Satellite Miniaturisation and the Democratisation of Space

Opportunities and Security Risks for Pakistan

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Satellite Miniaturisation and the Democratisation of Space: Opportunities and Security Risks for Pakistan

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Abstract

Where previously outer space was once accessible only to a handful of states, satellite miniaturisation has opened it to new actors, including developing countries, universities, and private companies. Small satellites, built on miniaturisation technology, have shorter development timelines and lower costs than traditional, large satellites. This paper examines how satellite miniaturisation intersects with the broader dynamics of NewSpace and the democratisation of space, highlighting both opportunities and risks for Pakistan. While small satellites support diverse applications in communication, Earth observation, and scientific research, they also raise challenges related to orbital debris, dual-use functions, and dependency on foreign suppliers. These trends are especially relevant to Pakistan as its space ecosystem enters a critical phase marked by clear goals set under the National Space Policy, closer cooperation with China, and research and innovation under the National Aerospace Science and Technology Park (NASTP). Through an exploratory approach, this study evaluates how small satellites can shape Pakistan's trajectory, and proposes policy options to balance innovation, sovereignty, and security in the evolving global space environment.

Keywords: Satellite Miniaturisation, Smallsat Constellations, Democratisation of Space, New Space, Pakistan, China, SUPARCO, NASTP, Space Policy, Space Weaponisation

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Introduction

Outer space, once accessible only to a handful of states, is now increasingly democratised. Satellite miniaturisation is driving this transformation by lowering barriers to entry: developing countries, universities and private companies can build smaller, cheaper satellites such as microsats and nanosats, as opposed to large and costly ones. For Pakistan, this trend opens new opportunities for space exploration, scientific research, and civilian applications, while also introducing security risks in the strategic domain. While Pakistan continues to view outer space as a global common and a peaceful domain, major spacefaring nations approach it as an arena of great power competition, with clear trends towards space weaponissation. This evolving environment complicates Pakistan's efforts in the space sector, as it must balance peaceful aspirations with the security challenges of a militarised, and increasingly weaponised, outer space.

A presence in space affords several advantages. It is most often portrayed as a symbol of national pride. Russia’s first human spaceflight and satellite in space, US’ Apollo missions, and China’s Chang’e lunar program, all carry undertones of national prestige. Beyond symbolism, however, space activities carry practical significance. Satellites perform critical functions, shaping the economy, health, education, communication, navigation, and disaster management on Earth, and helping protect critical land infrastructures.[2] Space activities also shape national security, as seen by applications such as missile warning and command, control, communication, and information (C3I). Hence, access to and use of space is a vital national interest.

Historically, only a few states have led the race to the stars, owing in large part to the vast technological infrastructure, advanced human resource, launch vehicles, and large financial capital that space missions demand.[3] Large satellites, for instance, can cost hundreds of millions of dollars to design, build, launch, and maintain. Even established spacefaring nations have historically relied on partnerships to sustain their space programs. As a result, space competition and exploration have traditionally remained confined to a small number of states.

Several trends are reshaping this dynamic, however. The number of active satellites in 2005 was 217 (primarily operated by the US, Russia, China, and Europe) as opposed to 5,465 in 2023 (operated by more than 74 countries).[4] The rise of private actors, commercialisation, and new technologies have lowered barriers to entry to space. Among these technological breakthroughs,

[2] The Space Economy in Figures: Responding to Global Challenges. OECD, https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/12/the-space-economy-in-figures_4c52ae39/fa5494aa-en.pdf.

[3] Deganit Paikowsky, The Power of the Space Club (Cambridge: Cambridge University Press, 2017).

[4] Union of Concerned Scientists, “Satellite Database,” 2023, https://www.ucsusa.org/.

satellite miniaturisation stands out as a transformative development, offering smaller, cheaper, and more accessible alternatives to traditional satellites.

Satellite miniaturisation and space democratisation are not new phenomena; they have been discussed for decades. The first satellite launched into space by the Soviet Union in 1957, Sputnik-I, was a smallsat weighing 83kg.[5] Shortly after, 1961 marked the first smallsat built by amateur satellite operators rather than a state: OSCAR-I. Although not based on modern satellite miniaturisation technology, it foreshadowed the democratisation of space and demonstrated that satellites did not have to be large or complex, and entities other than states could build them.[6] Satellite miniaturisation technology took off later in the 1980s and 1990s, with the development of microsatellites and CubeSats. Small-scale projects have now speedily exploded into mega-constellations such as Starlink, OneWeb, Planet Labs, and Iridium NEXT. This reflects a new and emerging phase for miniaturised satellites marked by an exponential increase in small satellite launches (97 percent of all spacecraft launched in 2024) and a surge in private-sector involvement.[7]

At the same time, Pakistan is making steady advances in its space program. Recent satellite launches, a deepening partnership with China, and the articulation of clear priorities in the National Space Policy reflect a growing commitment to gaining greater autonomy in space while building infrastructure to foster innovation. The establishment of the National Aerospace Science and Technology Park (NASTP) stands out as a flagship initiative, providing a hub for research, development, and incubation. Coupled with the creation of a regulatory framework for commercial space activities, these developments are shaping an environment increasingly conducive for Pakistan to benefit from emerging technologies such as satellite miniaturisation. Through an exploratory approach, this study evaluates how small satellites can shape Pakistan's trajectory, and proposes policy options to balance innovation, sovereignty, and security in the evolving global space environment.

