, "White Paper on Competitive Endurance," United States Space Force, January 11, 2024, https://www.spaceforce.mil/Portals/2/Documents/White_Paper_Summary_of_Competitive_Endurance.pdf.

15 Ron Gurantz, *Satellites in the Russia-Ukraine War* (Carlisle Barracks, PA: U.S. Army War College Press, 2024), https://press.armywarcollege.edu/monographs/971.

have proven cost-prohibitive against smaller threats in greater numbers.[16] It is also noteworthy that large, slow-moving satellites are easier to target. In contrast, NanoSats and CubeSats have smaller radar cross-sections with reduced signatures, and they can employ camouflage, concealment, and deception (CCD) tactics. While such characteristics do not make NanoSats invisible, they do offer obfuscation, which significantly improves the resilience of the overall space architecture. Therefore, this is how NanoSats could deny first-mover advantages to adversaries by disaggregating deterrence.

2. Avoiding Operational Surprise through Tactical Responsiveness

Almost two decades ago, the DARPA and the U.S. Air Force pioneered Rendezvous and Proximity Operations (RPOs) involving CubeSat platforms for tactical manoeuvring in space and potentially disabling adversary satellites by physical interference.[17] The USSF also plans to launch the Victus Haze mission in late 2025 to demonstrate RPOs by simulating a space-based dogfight.[18] These demonstrations are aligned with the second tenet of Competitive Endurance, which stresses ensuring persistent space domain awareness (SDA). NanoSats and CubeSats are optimal for executing such missions because they offer a cost-effective way to saturate the adversary's defences and respond to threats to terrestrial and military space operations. To this end, NanoSats and CubeSats can be deployed in multiple orbits to form a multi-tier SDA network that would be scalable, agile, and deployable on short notice, unlike legacy space domain networks. Moreover, they could offer real-time terrestrial tactical responsiveness and flexibility, which can be expanded to the space domain. Their deployment with expedited launch capabilities would yield a concept termed by the US as 'Tactically Responsive Space (TacRS)' functionalities. TacRS centres would be able to swiftly restore lost capability, which could be achieved by rapidly deploying NanoSats and CubeSats.[19] Thus, NanoSats can enable avoidance of operational surprises through tactical responsiveness.

3. Responsible Counterspace Campaigning

Responsible counter space campaigning is the third pillar in the Competitive Endurance framework. As the name implies, it is grounded in managing escalation control in a

---

16 Michael P Kreuzer, "Beyond Air Superiority: The Growing Air Littoral and Twenty-First-Century Airpower," *Æther: A Journal of Strategic Airpower & Spacepower* 3, no. 3 (2024): 40-52, https://www.jstor.org/stable/48793177.

17 Joshua J. Garretson, "Satellite Servicing: A History, the Impact to the Space Force, and the Logistics Behind It," *Air University*, March 29, 2021, https://www.airuniversity.af.edu/Wild-Blue-Yonder/Articles/Article-Display/Article/2538269/satellite-servicing-a-history-the-impact-to-the-space-force-and-the-logistics-b/.

18 Greg Hadley, "Space Force Pursues Quick Launch Capability with New 'Victus' Program," *Air & Space Forces Magazine*, February 14, 2025, https://www.airandspaceforces.com/ussf-victus-sol-launch-tactically-responsive-space/.

19 Charles S. Galbreath, "Small Satellites: Answering the Call for Space Superiority," (paper, Mitchell Policy Papers 52: 1-25, July 2024), https://mitchellaerospacepower.org/small-satellites-answering-the-call-for-space-superiority/.

crisis by disabling an adversary's space assets and denying them control of space. Kinetic anti-satellite weapons (ASATs) can be easily attributed to the launching state. Debris generated by a collision can also be discerned. To overcome these inherent disadvantages in employing kinetic ASATs, NanoSats can be equipped with non-kinetic counter-space capabilities ranging from EW payloads to spoofing technologies. These capabilities would enable NanoSats to perform various functions, such as disabling the optical sensor of an adversary's satellite or degrading its command uplink. The modularity of NanoSats also allows them to perform defensive missions (escorting larger satellites) and offensive roles (hunter-killer). For instance, a military NanoSat could escort a larger friendly satellite in peacetime, shadow an adversary's high-value space asset, and disable it via localised jamming during a conflict. Moreover, it could also take images of hostile interceptors or transmit early warnings to allow for evasive manoeuvres. This makes NanoSats suitable for executing responsible counter-space campaigning.

Military NanoSats and Traditional Deterrence Dynamics

The preceding discussion highlights how NanoSats have transformed from passive surveillance tools in orbit to tools of orbital manoeuvre warfare with a potent military utility. However, insights from deterrence theory would suggest that this transformation also entails unintended escalation risks. Notably, the first tenet of Competitive Endurance is based on the 'deterrence by denial' principle.[20] This implies that a proliferated NanoSat architecture would reduce an adversary's incentive to initiate a conflict, knowing that the network will still be functional if a few nodes are lost. The second and third tenets could be linked to the 'deterrence by punishment'[21] approach, where the threat of space assets being rapidly disabled, degraded, or destroyed in retaliation would deter the adversary from aggression. However, covert payloads and dual-use ambiguity associated with NanoSats could undermine space deterrence. This is because the difficulties in ascertaining attribution and intent could lower the threshold of an escalating conflict, especially considering lack of military-to-military transparency regarding deployment of military space assets. This dilemma underscores the interplay between development of military NanoSats and traditional deterrence dynamics.

