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ADVANCING INDIA'S TECHNOLOGY
SOVEREIGNTY IN

UAVS

UNMANNED AERIAL VEHICLES

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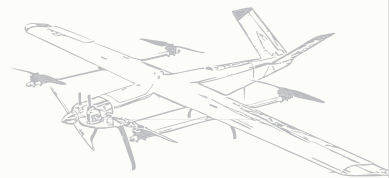
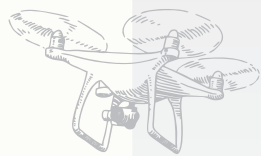
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Foreword



Prof. Ajay Kumar Sood

Principal Scientific Adviser to the
Government of India



The drone era is not merely about a new class of flying machines. It is about reshaping how we move goods and services, how we observe and protect our environment, and how we secure our nation. As India stands at the cusp of large-scale adoption of unmanned aerial systems (UAS) across civilian and defence domains, our task is to translate promise into practice through clear vision, sustained research and an industrial ecosystem that can deliver reliable, affordable and sovereign capability.

Our national vision for drones is straightforward and ambitious. We see a country where aerial mobility and sensing are seamlessly integrated into public life, where remote and

underserved communities receive timely medical care and essential supplies, where agriculture benefits from precision observation and intervention, and where cities and infrastructure are monitored continuously for safety and resilience. At the same time, we recognise the dual use nature of this technology. Its power to enhance welfare coexists with its potential to create new vulnerabilities.

The objective of policy therefore must be twofold: to maximise public benefit while minimising risk, both to citizens and to national security. Research and Development (R&D) are the backbone of that objective. Drone systems are an intricate fusion of materials science, propulsion, avionics, sensing,

Breakthroughs in any one of these areas reverberate across the entire system. Without deep R&D, and investment we will depend on others for critical subsystems and remain vulnerable to supply chain disruptions. Beyond component level innovation, India must also lead in systems integration, in trustworthy autonomy, and in verifiable safety mechanisms that work reliably in contested or degraded environments. Investment in basic science eventually leads to applied technologies that are lighter, safer, and more energy-efficient, even if those benefits take decades to materialise. Investment in testbeds and facilities, where ideas can be matured into certified systems through rigorous trials under realistic conditions, is equally important.

If research is the skeleton, then industry is the muscle. Empowering the domestic drone industry is essential not only for jobs and economic growth but for strategic autonomy. Empowerment is more than procurement orders. It requires predictable demand signals, transparent regulatory pathways, early-stage funding for deep-tech startups, and public infrastructure that lowers the cost of scaling. It means aligning procurement with localisation goals while providing clear road maps and timelines so manufacturers and suppliers can invest with confidence. It also calls for fostering an ecosystem of MSMEs (Micro, Small, and Medium Enterprises) that build components and software, enabling system suppliers to source reliably within India. Wherever possible the government should act as a catalyst rather than a permanent buyer, seeding markets through pilot deployments and shared infrastructure such as charging nodes, authorised vertiports and secure data

exchange platforms.

Standards, certification and safety frameworks are the thread that binds vision, research and industry together. Clear standards reduce friction for innovators and reassure citizens that drones will be safe, secure and respectful of privacy. Certification regimes should be proportionate, and performance based. Where technology allows, we should build privacy preserving designs and data minimisation into systems from first principles rather than as afterthoughts. International engagement also matters. As the technology matures, India must take an active role in setting norms for responsible civilian use and for limiting destabilising military deployments.

Finally, this transformation must be inclusive. The benefits of drones should reach farmers, health workers and small businesses across our states. Training programmes, skill development and academic partnerships will ensure that the workforce of tomorrow can design, maintain and operate these systems. Attention to lifecycle economics, recyclability and environmental impact will keep the growth sustainable.

This edition of *Vigyan Dhara* captures a moment of choice. The choices we make now on research priorities, on industrial policy and on the ethical guardrails for deployment will determine whether drones become instruments of empowerment or sources of new risk.

I invite researchers, industry leaders, policymakers and citizens to read, reflect and engage. Together we can build an India where drone technology enhances prosperity, strengthens security and upholds democratic values.