Satellite Miniaturisation

Satellite miniaturisation allows "sophisticated payloads and subsystems [to] be integrated into smaller form factors."[8] This has enabled the rise of small satellites (smallsats), which are

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[5] Kathy Pretz, "How Small Satellites Are Providing Low-Cost Access to Space," *IEEE Spectrum*, November 9, 2018, https://spectrum.ieee.org/how-small-satellites-are-providing-lowcost-access-to-space.

[6] Smithsonian National Air and Space Museum, "Communications Satellite OSCAR I," https://airandspace.si.edu/collection-objects/communications-satellite-oscar-i/nasm_A19640011000.

[7] Bernardo Schneiderman, "Executive Roundtable on the Small and Medium Satellite Launch Market," March 3, 2025, *Satellite Markets*, https://www.satellitemarkets.com/people/executive-roundtable-small-and-medium-satellite-launch-market.

[8] Iqtiar Siddique, "Small Satellites: Revolutionising Space Exploration and Earth Observation," *European Journal of Advances in Engineering and Technology* 11, no. 3 (2024): 118–124, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4908526.

generally defined as satellites weighing under 500 kilograms (although they can also sometimes be defined as a separate category of 500-1200kg as large satellites are >1200kg). Within the smallsat category, minisatellites typically range from 100–500 kg, microsatellites from 10–100 kg, and nanosatellites from 1–10 kg, with even smaller categories such as picosatellites (<1 kg) also in use.[9] Smallsats cost significantly less to build and launch than traditional large satellites and have much shorter development timelines. Despite their compact size, they are capable of supporting diverse functions, including navigation, Earth imaging, broadcasting, and communications.

The trade-off, however, is that smallsats have much shorter mission lifespans and cannot completely replace the capabilities of larger satellites that have the highest payload capacity and support critical functions such as geostationary communications, global navigation, and precise measurements. High-power and long-term missions like those of Direct Broadcasting Satellites (DBS) in Geosynchronous Orbit (GEO), require powerful transmitters, large solar panels and antennas, and advanced electronics.[10] Nevertheless, constellations of micro- and nanosatellites in Low Earth Orbit (LEO) offer clear advantages: GEO slots (allocated by the International Telecommunication Union) are limited and increasingly scarce, and GEO satellites have issues of coverage at very high altitudes. These factors, combined with a growing demand for faster internet and lower-cost launches, have led the shift from reliance on large GEO satellites to constellations of small LEO satellites.

Short deployment times mean miniaturised satellites enable rapid access to space. The typical deployment time for a large satellite is 5-10 years, with a mission life 10-20 years. A large satellite may cost US$ 100-500M. In contrast, CubeSats – standardised nanosatellites with a 10x10x10 form factor – weigh 1-10kg, and have a wide range of applications, from research to Earth observation. Nanosats take 1-3 yrs of deployment time, and cost US$ 0.1-10M.[11]

Several critical technological advancements in modern aerospace engineering, including miniaturisation, propulsion and communication systems, and onboard electronics, have enabled the integration of more functions within compact satellites while retaining functionality.[12] In particular, advancements in very-large-scale-integration (VLSI) technology have made it possible

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[9] Lucien Rapp, Victor Dos Santos Paulino, and Adriana Martin, "Satellite Miniaturization: Are New Entrants About to Threaten Existing Space Industry?" *SIRIUS*, 2016, https://publications.ut-capitole.fr/id/eprint/23563/1/Rapp_23563.pdf.

[10] Fuat Ince, "Nano and Micro Satellites as the Pillar of the 'New Space' Paradigm," Journal of Aeronautics and Space Technologies 13, no. 2 (July 2020): 235-250.

[11] Philippe Rapp, Small Satellites: A Revolution in Space? (Université Toulouse 1 Capitole, 2016), https://publications.ut-capitole.fr/id/eprint/23563/1/Rapp_23563.pdf; Shaharyar Ahmed Khan Tareen and Umair Nadeem, "Smaller Satellites for Pakistan – Applications, Cost Analysis, and Design Philosophy," Journal of Space Technology 6, no. 11 (July 2016), https://www.ist.edu.pk/downloads/jst/previous-issues/july-2016/final-smaller-satellites-for-pakistan-applications-cost-analysis-design-philosophy-jst.pdf.

[12] Siddique, "Small Satellites."

to produce small sensors, processors and other electronic components, making satellites smaller, lighter, and more cost-effective.[13]

Technological advancements, more affordable launch costs, and a growing demand for constant connectivity have all contributed to fueling the small satellite boom.[14] While large satellites still form the backbone of space infrastructure, smallsats can play a strong complementary role and even make outer space more accessible for new entrants.

Technological Challenges

Satellite miniaturisation must overcome several technological challenges to be effective.[15] Thermal management is imperative, as some satellite components are temperature sensitive, while others dissipate significant heat when in orbit, making stable operating conditions difficult to maintain within a compact design. A reliable power supply is required for power optimization, as are compact communication subsystems. Structural integrity presents another challenge. Smallsats are made of lightweight and durable materials but they must be able to withstand the stresses of launch and a harsh space environment. Commercial off-the-shelf (COTS) components can lower costs but it is challenging to ensure their reliability and durability.[16] Lastly, satellite electronics must be able to withstand space radiation through radiation hardening. These challenges highlight that miniaturised satellites require continued innovation in design and materials to fully realise their potential.