20 Amir Lupovici, "Deterrence through Inflicting Costs: Between Deterrence by Punishment and Deterrence by Denial," *International Studies Review* 25, no. 3 (September 2023), https://doi.org/10.1093/isr/viad036.

21 Ibid.

Commercial NanoSat Development and Potential Military Applications

Dr Charles Norton, Special Advisor for Small Spacecraft Missions at NASA, described NanoSats and CubeSats as disruptive technologies poised to exert lasting influence, akin to the mobile camera.[22] His camera analogy aptly captured how NanoSats and CubeSats have transformed Earth Observation (EO). Legacy surveillance satellites are large and expensive, much like old handheld cameras; nowadays, most people have access to mobile cameras similar to the ease of accessibility offered by NanoSats and CubeSats for taking images of Earth. For example, the Dove satellite constellation, operated by Planet Labs Inc., is the largest fleet of Earth-imaging NanoSats, comprising over 130 CubeSats called 'Doves', with each weighing merely 11 pounds and delivering three-metre multispectral image resolution for diverse mapping applications.[23] The constellation can image the surface of the Earth in a day, with revisit rates surpassing those of some government or commercial satellites. Similarly, Spire operates the Lemur-2 constellation of NanoSats comprising 3U CubeSat platforms. The constellation tracks maritime, aviation, and weather activity.[24]

Notably, Planet Labs launched its first fleet of NanoSats in 2014, followed by the launch of Spire's NanoSats in 2015. Both firms have become the largest in their respective niches in a decade. This underscores how the commercial EO market has expanded rapidly. This expansion could partly be explained by the growing significance of EO in military applications. With development of NanoSat and CubeSat constellations like Doves and Lemur-2, EO and space-based intelligence, surveillance and reconnaissance (ISR) capabilities, once the preserve of superpowers, have become increasingly accessible to even less developed states. Space-based ISR is valuable for its ability to capture and quickly disseminate actionable intelligence to military commanders by analysing variations observed on different days and providing high-resolution images. Consequently, such capabilities provide an asymmetric advantage for weaker states, as underscored by the critical reliance of Ukrainian forces on space-based ISR capabilities for defensive and counter-offensive military operations against their Russian counterparts.[25]

Constellations like Dove and Lemur-2 also highlight how NanoSats and CubeSats could act as 'gap fillers' and adjuncts to conventional, multi-sensor satellites for space-based ISR. A military NanoSat constellation equipped with high-resolution multispectral

---

22 Stephen G. Anderson, "CubeSats: The Smallest Big Thing in Remote Sensing Sciences," *SPIE,* July 1, 2019, https://www.spiecareercenter.org/news/spie-professional-magazine-archive/2019-july/cubesats.

23 Planet, "Our Constellation," Accessed December 20, 2024, https://www.planet.com/our-constellations/.

24 eoPortal, "Spire Global Nanosatellite Constellation," Accessed December 20, 2024, https://www.eoportal.org/satellite-missions/spire-global.

25 Gurantz, *Satellites in the Russia-Ukraine War*.

cameras could adequately address the requirements of a space-based imaging system by enabling surveillance and mapping of adversary positions and enhancing geospatial intelligence for ground troops. Such a constellation would be conceptually similar to the 'Brilliant Eyes' project of the Cold War era Space Defence Initiative (SDI) that envisioned enmasse space-based sensors deployed for ISR purposes.[26] Hence, militaries could augment deployment of space-based sensors through NanoSats and CubeSats to avert operational surprise in a potential conflict scenario (following the second principle of Competitive Endurance).

Trade-Offs in NanoSat Development: COTS, Radiation, and Cybersecurity

The past 20 years have shown how satellites, the size of a loaf of bread, have become increasingly capable. This warrants questioning whether development of larger spacecraft is still worth it. To address this question, academics from the National Defence University of Romania conducted a SWOT analysis of NanoSats and CubeSats to determine their utility for military space operations. They have argued that these satellites are considerably less competent than larger spacecraft like MicroSats, especially in military contexts, because of vulnerabilities to single-point upsets (SEUs); meanwhile, larger spacecraft can sustain the loss of several components while retaining backup functionality.[27] Larger spacecraft can also accommodate instruments that are more adept at executing strategic functions like nuclear C2 while deployed in much higher orbits than NanoSats, mostly limited to Low Earth Orbit (LEO).[28] Therefore, while NanoSats are not a replacement for larger satellites and cannot perform all the functions their larger counterparts are capable of, the strength of NanoSats and CubeSats lies in their numerical advantage. For instance, a distributed space systems architecture comprising dozens of NanoSats would mitigate the vulnerabilities inherent in operating limited legacy systems.