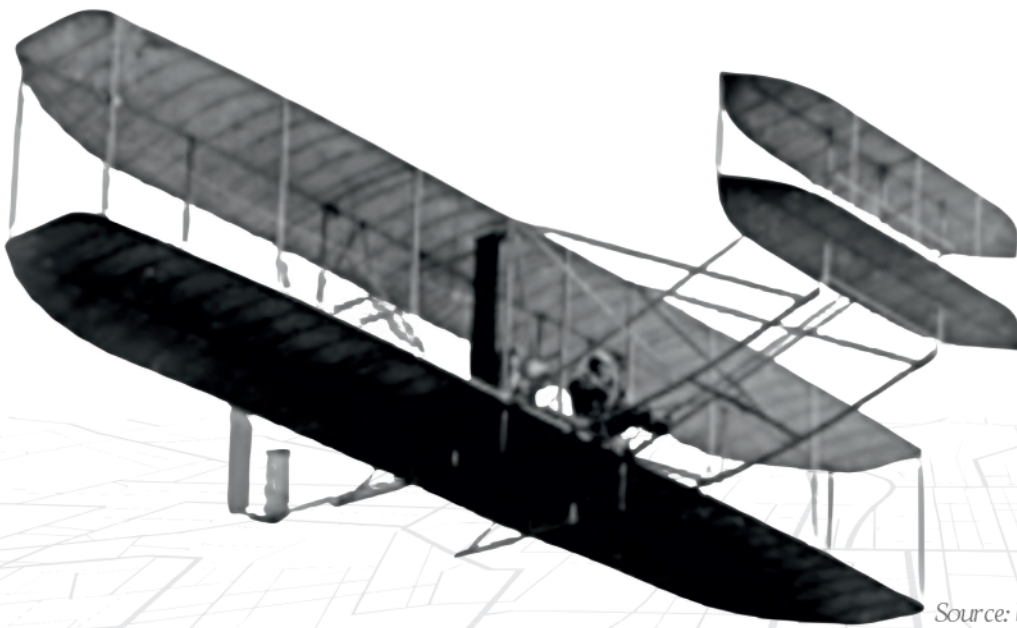
Drones Decoded

Technology, Ecosystem & Opportunities



Prof. P. A. Ramakrishna

Chair Professor,
Department of Aerospace Engineering,
Indian Institute of Technology Madras



Source: britannica

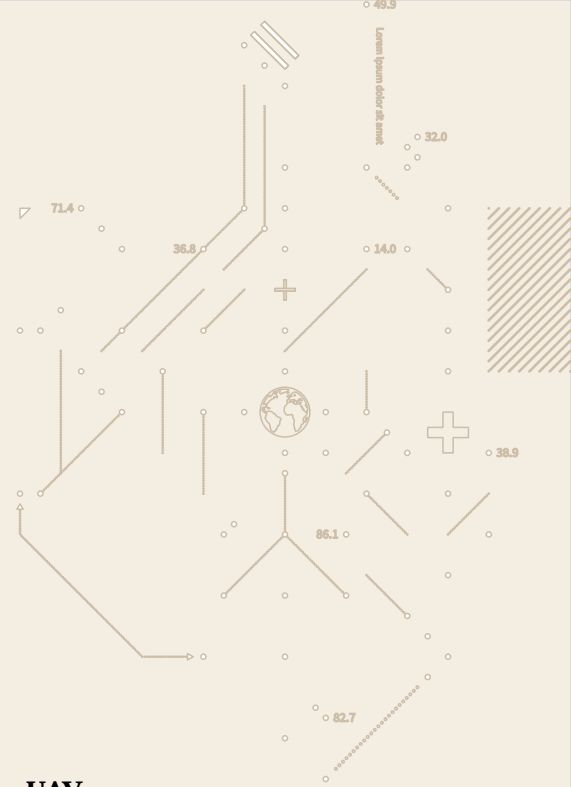
The world of aviation changed on 17 December 1903, when the Wright brothers achieved the first powered flight. Humanity had discovered how to use the third dimension, opening the door to a century of innovations that eventually led to the development of unmanned aerial vehicles (UAVs) or what we commonly call drones.

The terms UAV and drone are often

used interchangeably, though they are not identical. UAV stands for Unmanned Aerial Vehicle, referring specifically to an aircraft that flies without a human pilot on board. Drones are vehicles capable of navigating autonomously or semi-autonomously using the Global Positioning System (GPS) or other positioning sensors, eliminating the need for a pilot to manually steer them to their destination.