Applications and Opportunities

The shift from sole reliance on large, costly satellites to miniaturised ones has opened new opportunities in space activities. Smallsat constellations can be assembled and deployed relatively quickly because of their modular architecture and standardised components. This enhances flexibility, reduces costs, and ensures that multiple smallsats can work in tandem, providing wider coverage and greater redundancy.[17]

Miniaturised satellites can perform certain tasks traditionally reserved for large satellites well. These include high-resolution imaging of the Earth's surface, aiding scientific research and

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[13] P. Fortescue, G. Swinerd, and J. S. Book, "Small Satellite Engineering and Applications," in *Spacecraft Systems Engineering*, 4th ed. (Chichester, U.K.: Wiley, 2011), 575–605.

[14] Neerja Shah, "The Future of Satellite Miniaturisation in Manufacturing," Pixxel, June 14, 2024, https://www.pixxel.space/knowledge-hub/the-future-of-satellite-miniaturisation-in-manufacturing.

[15] Cadence PCB Solutions, "Miniaturisation of Satellite Technology Advancements," September 11, 2024, https://resources.pcb.cadence.com/blog/2024-miniaturization-of-satellite-technology-advancements.

[16] Cadence PCB Solutions, "Miniaturisation of Satellite Technology Advancements."

[17] Siddique, "Small Satellites."

disaster response through real-time data collection, and monitoring environmental changes.[18] Smallsats can carry out autonomous operations and there are prospects for Artificial Intelligence (AI)-driven autonomy.[19] AI can help reduce the risk of collisions during Rendezvous and Proximity Operations (RPO) in increasingly crowded orbits.

CubeSats have been pivotal in the growth of smallsats, offering cost-effective solutions for Earth observation, environmental monitoring, and technological testing.[20] For example, NASA's CubeSat-compatible Compact Thermal Imager (CTI) has been instrumental in monitoring wildfires and agriculture. Other innovative designs, such as disk-shaped compact satellites, allow smallsats to maintain LEO altitudes as low as 200 km without the need for propulsion, further reducing energy needs. Micro-electro-mechanical systems (MEMS) technology compresses the size of mechanical circuit functions, while precision lithography and high-quality substrate materials allow satellites to meet demanding thermal and electromagnetic standards.[21] Overall, smallsats can fulfill up to 80 percent of mission needs at roughly 20 percent of the cost of large satellites, making them indispensable to the modern space ecosystem.[22]

The Democratisation of Space

The "democratisation of space" refers to the lowering of barriers to entry in outer space. A wider range of actors, including developing states, universities, and private companies, can now access space owing to several factors such as reduced costs, faster development timelines, and the availability of off-the-shelf components. Previously, space was the preserve of a handful of technologically advanced states. This shift coincides with the rise of NewSpace and a broader trend of privatisation and commercialisation of outer space. One author has aptly described NewSpace as a trend where:

> Space business and space technologies are taking a new turn: from big to small, from primarily government to extensively private sector and from a few players to profusely many… it can be characterized by new startups with venture capital backing entering the field or in fact leading the field in new innovative applications, universities and countries with no previous space experience joining the bandwagon, lean design and development techniques benefitting from the newly

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[18] Klaus Schilling, "Perspectives for Miniaturized, Distributed, Networked Cooperating Systems for Space Exploration," *Robotics and Autonomous Systems 90* (April 2017): 118-124, https://www.sciencedirect.com/science/article/abs/pii/S0921889016305863.

[19] Siddique, "Small Satellites."

[20] Cadence PCB Solutions, "Miniaturisation of Satellite Technology Advancements."

[21] Kevin Walker, "Miniaturisation — Driving the Next Generation of Space Technology," *Benchmark*, June 11, 2024, https://www.bench.com/setting-the-benchmark/miniaturization-is-accelerating-modern-aerospace-technology.

[22] R. Sandau, H. P. Roser, and A. Valenzuela, "PROBA Spacecraft Family: Small Mission Solutions for Emerging Applications," in *Small Satellites for Earth Observation: Selected Contributions*, ed. R. Sandau, H. P. Roser, and A. Valenzuela (Dordrecht: Springer, 2008), 67–76.

> available COTS parts and subsystems, mass production of satellites, constellations of hundreds or thousands of small satellites serving old and new emerging niche needs, small launchers available for reaching orbit at low cost and rather short notice, capability to launch a rocket several times a month, and more exotic applications such as the coming space tourism and asteroid mining.[23]

In 2023, global commercial space launch activity increased by 50 percent from 2022, as 90 percent (2,507) of all satellites deployed that year were commercial.[24] 2024 saw a 20 percent increase in successful launches from 2030, a portion of these were "representative of the increasing number of governmental, civil or commercial space activities conducted by new and established space actors."[25]

As seen from the above trends, democratisation also reflects a shift from the leading role of governments in space to that of commercial interests, where revenue, sustainability, and the demand for space services come into focus.[26]

Despite the optimism, the democratisation of space is not absolute. Legal, sustainability, and sovereignty issues persist. Article VI of the Outer Space Treaty (1967) holds sovereign states responsible for the activities of private actors.[27] Read together with the Liability Convention (1972), this creates ambiguity about who takes financial liability when, for example, a company incorporated in one country launches a satellite from another. The Registration Convention (1976) adds another layer of ambiguity: which state should register a space object if it is incorporated in one state but launched from another? The scale of this issue could be massive. In 2024, there were 18,123 registered objects in orbit.[28] Another issue is that some states have begun incentivising private companies with property rights over space resources. For example, the US Space Resource Exploration and Utilisation Act does so. This raises questions about

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[23] Ince, "Nano and Micro Satellites as the Pillar of the "New Space" Paradigm."