Based on the above argument, parallels can be drawn between the debate about the military efficacy of NanoSats and larger satellites and discussion about the military utility of smaller unmanned aerial systems (UAS) compared with larger fighter aircraft.[29] Similar to UAS, quick development timelines of NanoSats and CubeSats allow for periodic replacements, facilitate quick technological advancements, reduce unit dependability demands, and promote economies of scale in manufacturing.[30] These

---

26 Aaron Bateman, *Weapons in Space: Technology, Politics, and the Rise and Fall of the Strategic Defense Initiative* (Cambridge: MIT Press, 2024): 171-205.

27 Danuț Turcu and Gheorghe Adrian Stan, "Purpose of Using Cubesat Satellite Technologies in the Military Domain," *Strategies XXI - Security and Defense Faculty* 17, no. 1 (2021): 272–78, https://revista.unap.ro/index.php/XXI_FSA/article/view/1258.

28 Erik Kulu, *NanoSats Database*, Accessed January 1, 2025, figure 'Nanosatellite Approximate Orbits after Launch,' https://www.nanosats.eu/img/fig/Nanosats_orbits_2024-12-31.png.

29 Shaza Arif, "Era of Drone Swarming: Exploring Battlefield Implications," (paper, Centre for Aerospace and Security Studies, Islamabad, December 26, 2024), https://casstt.com/era-of-drone-swarming-exploring-battlefield-implications/.

30 Turcu and Stan, "Purpose of Using Cubesat Satellite Technologies in the Military Domain," 276.

characteristics make them well-suited for military space operations, even if they are not as capable as larger spacecraft. Thus, as UAS is key in modern aerial warfare, NanoSats could offer significant military utility in future terrestrial and space conflicts. Arguments regarding cost-effectiveness of UAS can also be put forward for investing in the development of NanoSat constellations. Like UAS, NanoSats offer 'affordable mass', which is crucial in attrition warfare as legacy systems come with exorbitant budgets. This is underscored by how a single CubeSat constellation can be launched at the price of a single conventional satellite. Two popular examples, often referenced to emphasise the cost-effectiveness of CubeSats, is how NASA developed a lunar reconnaissance orbiter for approx. USD 600 million whereas ten Lunar CubeSats were developed for only USD 13 million. Similarly, NASA developed the Mars Reconnaissance Orbiter for more than USD 700 million, meanwhile development cost of two Mars CubeSats was USD 20 million.[31]

The trade-offs between NanoSats and larger satellites are a central consideration in contemporary space mission planning, weighing cost-effectiveness against performance capability. NanoSats benefit from substantial cost savings from miniaturisation, standardised designs (e.g., CubeSats), and economies of scale in production and launch. These cost savings result from fewer components, fewer radiation-hardening requirements at lower altitudes (due to atmospheric shielding), and COTS electronics. These savings are, however, achieved at performance compromises: NanoSats typically have less power, propulsion, and sensor resolution than larger satellites. The operational lifespan of NanoSats also exhibits this duality. Geostationary orbit (GEO) satellites, which are much larger, have 15+ years' lifetimes with heavy propulsion for orbital adjustment, while very low Earth orbit (VLEO, <500 km) NanoSats experience high atmospheric drag decay, requiring propulsion for drag compensation and confining lifetimes to two-five years. While propulsion systems like electric thrusters could extend NanoSat lifetimes, they are expensive and high-powered, with hydrazine or ion thrusters being power-consuming and contributing to satellite weight, which partly negates the initial cost benefits. Moreover, atomic oxygen erosion at VLEO altitudes accelerates degradation of materials, and new coats or redundancy are required compared to the signature minimalist development approach of NanoSats. Therefore, while promising, the military application of NanoSats reveals key technical shortcomings stemming from the dependence on COTS components.

Cybersecurity is the biggest concern in military NanoSat development, as the predictability of components and standardisation of protocols in COTS software could expose these satellites to cyberattacks. Compared to larger military satellites, NanoSats lack the computing power and onboard hardware to enable full-spectrum antivirus defence or real-time encryption defence. Attackers can exploit this structural

31 Mustafa Aksoy, "Cubesats Are Changing the Way We Explore the Solar System," *The Space Review*, October 7, 2024, https://www.thespacereview.com/article/4867/1.

vulnerability to initiate power-depletion or thermal heating attacks, rendering military NanoSats partially or wholly inoperable.[32] Such attack threats are compounded in space-based grey zone operations, where responsibility is obfuscated. The second drawback of COTS in military NanoSat development is that while they offer cost-effective modularity, COTS electronics are not as hardened against radiation as larger satellites. This makes them susceptible to single-event upsets (SEUs). For instance, it has been noted that the unpredictable effects of radiation are particularly interesting in military NanoSats, where mission failure could have far-reaching implications for multiple layers of military space operations.[33]

Radiation-hardened architectures are being researched for military NanoSat development to mitigate such critical vulnerabilities. Additionally, fault-detecting subsystems that can correct system anomalies and use segmented bus architectures in military NanoSats could offer promising solutions for continuing operations in high-radiation orbits.[34] Thus, during the development phase, it is imperative to undertake multi-level risk analysis of mission-centric NanoSat security architectures. Fundamentally, military Nanosats must be designed following the idea that resilient space systems can deter adversaries from initiating cyberattacks through denial-based deterrence. It is also important to draw lessons from other sensitive systems like UAVs, where the use of COTS has endangered not just the missions but compromised the intellectual property of the technical systems on board, as has been widely observed in the Ukrainian battlefield, where both sides have reverse-engineered hardware designs of disabled drones.[35]