The types of **UAVs** and **supporting technologies**

UAVs have many different types based on size, use cases and the number of rotors or propellers used. Many drones range from a few grams to a few 100 kgs. Based on their configuration and propulsion, they can be categorised as:



Fixed wing UAV
(mostly one propeller)

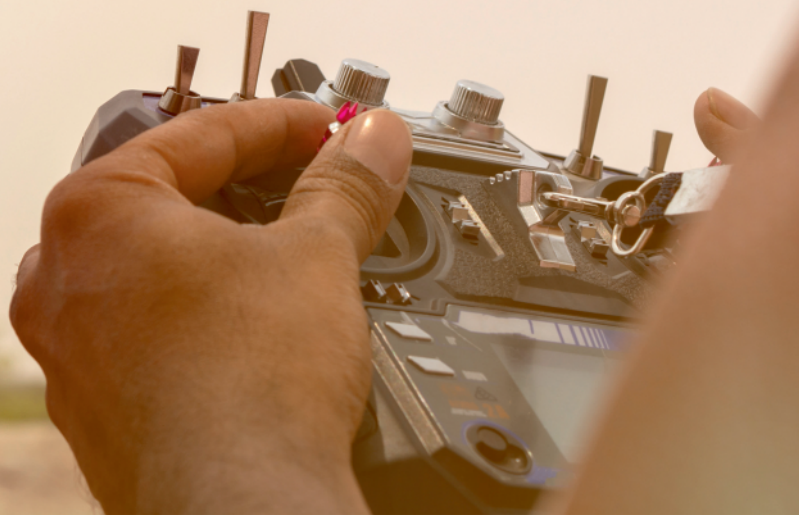
Helicopter
(two propellers)



Quadcopter
(four propellers)

Hexacopter
(six propellers)





Advances in **airfoil technology** have significantly enhanced UAV performance by enabling greater lift generation while continually reducing drag. This improvement allows unmanned aircraft to carry heavier payloads more efficiently. Fixed-wing UAVs commonly use **internal combustion engines**, which contribute to their high operational efficiency. In such systems, lift generated by airflow over the wings counteracts the aircraft's weight, while drag is offset by engine thrust. Large fixed-wing aircraft operating under cruise conditions typically achieve a lift-to-drag ratio between 15 and 20, reflecting a highly efficient aerodynamic configuration. Engine development over the years has focused on lowering fuel consumption and improving the power-to-weight ratio. Current figures indicate a fuel consumption of roughly 250 g/kW-hr and a power-to-weight ratio of about 1 to 1.5 kW/kg.

In parallel, **Brushless Direct Current (BLDC) motors** and modern **battery technologies** have evolved rapidly. BLDC motors offer several advantages, including a high power-to-weight ratio, high rotational speeds, precise control over speed and torque, high efficiency, and low maintenance. These features have made them the preferred

choice for multirotor platforms such as quadcopters and hexacopters.

Simultaneously, advancements in lithium-ion batteries, with power-to-weight ratios of around 200 W/kg, have further supported the widespread adoption of these multirotor UAV systems.

Another key enabler of the rise of quadcopters and hexacopters has been the development of extremely **lightweight onboard computers**, some weighing only a few grams. The miniaturisation of computing hardware to this scale has made it possible to integrate sophisticated control systems into small UAVs.

GPS fundamentally transformed drone navigation. Earlier aircraft required pilots to rely on multiple cockpit instruments to determine their location within three-dimensional space. The advancement of electronics, along with the miniaturisation of components and the rise of programmable computers, made GPS technology compact and affordable. This miniaturisation enabled the creation of smaller, lighter vehicles and ultimately paved the way for the widespread development and deployment of UAVs across civilian, industrial, and defence applications.