[24] Space Foundation, "The Space Report 2023 Q4 Shows Record Number of Launches for Third Year in a Row, Technological Firsts, and Heightened Focus on Policy," January 23, 2024, https://www.spacefoundation.org/2024/01/23/the-space-report-2023-q4/.

[25] United Nations Office for Outer Space Affairs, *From Strategy to Action: Annual Report 2024* (Vienna: UNOOSA, 2025), https://www.unoosa.org/documents/pdf/annualreport/UNOOSA_Annual_Report_2024.pdf.

[26] William Welser, "The Democratisation of Space," RAND, March 28, 2016, https://www.rand.org/pubs/commentary/2016/03/the-democratization-of-space.html.

[27] United Nations Office for Outer Space Affairs, *United Nations Treaties and Principles on Outer Space* (New York: UNOOSA, 2006), https://www.unoosa.org/pdf/publications/STSPACE11E.pdf.

[28] UNOOSA, *From Strategy to Action: Annual Report 2024*.

legitimacy, as Article II of the Outer Space Treaty repudiates national appropriation of outer space.[29]

Furthermore, while more actors can access space, the inequalities among space players remain.[30] Developing countries still face financial, technical, and infrastructural barriers, limiting their ability to benefit from democratisation on equal footing. The situation is further complicated by a push toward the weaponisation of outer space, led by major spacefaring nations. Constellations of miniaturised satellites can create enabling conditions for space-based warfare due to their dual-use nature. While they support global internet and Earth observation, the same networks can enable precision targeting, Intelligence Surveillance and Reconnaissance (ISR), and resilient communications in wartime. Their rapid deployment and swarming potential introduce new military applications, while their sheer numbers increase congestion, collision risks, and the long-term challenge of managing space debris, hence raising sustainability concerns. With the increase of actors and activities in space, there need to be corresponding international regulatory frameworks, such as to ensure that the orbital environment is free of debris,[31] and arms control initiatives that prevent an arms race in outer space.[32]

The Case of Pakistan

Pakistan's approach to outer space is laid out in its National Space Policy (2024). It views space as a global common and peaceful domain, and aims to leverage "scientific technologies for improving socio-economic development indicators."[33] State priorities include achieving self-reliance by increasing private sector involvement and promoting commercial activities in space, fostering international collaborations, and protecting national interest and sovereignty. Pakistan is the only nuclear state that has ratified all five of the core multilateral treaties on the peaceful uses of outer space, including the Outer Space Treaty, Moon Agreement, and Liability Convention.

According to John J. Klein, a state's space activities can be divided into three major sectors: civil, commercial, and national security.[34] Civil space activities are geared toward space exploration

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[29] Eleonora Bassi and Ugo Pagallo, *The Democratisation of Outer Space: On Law, Ethics, and Technology*, SSRN, March 2024, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4790211.

[30] Aganaba et al., "'Democratising Space' Is More than Just Adding New Players."

[31] Danielle Wood, *New Models for Democratic Engagement in the Application of Space Technology for Sustainable Development*, Session: "Democratic Discontent, Technocratic Agendas, and Emerging Alternatives," https://projects.iq.harvard.edu/files/spc/files/wood.pdf.

[32] Arooj Fatima, "Call for Arms Control in the Final Frontier," BTTN, August 11, 2024, https://bttn.org.pk/call-for-arms-control-in-the-final-frontier/.

[33] Space and Upper Atmosphere Research Commission (SUPARCO), *National Space Policy*, January 2024, https://suparco.gov.pk/wp-content/uploads/2024/01/National-Space-Policy.pdf.

[34] John J. Klein, *Space Warfare: Strategy, Principles and Policy*, 2nd ed., *Space Power and Politics* (New York: Routledge, 2019).

and improving human understanding of outer space, such as through human spaceflight missions and uncrewed scientific missions. Commercial space activities involve private companies providing services with the intent of making a profit. These include satellite manufacture and launches, satellite communication (SATCOM), and remote sensing. The national security sector includes military and intelligence space activities for warfighting and strategic decision making. While this framework offers a useful conceptual definition, it is difficult to neatly demarcate the three sectors in the case of Pakistan, where the space program is in its developmental stage and efforts to create a robust private sector are still underway.

Recent Developments in the Space Sector

The Space and Upper Atmosphere Research Commission (SUPARCO), established in 1981, has spearheaded Pakistan's space journey through space science, exploration initiatives, and satellite launches. Over the years, SUPARCO has led initiatives in atmospheric studies, remote sensing, and satellite applications for agriculture, disaster management, and climate monitoring. Through outreach initiatives such as the Space Education Program Space Education and Awareness Drive (SEAD), SUPARCO engages students, professionals, and the wider public. Events like the World Space Week fall under SEAD and promote space education on a wider scale.[35] Several universities offer programs in space science and aerospace engineering, such as the Institute of Space Technology (IST), National University of Sciences and Technology (NUST), Air University (AU), and the University of Engineering and Technology (UET). This is helping shape an environment conducive to future space exploration and building a skilled human resource base.