US Militarisation of NanoSats: Key Developments and Initiatives

The US military has been exploring the potential military applications of NanoSats and CubeSats since the early 2010s. The US Army's first service-built and operated NanoSat, the Space and Missile Defence Command-Operational NanoSatellite Effect

[32] Jan Budroweit and Hagen Patscheider, "Risk Assessment for the Use of COTS Devices in Space Systems under Consideration of Radiation Effects," *Electronics 10*, no. 9, (2021): 1008, https://www.mdpi.com/2079-9292/10/9/1008.

[33] John M. McHale III, "Contested Space, Small Sats, and the Gamble on COTS in Space," *Military Embedded Systems*, June 4, 2020, https://militaryembedded.com/comms/satellites/contested-space-small-sats-and-the-gamble-on-cots-in-space.

[34] Gregory Falco, Aaron Viswanathan and Andrew Santangelo, "CubeSat Security Attack Tree Analysis," (paper presented at the IEEE 8th International Conference on Space Mission Challenges for Information Technology, Pasadena, pp. 68-76, July 26-30, 2021), https://ieeexplore.ieee.org/document/9697673.

[35] Kateryna Bondar, *Ukraine's Future Vision and Current Capabilities for Waging AI-Enabled Autonomous Warfare*, report (Washington, D.C.: Center for Strategic and International Studies, 2025), https://www.csis.org/analysis/ukraines-future-vision-and-current-capabilities-waging-ai-enabled-autonomous-warfare.

(SMDC-ONE), surpassed expectations and successfully transmitted communications several times daily to multiple ground stations.[36] Afterwards, the U.S. Operational Responsive Space office financed a project for SMDC to alter one of the NanoSats by substituting its communication component with a software-defined radio. This was intended to significantly enhance the capabilities of the satellite, facilitating transmission of not only text messages but also other data, potentially saving soldiers' lives in isolated situations. Years later, in 2018, the US Army and NASA conducted tests of 100 megabits per second laser communication on the Optical Communications and Sensor Demonstration (OCSD) NanoSat.[37] This was 50 times superior to the standard two MB per second radio communication. Moreover, it was estimated that it could achieve up to 2.5 GBs per second, which would enable the utilisation of NanoSats in applications like synthetic aperture radar (SAR) or hyperspectral Earth photography, which generate data volumes that considerably exceed the capabilities of radio-frequency downlink systems.[38]

The US Air Force Space and Missile Systems Center (SMC/XR) has similarly evaluated the efficacy of NanoSats for conducting operational space weather missions. The demonstration was named 'Space Environmental NanoSatellite Experiment (SENSE)', comprising two 3U CubeSats.[39] The SENSE project was a successful technology demonstration, and the USSF has built on this programme by launching the Electro-Optical/Infrared Weather Systems demonstration mission in March 2024, deploying 110 CubeSats into LEO to provide vital weather data for various military activities.[40] The EWS CubeSat, developed by Orion Space Solutions, aims to mitigate the deficit in weather monitoring caused by the obsolescence of the Defence Meteorological Satellite Program (DMSP) satellites, which are expected to be decommissioned by 2026.[41] The U.S. Department of Defense (DoD)'s Missile Defence Agency (MDA) has also developed a system for tracking adversarial ballistic and hypersonic missiles from launch to impact using CubeSats. The CubeSat Networked Communications Experiment (CNCE) Block 1 was part of the NanoSat Testbed Initiative.[42] The CubeSats

---

36 Erik Kulu, "SMDC-ONE Spacecraft," *Nanosats Database*, Accessed January 1, 2025, https://www.nanosats.eu/sat/smdc-one.

37 Maddy Longwell, "These Satellites Are Communicating Way Faster Thanks to Lasers," *C4ISRNet*, August 7, 2018, https://www.c4isrnet.com/c2-comms/satellites/2018/08/07/these-satellites-are-communicating-way-faster-thanks-to-lasers/.

38 Ibid.

39 Lyle Abramowitz and John Avrett, "SENSE: Lessons Learned through Acquisition and On-Orbit Operations," (paper presented at the Small Satellite Conference, August 11, 2015), https://digitalcommons.usu.edu/smallsat/2015/all2015/30/.

40 Capitol Technology University, "The U.S. Space Force's CubeSat Weather-Imaging Mission Takes Flight Again To Transform Space Technology," *Capitology Blog*, June 18, 2024, https://www.captechu.edu/blog/how-cubesats-are-transforming-space-technology.

41 Ibid.

42 David Vergun,"Nanosatellites Could Play Pivotal Role in Defense Against Enemy Missiles," *U.S. Department of Defense*, July 21, 2021, https://www.defense.gov/News/News-Stories/Article/Article/2685840/nanosatellites-could-play-pivotal-role-in-defense-against-enemy-missiles/.

demonstrated networked communications to facilitate the future missile defence system envisioned under the Hypersonic and Ballistic Tracking Space Sensor (HBTSS), which is being designed to monitor hypersonic missiles worldwide and provide data to command centres for identification and interception.[43] The MDA plans to implement upgrades and conduct space tests using CubeSats constructed with commercially available components as the technology advances. For example, in 2022, Voyager Space, a commercial space firm, successfully operated its Software-Defined Radios (SDRs) to enhance the communication capabilities of MDA's CubeSats.[44]

The U.S. Navy has also led multiple programmes to develop and deploy NanoSats to meet operational requirements. For example, it established the Accelerated Capability for Integration and Testing of NanoSats laboratory, ACTION, in 2016.[45] ACTION's five-year mission was to align payloads developed by various companies or government entities with NanoSats, facilitating their rapid integration, testing, and launch for maritime operations. The compact size enabled testing and prototyping of NanoSats at an appreciably reduced cost compared to conventional military communications or reconnaissance satellites. The testing also allowed ACTION to evaluate the resilience of NanoSats against cyberattacks, with one of the laboratory's objectives being to incorporate cybersecurity from the start of the development process.[46] ACTION was successful in demonstrating multiple NanoSat initiatives. For example, the Integrated Communications Extension Capability (ICE-Cap) was developed to compensate for communication gaps for US forces stationed in the Arctic.[47] Interestingly, ICE-Cap integrated technology from four commercial firms. One company developed the satellite's radio, another supplied cryptographic software, a third constructed the satellite's sizeable retractable antenna, and a fourth offered a smaller antenna. ACTION then consolidated these components into a single package for the US Navy.[48]

Another project was initiated in March 2024, when a Rocket Lab Electron rocket launched a National Reconnaissance Office (NRO) payload, including the Mola CubeSat mission from the U.S. Naval Postgraduate School (NPS). Mola's payloads were directly facilitated by the Mobile CubeSat Command and Control (MC3) network of NPS, an

43 Ibid.

44 Voyager, "Voyager's Space Micro Software Defined Radio Supports Success of Missile Defense Agency's CubeSat Networked Communications Experiment," press release, August 23, 2022, https://voyagertechnologies.com/press-releases/voyagers-space-micro-software-defined-radio-supports-success-of-missile-defense-agencys-cubesat-networked-communications-experiment/.

45 Henry Kenyon, "Inside the Navy's Nanosat Lab," *C4ISRNet*, April 3, 2017, https://www.c4isrnet.com/c2-comms/satellites/2017/04/03/inside-the-navys-nanosat-lab/.

46 Ibid.

47 United States Navy, "Navy to Expand Communications Reach with Nanosatellite Launch," press release, November 19, 2018, https://www.navy.mil/Press-Office/News-Stories/Article/2248853/navy-to-expand-communications-reach-with-nanosatellite-launch/.

48 Peter Yoo, Dmitriy Obukhov and Austin Mroczek, "Integrated Communication Extension Capability (ICE-Cap)," (paper presented at the Small Satellite Conference, August 11, 2015), https://digitalcommons.usu.edu/smallsat/2015/all2015/19/.

initiative sponsored by the DoD that began in 2011.[49] The MC3 project enhances the Five Eyes (FVEY) security partnership, an intelligence alliance comprising Australia, Canada, New Zealand, the United Kingdom, and the US.

Commercial Aerospace Firms and Military NanoSat Development

The rapid success of NanoSats and CubeSats in the commercial sector discussed in the preceding section has prompted major US aerospace firms to explore the military utility of NanoSats. For example, Raytheon developed a unique CubeSat to conduct a proof of concept for a prototype design for delivering on-demand tactical imagery directly to combat personnel in the field.[50] Notably, Raytheon chose to develop the 'SeeMe' CubeSat on its missile manufacturing line due to how compact electronic components, guiding equipment, sensors for star recognition, geolocation, and GPS used for developing precision-guided missiles could be repurposed for developing satellites as well.[51] Moreover, most of the SeeMe satellite was constructed using COTS such as batteries, solar panels, and power-conditioning units, excluding its telescope.

Lockheed Martin has also collaborated with the Space and Engineering Research Centre at the University of Southern California's Information Sciences Institute to develop the La Jument NanoSats (CubeSats).[52] It developed mission payloads for NanoSats, utilising SmartSat software-defined satellite architecture, enabling operators to modify missions in orbit swiftly. The La Jument NanoSats facilitated Artificial Intelligence (AI)/Machine Learning (ML) algorithms in orbit given their sophisticated multicore computing and onboard graphics processing units.[53] AI algorithms can augment NanoSats' capabilities by enhancing onboard processing and communication efficiency and enabling independent control of navigation and propulsion systems.[54]

The abovementioned military NanoSat development projects signal a shift from platform-oriented to capability-oriented space architectures in which responsiveness, interoperability, and redundancy are prioritised over legacy space systems. They successfully enabled low-latency, decentralised, and resilient space communication

---

49 Javier Chagoya, "NPS Latest Small Satellite Launch Advances Comms Experimentation, International Collaboration," *Naval Postgraduate School*, March 27, 2024, https://nps.edu/-/nps-latest-small-satellite-launch-advances-comms-experimentation-international-collaboration.