Recent years have also seen a notable progress in satellite launches. Pakistan launched PRSS-2 in July 2025, a remote sensing satellite jointly developed with China to enhance Earth observation, including projects linked to the China–Pakistan Economic Corridor (CPEC). In January 2025, the PRSC-EO1, an indigenously developed electro-optical Earth observation satellite, was launched from China. Earlier, in May 2024, the PakSat-MM1R communications satellite was placed into orbit, developed in collaboration with China to deliver high-speed internet and broadcast services. This illustrates Pakistan's gradual move toward diversifying applications, from Earth observation to telecommunications. The Space Vision 2047 plans to establish Pakistan as a technologically advanced and self-reliant space nation, and deploy multiple communication, remote sensing and navigation satellites.

Pakistan has also integrated itself into regional networks of space collaboration by being an active member of the Asia-Pacific Regional Space Agency Forum (APRSAF) and the Asia-Pacific Space Cooperation Organization (APSCO). The country's space trajectory is marked by a thriving partnership with China. The CMSE–SUPARCO Cooperative Agreement is set to train and send a Pakistani astronaut to space by 2026, marking its debut in human spaceflight. Moreover, Pakistan joined China's International Lunar Research Station (ILRS) in 2023, opening avenues for future

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[35] SUPARCO, "Short Training Courses," https://suparco.gov.pk/education-and-training/short-trg-courses/#:~:text=SUPARCO%20conducts%20various%20short%20training,%2Dart%20SRS/GIS%20technologies.

participation in lunar science. This includes the Chang'e lunar mission in 2028, which will carry a Pakistani lunar rover.[36] Pakistan-China space cooperation is expected to serve as a "launchpad for long-term self-reliance in space."[37] At the 2025 BeiDou Summit, Pakistan acknowledged that the BeiDou Navigation Satellite System is playing a "pivotal role" in driving Pakistan's economic development.[38]

Commercially, PakSat operates PakSat-1R and PakSat-MM1, offering commercial capacity leases and managed services. It is a state-owned company – a subsidiary of SUPARCO. Its customer base spans South Asia, Central Asia, the Middle East, Africa, and parts of Europe, serving television broadcasters, cellular operators, internet providers, and government agencies. Within Pakistan its internet services mainly target the corporate sector, armed forces, and telecom providers for remote regions.[39] Overall, PakSat has a potential global reach of over 4 billion population in more than 60 countries.[40]

Historically, SUPARCO has managed satellite programs in Pakistan. To enable private sector involvement and ensure state regulation, the Pakistan Space Activities Regulatory Board (PSARB) was formed in 2024. It serves to regulate, authorise, supervise, and monitor space-related activities under the Space Activities Rules. Currently, private space companies are invited to register to deploy LEO communication satellites. OneWeb, Shanghai Spacecom Satellite Technology (SSST), and Sateliot (a satellite constellation) have shown interest in operating in Pakistan. Prior registration with the Securities and Exchange Commission of Pakistan (SECP) is required to register with the PSARB. Starlink has registered with the SECP and is awaiting approval by the PSARB.[41] Once registered, satellite internet providers will also have to obtain licenses from the Pakistan Telecommunications Authority (PTA).

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[36] Andrew Jones, "Pakistan Rover to Fly on China's Chang'e=8 Lunar South Pole Mission," *SpaceNews*, https://spacenews.com/pakistan-rover-to-fly-on-chinas-change-8-lunar-south-pole-mission/.

[37] Arooj Fatima Kazmi, "Pak-China Space Cooperation: Why It Fuels, Not Hinders, Pakistan's Space Autonomy," *Strategic Vision Institute*, July 24, 2025, https://thesvi.org/pak-china-space-cooperation-why-it-fuels-not-hinders-pakistans-space-autonomy/.

[38] "Ahsan Highlights Beidou's Revolutionary Role in Pakistan's Economic Growth," *Associated Press of Pakistan*, https://www.app.com.pk/foreign-correspondent/ahsan-highlights-beidous-revolutionary-role-in-pakistans-economic-growth/.

[39] Kalbe Ali, "Govt Looks to Invite Several Satellite-Based Internet Firms," *Dawn,* https://www.dawn.com/news/1923666#:~:text=India%2DPakistan%20and%20Iran%2DIsrael%20conflicts.%20Following%20the%20expiration,no%2Dobjection%20certificate%20(NOC)%20for%20Starlink%20in%20March.

[40] "PAKSAT Satellites," *PAKSAT*, https://paksat.com.pk/.

[41] "Information on Space Sector Regulations in Pakistan," Pakistan Space Activities Regulatory Board, https://psarb.gov.pk/media-center/public-notices/2025/information-on-space-sector-regulations-in-pakistan-1737977700 pakistan space activities regulatory board.