50 Sally Cole, "Small Sats Aim to Provide On-Demand Tactical-Level Imagery for Warfighters," *Military Embedded Systems*, November 30, 2018, https://militaryembedded.com/comms/satellites/small-on-demand-tactical-level-imagery-warfighters.

51 Ibid.

52 Lockheed Martin, "Lockheed Martin and University of Southern California Build Smart CubeSats, La Jument," press release, August 5, 2020, https://news.lockheedmartin.com/news-releases?item=128962.

53 Fino Mornasco, "D-Orbit Deploys USC's La Jument System Cubesat to Prove-out Space Artificial Intelligence (AI) Technologies," *Military Aerospace*, February 15, 2022, https://www.militaryaerospace.com/commercial-aerospace/article/14234003/usc-la-jument-3u-cubesat.

54 Paneru, Paneru and Poudyal, "Emergence in Space Technologies," 17.

networks that can support military operations in degraded or denied communication environments. Therefore, the US Armed Forces and aerospace firms have demonstrated that NanoSats are not just test demos but can become building blocks in a multi-tier military space architecture, communicating with larger satellites, ground stations, and command structures.

Beyond the US, military-focused start-ups are increasingly venturing into the domain of military NanoSat development. Companies such as DEWC Systems (Australia), ICEYE (Finland), and QinetiQ (UK) are developing electronic warfare payloads, SAR imaging platforms, and defence-commissioned CubeSats directly addressing national security requirements. These partnerships allow for the quick incorporation of dual-use technologies and facilitate streamlined procurement procedures. Notably, they are part of a broader transformation of the dynamics of military-industrial space relations, where military satellite development is increasingly outsourced or co-developed with the private space industry.

Military NanoSat Development beyond the US

In addition to the US, several states are advancing the militarisation of NanoSats. In 2019, the Australian Defence Force (ADF) contracted DEWC Systems for a CubeSat-based space tactical sensor system. This resulted in the development of the Miniaturised Orbital Electronic Warfare Sensor System (MOESS). The constellation consisted of almost 20 CubeSats equipped with specialised sensors to identify radio signals and frequencies for monitoring aerial assets.[55] In 2021, UNSW Canberra Space also collaborated with the ADF to execute NanoSat (CubeSat) missions, aiming to enhance capabilities in space situational awareness (SSA) and facilitate the ADF's development and operation of cost-effective satellite-based ISR capabilities, fostering space self-reliance and resilience to support ADF operations.[56] The initiative also offered educational and training opportunities for the Royal Australian Air Force (RAAF) concerning developing and operating a NanoSat. More recently, an Australian military NanoSat was launched on 18 March 2025 to advance space-based defence systems.[57] The private space sector designed and developed the payload and satellite bus with assistance from the Royal Australian Air Force and Space Command. Lessons

55 Defence Innovation Partnership, "Miniaturised Orbital Electronic Warfare Sensor Systems (MOESS) - Phase 1," Accessed December 20, 2024, https://www.defenceinnovationpartnership.com/research-funding/funded-projects/miniaturised-orbital-electronic-warfare-sensor-systems-moess-phase-1/.

56 University of New South Wales, "UNSW Canberra Space Launches World-Leading CubeSats," news release, March 21, 2021, https://www.unsw.edu.au/news/2021/03/unsw-canberra-space-launches-world-leading-cubesats.

57 Australian Department of Defence, "Defence Nanosatellite Launched into Orbit," media release, March 18, 2025, https://www.defence.gov.au/news-events/releases/2025-03-18/defence-nanosatellite-launched-into-orbit-0.

of this mission are likely to inform 'future defence capability while driving innovation in Australia's domestic space industry through technology transfer.'[58]

The UK has also incorporated NanoSats in its military space strategy, combining defence needs and commercial innovation to improve SDA and operational resilience. It is expediting missions like the Amber-2 CubeSat to demonstrate the dual-use potential of NanoSats, bridging military reconnaissance (e.g., detecting 'dark vessels') with civilian applications like environmental monitoring.[59]

Elsewhere in Europe, the German Aerospace Centre's Responsive Space Cluster Competence Centre (RSC³) is executing the 3U-CubeSat mission OTTER (Optical Traffic Tracking Experiment for Responsive Space). The mission aims to demonstrate the utility of CubeSats in providing a timely solution for maritime security applications by identifying capability gaps related to responsive space over the next three years.[60]

In the Asia-Pacific, South Korea has launched the STEP Cube Lab 2 for EO[61] and SNUGLITE-2 to investigate atmospheric conditions.[62] Though labelled as 'science missions', the payloads also provided data that could be applied to military uses, such as tracking missile plumes or re-entry vehicles, likely from North Korean missile launches. South Korean civil CubeSats such as RANDEV[63] and MIMAN[64] have also produced valuable data for military applications. The South Korean NanoSat development strategy rests on civilian-academic partnerships to enable dual-use capability. Notably, the Korea Advanced Institute of Science and Technology (KAIST), the institution behind the NEONSAT-1, has collaborated with defence agencies on a project that unites scientific and military goals.[65]

India is another emerging player in the development of NanoSat technology. In 2017, the country set a world record by launching 101 CubeSats on a single mission onboard

---

58 Ibid.

59 UK Space Agency, "UK Satellites to Boost Maritime Security on Track for 2025 Launch," *GOV.UK*, press release, October 23, 2024, https://www.gov.uk/government/news/uk-satellites-to-boost-maritime-security-on-track-for-2025-launch.

60 David Freiknecht and Marc Hafemeister, "OTTER: A Small Satellite for Responsive Space" (paper presented at the Small Satellite Conference, Utah State University, Logan, August 3, 2024), https://digitalcommons.usu.edu/smallsat/2024/all2024/5/.

61 Erik Kulu, "STEP Cube Lab-II Spacecraft," *Nanosats Database,* Accessed May 10, 2025, https://www.nanosats.eu/sat/step-2.

62 Erik Kulu, "Snuglite-II Spacecraft," *Nanosats Database*, Accessed May 10, 2025, https://www.nanosats.eu/sat/snuglite-2.

63 Erik Kulu, "RANDEV Spacecraft," *Nanosats Database*, Accessed May 10, 2025, https://www.nanosats.eu/sat/randev.

64 Erik Kulu, "MIMAN Spacecraft," *Nanosats Database*, Accessed May 10, 2025, https://www.nanosats.eu/sat/miman.

65 Wu Jinhua, "Nation's First Nanosatellite NEONSAT-1 Enters Normal Orbit," *KOREA.net,* April 25, 2024, https://www.korea.net/NewsFocus/Sci-Tech/view?articleId=250524.

an indigenous satellite launch vehicle.[66] This demonstrated how India has acquired advanced deployment capabilities. Meanwhile, on the development side, startups like Dhruva Space and Sarathi have spearheaded indigenous development of NanoSats that might be employed for military applications.[67] If India acquires mass development and deployment capabilities, it could significantly enhance its space-based ISR and EO capabilities during peacetime. Moreover, in potential future conflicts, India could rapidly deploy NanoSats to replace destroyed or damaged nodes, thus providing continuous ISR coverage over critical areas such as the borders with Pakistan and China and maritime chokepoints in the Indian Ocean. NanoSat swarms could also enhance India's offensive space capabilities, such as proliferated electronic warfare operations (jamming or spoofing adversary communications).

Proliferation of Military NanoSats and Implications for Space Security

The military utility of commercial EO capability has been demonstrated on the battlefield in Ukraine. Commercial satellite imagery providers negated Russia's military advantage of operating state-owned space-based ISR capability, which greatly assisted Ukraine in tracking Russian troop movements and assessing damage in near-real time.[68] Consequently, this underscores how advances in NanoSat technologies could potentially democratise space power by enabling new space actors to leverage commercial or indigenous NanoSat-based ISR and EO assets to counter conventional asymmetries in space capabilities with adversaries.

However, the global diffusion of military NanoSats could destabilise the contemporary space security and deterrence framework. With India and other rising powers able to access cheap means of launching and deploying NanoSats, the technology can be anticipated to be universalised, lowering the cost of entry and allowing greater influence to be exercised by middle powers and non-state actors (NSAs) in Low Earth Orbit (LEO). Such technologies are likely to disrupt business-as-usual deterrence norms. For instance, affordability and modularity of NanoSats would allow states to launch large constellations at ease, making targeting strategy problematic: swarms of CubeSats can be easily replaced by lost assets, making kinetic ASAT weapons ineffective as deterrents.

---

66 Andra Gentea, "ISIS Gets 101 CubeSats Launched during Recordbreaking PSLV Launch," *ISISPACE*, February 15, 2017, https://www.isispace.nl/news/dutch-nanosatellite-company-gets-101-cubesats-launched-recordbreaking-pslv-launch/.

67 P. B. Jayakumar, "How India's Aerospace and Defence Startups Are Waging a New War for Dominance," *Fortune India*, April 1, 2025, https://www.fortuneindia.com/long-reads/how-indias-aerospace-and-defence-startups-are-waging-a-new-war-for-dominance/121087.

68 Inesa Kostenko and Andrii Manzhula, "From Space to the Battlefield: Ethical and Legal Aspects of the Use of Satellite Technologies in the Russian-Ukrainian War," *Philosophy and Cosmology* 34 (1 January 2025): 4–43, https://doi.org/10.29202/phil-cosm/34/1.