The domestic private sector is also beginning to take root, although at an early stage. The Rocket and Satellite Company Limited, a startup registered with the SECP, is exploring low-cost solutions in satellite manufacturing, launch systems, space debris mitigation, and in-orbit servicing. Though still nascent, such ventures hint at the gradual emergence of a local commercial space ecosystem.[42]

Pakistan is making a strategic shift toward innovation in space and aerospace through the National Aerospace Science and Technology Park (NASTP), a dynamic ecosystem where industry, academia, and government collaborate to drive technological advancement.[43] Within this ecosystem, the National Incubation Center for Aerospace Technologies (NICAT) has been set up by a consortium including Ignite, Netsol, AU, PAC Kamra, and NASTP itself.[44]

Scope of Smallsats for Pakistan

Long before satellite miniaturisation became widespread, Pakistan began its journey into space with small experimental satellites in the 1990s. Badr-I (52kg) and Badr-II (68.5kg), though not based on miniaturisation technology, reflected a low-cost approach to entry in space.[45] The aim was to test and validate low-cost space hardware and techniques. Badr-I helped in the feasibility study for an earth observation satellite and opened new avenues for future communication missions, laying a critical foundation for Pakistan's space program.

Pakistan has launched missions that demonstrate the promise of small satellites. PAUSAT-1, a CubeSat launched in January 2025, exemplifies the potential of university-led initiatives to contribute to national capabilities. Similarly, ICUBE-Qamar (ICUBE-Q), Pakistan's first deep-space lunar orbiter launched in May 2024, was jointly developed by the IST, SUPARCO, and China's Shanghai Jiao Tong University. It successfully entered moon orbit and transmitted data back.[46] Other important initiatives include PakTES-1A (300 kg), an experimental Earth observation

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[42] Saadeqa Khan, "Pakistan Venture into the Private Space Industry," *Scientia,* September 23, 2020, https://scientiamag.org/pakistan-ventures-into-the-private-space-industry/#:~:text=Sami%20Ullah:%20I%20believe%20that,on%20the%20moon%20and%20beyond.

[43] Ezba Walayat Khan, "Launching New Frontiers: Why Pakistan Needs Public-Private Partnerships In Space Exploration," *The Friday Times,* May 20, 2025, https://thefridaytimes.com/20-May-2025/launching-new-frontiers-why-pakistan-needs-public-private-partnerships-in-space-exploration.

[44] "Ignite Signs Agreement for 8th Incubation Center In Aerospace Technologies," *The Nation,* November 13, 2022, https://www.nation.com.pk/13-Nov-2022/ignite-signs-agreement-for-8th-incubation-center-in-aerospace-technologies.

[45] Shaharyar Ahmed Khan Tareen and Umair Nadeem, "Smaller Satellites for Pakistan – Applications, Cost Analysis, and Design Philosophy," *Journal of Space Technology* 6, no. 11 (July 2016), https://www.ist.edu.pk/downloads/jst/previous-issues/july-2016/final-smaller-satellites-for-pakistan-applications-cost-analysis-design-philosophy-jst.pdf.

[46] Institute of Space Technology (IST), "ICUBE-Q Mission Successful – Initial Images Received," https://www.ist.edu.pk/news-2024-icube-q.

satellite, and the PRSC-EOS programme, under which EO-1 was launched in January 2025. These projects reflect a trajectory toward harnessing smallsats for both scientific and applied purposes.

Smallsats offer multiple advantages for Pakistan's civil and commercial space program. Their cost-effectiveness, compact design, and technological versatility make them particularly suitable for applications in Earth observation, environmental monitoring, and telecommunications. The "Space4SDGs" framework by the United Nations Office for Outer Space Affairs (UNOOSA) stresses that Earth Observation (EO) and Global Navigation Satellite Systems (GNSS) are crucial for achieving the UN's 2030 Agenda for Sustainable Development.[47] The Sustainable Development Goals (SDGs) fall under this agenda and Pakistan is committed to achieving them.[48] As mentioned before, small satellites are especially well suited to climate change monitoring, disaster management, tracking crop health, or supporting urban planning, which can contribute to several SDGs, particularly 2 (Zero Hunger), 11 (Sustainable Cities and Communities), and 13 (Climate Action). In fact, Pakistan's EO-1 is precisely intended for "precision farming by monitoring crops, assessing irrigation needs, predicting yields, and supporting food security initiatives in the agriculture sector."[49] Flooding, agricultural productivity, and urbanization pose significant challenges and smallsats could provide timely data.

Beyond direct applications, smallsats complement large satellite systems by offering flexibility and opportunities for experimentation. They can support rapid technology demonstrations, enable testing of indigenous components in orbit, and serve as platforms for scientific research.[50] Designs proven in smallsat missions can later be scaled up for larger spacecraft. Their shorter development cycles and lower workforce requirements allow multiple missions to be carried out in parallel, building technical capacity and expanding the knowledge base of Pakistani scientists and engineers. Importantly, university-led smallsat projects such as PAUSAT-1 and ICUBE-Q illustrate how smaller missions enable collaboration between academia and the space industry, fostering innovation while inspiring future scientists and engineers.

Challenges

Successfully launching and sustaining a space program involves multiple constraints, including adequate funding, expertise, access to space-grade components, and the ability to navigate political hurdles such as the technology denial regime (in the form of the Missile Technology Control Regime (MTCR)). These challenges are compounded by orbital debris management

[47] United Nations Office for Outer Space Affairs, "Space Supporting the Sustainable Development Goals (Space4SDGs)," UNOOSA, https://www.unoosa.org/oosa/en/ourwork/space4sdgs/index.html.