Additionally, the dual-use nature of NanoSats, presented as civilian but easily convertible to military use in ISR, electronic warfare, or even directed-energy missions, blurs the line of conflict escalation. Adversaries may fail to distinguish benign from hostile NanoSat deployments, which may increase the risk of miscalculations, particularly in a crisis when ambiguous action (such as satellite jamming or close-quarters operation) could be misinterpreted as aggressive intent. Mass deployment of NanoSats would thus complicate arms control and escalation management options. The deployment of NanoSat constellations by states worldwide would also render attribution very difficult, with commercially launched NanoSats potentially hiding state-sponsored military payloads for plausible deniability. With states allowed to offload militarily critical capabilities to the commercial sector without being accountable, this could spur an arms race in military NanoSat development as states build their constellations to counter threats, creating increasing orbital traffic and the risk of debris. Most fundamentally, the absence of mutually accepted NanoSat behaviour norms could render LEO a 'Wild West' for military NanoSat deployments where competition, not cooperation, would reign. Classical deterrence models of mutual vulnerability and red lines would be irrelevant, requiring new models that value transparency, debris management, and swarm operations rules of engagement. Hence, the NanoSat revolution can turn space into a more contested frontier without multilateral cooperation to balance global technological diffusion with international stability.

Conclusion

Military integration and technological innovation intersect in the development of Military NanoSats. The U.S. Space Force's Competitive Endurance doctrinal construct provides a framework to analyse the potential military applications of NanoSats in terrestrial and military space missions. NanoSats have the potential to transform military space architecture by overcoming the vulnerabilities of centralised legacy systems, ushering in an era of decentralised, responsive, and resilient space networks that can be replenished rapidly and cost-effectively. Yet, the trade-off between space resilience and escalation is at the core of this revolution. Whereas large constellations of NanoSats can provide redundancy against adversary attacks, reverse the offence-defence balance, and provide tactical responsiveness, they can also destabilise traditional deterrence models.

Public-private ventures and the commercialisation of NanoSats also have the risk of further blurring responsibility. For instance, as commercial players such as Planet Labs and SPIRE have commodified high-fidelity space-based EO, their NanoSats have lowered the bar for backdoor militarisation and NanoSat weaponisation. The dual-use payloads on NanoSats might make it harder to distinguish and attribute intent because they might carry out offensive and defensive space military missions at the same time.

Therefore, while commercialised military NanoSat constellations might improve battlefield transparency, the potential for their militarisation might normalise grey-zone aggression in space.

Although there are several technological challenges in military NanoSat development, from cost-performance and cost-effectiveness trade-offs with larger satellites to reliance on COTS components, shorter lifecycle, and susceptibility to radiation at higher orbits, there are fundamental limitations in NanoSat architectures. Moreover, while cost-effectiveness enables rapid deployment and replacement, component and protocol standardisation can compromise the cybersecurity of military NanoSats. This compromise is a central paradox to military NanoSat development. The characteristics that enable NanoSats to be feasible for inclusion in military command and control networks can also make them the most vulnerable nodes in contested space, which the adversary can exploit. Tackling such threats would need to include both technical countermeasures and reconsidering space system resilience as a deterrent in and of itself.

US defence agencies, all branches of the military, and aerospace firms spearheaded the militarisation of NanoSats. Other examples, from Australia, the UK, South Korea and India, have illustrated a global trend under which the NanoSat revolution can disrupt the global space-based EO market by democratising middle power access. Combating the destabilising threat of military NanoSat proliferation will require reviving traditional space governance regimes to foster more transparency on dual- use NanoSat launches. The NanoSat revolution thus poses a concerning question regarding the future of space security. Will swarms of indistinguishable NanoSats fuel crises through obfuscation and proxy confrontation, making space a theatre of constant contestation?

The answer depends on how states balance competitive requirements with establishing trust and transparency in military space operations. The success of all such efforts would rely on reconciling various national interests and acting in the greater good, ensuring space sustainability. A transparency programme or crisis communication forum supported by the United Nations would prevent miscalculations based on the dual-capability nature of military Nanosats, but only if opposing space actors sacrifice tactical military advantage for global stability. They will decide whether the proliferated deployments of military NanoSats would cement space as the final fragmented frontier.

ABOUT THE AUTHOR

Mustafa Bilal *is a Research Assistant at the Centre for Aerospace & Security Studies (CASS), Islamabad. He has done his BS in International Relations from the National Defence University (NDU), Islamabad. His research interests include technopolitics, astropolitics, military aviation and warfare.*

ABOUT CASS

The Centre for Aerospace & Security Studies (CASS), Islamabad, was established in 2018 to engage with policymakers and inform the public on issues related to aerospace and security from an independent, non-partisan and future-centric analytical lens. The Centre produces information through evidence-based research to exert national, regional and global impact on issues of airpower, emerging technologies and security.

VISION

To serve as a thought leader in the aerospace and security domains globally, providing thinkers and policymakers with independent, comprehensive and multifaceted insight on aerospace and security issues.

MISSION

To provide independent insight and analysis on aerospace and international security issues, of both an immediate and long-term concern; and to inform the discourse of policymakers, academics, and practitioners through a diverse range of detailed research outputs disseminated through both direct and indirect engagement on a regular basis.

CORE AREAS OF RESEARCH

Aerospace

Emerging Technologies

Security

Strategic Foresight

CASS www.casstt.com
CENTRE FOR AEROSPACE & SECURITY STUDIES, ISLAMABAD
Independence | Analytical Rigour | Foresight

Old Airport Road, Islamabad, Pakistan
cass.thinkers@casstt.com
Centre for Aerospace & Security Studies
+92 51 5405011
www.casstt.com
cassthinkers
@CassThinkers
cass.thinkers