[48] Ministry of Planning, Development and Reform, "Pakistan's Commitment to the SDGs," https://www.pc.gov.pk/web/sdg/sdgpak.

[49] "Pakistan to Launch Its 1st Fully Indigenous Electro-Optical Satellite Today," Radio Pakistan, January 17, 2025, https://www.radio.gov.pk/17-01-2025/pakistan-to-launch-its-1st-fully-indigenous-electro-optical-satellite-today.

[50] Tareen and Nadeem, "Smaller Satellites for Pakistan."

requirements, limited payload capacity of smallsats, and the growing need for robust regulatory frameworks. The National Space Policy also explicitly mentions that with the increase in the number of satellites in orbit, protection, monitoring, and tracking of assets, safeguarding them from space debris and clarifying liability will become imperative for ensuring the sustainability of Pakistan's space program.

The growth of a commercial space sector introduces new forms of risk, especially where the government relies on private operators.[51] In the event of a geopolitical crisis, an operator incorporated in some other country might restrict, censor, or cut access to services.[52] Satellite networks are increasingly attractive targets for cyberattacks such as jamming and spoofing. Weak data routing increases the risk or sensitive information being intercepted by unauthorised entities. A dominant satellite internet provider can exercise significant economic and political leverage e.g. by controlling prices and restricting services. Rapidly expanding private networks may outpace governments' capacity to regulate or exercise oversight, leading to a growing uncertainty over dual-use technologies. When state control over critical space infrastructure is weak or dispersed, this dual-use indistinguishability heightens security dilemmas.[53]

A case in point is how during the May 2025 conflict between Pakistan and India, the latter introduced strict rules for satellite-based internet operators like Starlink as a response to national security fears.[54] India's new regulation (a "29-point compliance framework") demands include data localization, lawful interception rights, and infrastructure placement within India.[55] Analysts point out that international governance frameworks, such as the International Telecommunications Union (ITU) or the UN's space treaties, remain largely technical or procedural, and are unable to address emerging questions of data sovereignty, cybersecurity, and private sector accountability.[56] Pakistan has also become cognisant of this following the conflict

[51] Skaar, Rolf. "Commercialisation of Space and Its Evolution: Will New Ways to Share Risks and Benefits Open up a Much Larger Space Market?" *European Space Policy Institute*, May 2007, https://www.files.ethz.ch/isn/124766/commercialisation.pdf.

[52] Dinesh Dino, "Private Satellites, Public Dangers: Be Alarmed," *KBI Media*, https://kbi.media/contributor/private-satellites-public-dangers-be-alarmed/#:~:text=Data%20Privacy%20and%20Surveillance%20Risks,share%20intelligence%20with%20its%20government.

[53] Dino, "Private Satellites, Public Dangers."

[54] Ali, "Govt Looks to Invite Several Satellite-Based Internet Firms."

[55] Vajiram, "India Tightens Security Rules for Satellite Communication Service Providers," Vajiram & Ravi, May 7, 2025, https://vajiramandravi.com/current-affairs/india-tightens-security-rules-for-satellite-communication-service-providers/.

[56] Sophie Goguichvili, Alan Linenberger, Amber Gillette, and Alexadra Novak, "The Global League Landscape of Space: Who Writes the Rules on the Final Frontier?" *Wilson Center,* October 1, 2021, https://www.wilsoncenter.org/article/global-legal-landscape-space-who-writes-rules-final-frontier ;
Audrey Schaffer, " Strengthening the International Governance of Space," *Center for Strategic and International Studies (CSIS),* October 31, 2024, https://www.csis.org/analysis/strengthening-international-governance-space#:~:text=This%20series%2C%20Space%20in%20Focus,for%20how%20to%20navigate%20them.

with India, as "new regulations [for foreign satellite operators] will include important security clauses that may have been overlooked if the recent wars [between Pakistan-India and Iran-Israel] had not occurred." [57]

Security Risks of Smallsat Constellations

Space technology is dual-use and space was militarised from the launch of the very first satellite. While space-based assets provide critical functions during conflict, their strategic value makes them vulnerable targets: "the role of space in conflict is to provide the information necessary to employ one's forces and weapons and to deny that ability to one's adversary… there is an obvious overlap between space in conflict and conflict in space."[58]

Nicholas Eftimiades argues that small satellites are a disruptive technology; the disruption can be both positive and negative. They can lower costs by up to 90 percent compared to large satellites and make it possible to deploy entire constellations for communications or Earth observation. This creates resilience since hundreds of smallsats are much harder to disable than a handful of large satellites, making direct-ascent and co-orbital anti-satellite (ASAT) weapons less effective. However, smallsats can be used covertly as reconnaissance platforms or even as kinetic ASATs. Satellites in orbit travel at over 17,000 miles per hour and even small objects can cause catastrophic collisions and damage. Swarming tactics, where large numbers of CubeSats carry out coordinated maneuvers raise the risk of miscalculation in crisis situations.[59]

He further highlights that a major challenge lies in attribution and transparency. With thousands of smallsats being launched every year, it is increasingly difficult to detect, identify, and track each one, let alone verify its capabilities or intent. Unlike communications satellites that must register with the ITU, there is no global mechanism to verify whether states or companies accurately disclose the purpose of their satellites. This ambiguity creates uncertainty: any smallsat could be a harmless scientific experiment, or it could serve as a covert collection platform. The inability to distinguish between benign and hostile missions feeds into a broader security dilemma, particularly in regions like South Asia where mistrust is already high.

Finally, smallsat proliferation greatly expands the cybersecurity attack surface. Each satellite is linked to ground stations, control centers, and internet-connected infrastructure, often relying on COTS hardware. Without robust encryption, authentication, and supply-chain security, adversaries

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[57] Ali, "Govt Looks to Invite Several Satellite-Based Internet Firms."

[58] Secure World Foundation, Global Counterspace Capabilities: An Open Source Assessment, April 2025, https://drive.google.com/file/d/1FA8aLXiQeAEK1Z8mTpHFls_c27Ne50qa/view.

[59] Douglas C. Youvan, *Space Warfare in the Age of Microsatellite Swarms: Challenges, Opportunities, and the Imperative for International Cooperation*, September 10, 2023, https://www.researchgate.net/publication/373808450_Space_Warfare_in_the_Age_of_Microsatellite_Swarms_Challenges_Opportunities_and_the_Imperative_for_International_Cooperation.

could jam signals, spoof data, or even hijack satellite control. This vulnerability extends beyond space to critical infrastructure on Earth, since governments increasingly depend on commercial constellations for communication and data services. Although smallsats promise resilience and affordability, they also raise important concerns about cybersecurity and regulatory oversight.

Policy Options for Strengthening Pakistan's Smallsat Ecosystem

To build a resilient, innovative, and strategically autonomous space program, Pakistan must pursue an integrated approach that leverages domestic talent, public-private partnerships, and international collaboration, while safeguarding security and promoting commercialisation.

1. Domestic Capacity Development

- University-Led CubeSat Projects: Fund and train students in leading universities; develop a pipeline of engineers, scientists, and entrepreneurs.
- Tech Incubation: Establish incubators for MEMS, miniaturized propulsion, and debris mitigation technologies.
- Robust Project Management: Front-loaded planning, rigorous verification, and high coordination to reduce mission failures.[60]
- Smallsat Constellations: Complement PakSat with constellations for frequent Earth observation and extended communications coverage.

2. Public-Private Partnerships and Market Development

- PPP Frameworks: Strengthen linkages between SUPARCO, NASTP, and private startups for commercialisation of smallsats.
- Lowered Entry Barriers: Encourage local firms to experiment in remote sensing, IoT, and communications without heavy capital requirements.[61]
- Innovative Business Models: Promote hybrid networks and diversified service providers to mitigate security and dependency risks.[62]
- Investor Ecosystem: Use subsidies, tax incentives, and venture capital to support startups and create new markets in disaster management, agriculture, and climate monitoring.

3. Strategic and Security Measures

- Sovereign Satellite Programs: Develop domestically designed smallsats to reduce reliance on foreign constellations.

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[60] Tareen and Nadeem, "Smaller Satellites for Pakistan."

[61] Welser, "The Democratisation of Space."

[62] Dino, "Private Satellites, Public Dangers."

- Hybrid Networks and Encryption: Complement private networks with government ground stations to enhance resilience.[63]
- Space Situational Awareness: Track smallsats, swarms, and potential hostile objects to ensure orbital security.

4. International and Diplomatic Engagement

- Strategic Partnerships: Collaborate with other states while ensuring knowledge transfer and integration of Pakistani engineers in satellite design and build.[64]
- Turnkey and Collaborative Models: Select high-performance turnkey projects strategically; promote collaborative development for local capacity building.
- Global Norms and CBMs: Advocate for military-use regulations, debris mitigation, and regional agreements on spectrum coordination and orbital slot management.
- South-South Cooperation: Position Pakistan as a hub for cooperative satellite programs among developing countries.

5. SDG Alignment and Ethical Imperatives

- Developmental Returns: Embed SDG priorities in smallsat missions to support agriculture, disaster response, and climate monitoring.
- Sustainable Innovation: Promote miniaturized propulsion, active debris removal, and safe orbital operations to ensure long-term sustainability.

Conclusion

Pakistan’s space program stands at a critical juncture, where strategic autonomy, technological innovation, and developmental impact intersect. The rapid emergence of miniaturised satellite technologies offers an unprecedented opportunity to build domestic capacity, foster a skilled workforce, and support sectors ranging from agriculture and disaster management to communications and climate monitoring. By leveraging public-private partnerships, targeted international collaboration, and robust project management, Pakistan can reduce dependency on foreign turnkey solutions while enhancing national security and resilience. Embedding ethical imperatives, SDG alignment, and commercial incentives will ensure tangible socioeconomic benefits. Ultimately, a balanced approach will enable Pakistan to transform its small satellite ecosystem into a sustainable, globally competitive, and strategically autonomous enterprise.

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[63] Dino, “Private Satellites, Public Dangers.”

[64] Danielle Wood and Annalisa Weigel, “Architectures of Small Satellite Programs in Developing Countries,” *Acta Astronautica* 97 (2014): 109-121, https://doi.org/10.1016/j.actaastro.2013.12.015.

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