Autonomous Flying Wing Technology Demonstrator

Source: Hindustantimes

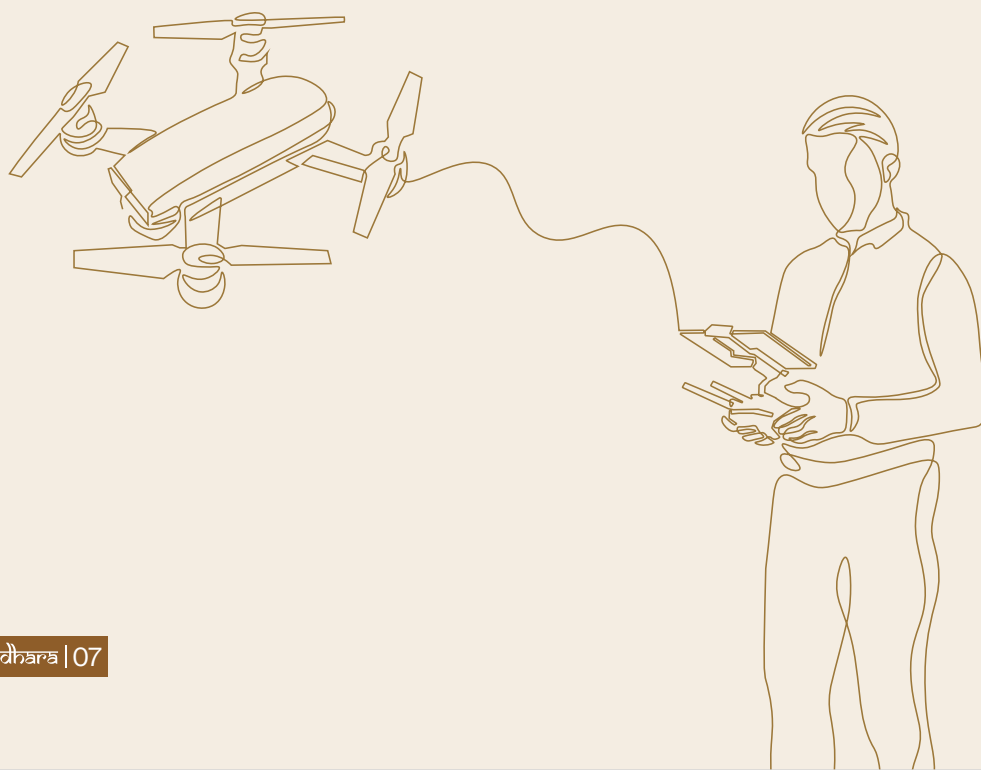
Use Cases of UAVs

UAV applications span diverse sectors, creating transformative socio-economic benefits. The technology's agility, quick deployment capability, and ability to collect high-resolution data in real-time make it particularly valuable. On *battlefields*, drones perform Intelligence, Surveillance and Reconnaissance (ISR), loitering-munition “kamikaze” strikes, and resupply as mule drones, enabling low-cost asymmetric effects against high-value assets. In *agriculture*, guided platforms are used to spray inputs, survey crop health, and perform a range of other precision-farming functions. In *healthcare*, drones move medicines, blood, and organs to hard-to-reach areas and can handle airport-to-hospital last-mile runs in cities. Emerging urban air-mobility concepts explore point-to-point goods and passenger *transport*. Drones also enhance *security* with fixed-wing *patrols*, improve *urban firefighting* using thermal cameras and targeted retardant drops, and more.

Further, with advancements in artificial intelligence (AI) and machine learning (ML), the vast data collected by drones can be processed quickly and effectively, enhancing drone capabilities and operational efficiency.

At Indian Institute of Technology (IIT) Madras, researchers in the Geophysical Flows Lab (GFL) are developing innovative uses of drones for weather forecasting and climate studies. They aim to replace traditional weather balloons, which use helium and are single-use, with UAVs that can carry radiosondes to monitor temperature, pressure, and other atmospheric parameters at high altitudes. UAVs reduce costs and allow for more frequent data collection, improving weather prediction accuracy.

While the use cases of drones cover a wide array of sectors, this article highlights some of the key ones.



Revolutionising Agriculture Management



India's agriculture sector is undergoing a significant transformation with the adoption of drones. These systems are enabling farmers to make data-driven decisions tailored to local conditions, helping optimise yields while reducing input costs.

Drones are now being used for *precision spraying and application*, ensuring uniform delivery of fertilisers, pesticides, and herbicides. They also support soil health monitoring, crop assessment, reduced chemical usage, and lower labour dependency, contributing to safer and more sustainable farming practices. Precision farming is becoming more accessible as farmer producer organisations, krishi vigyan kendras, and custom hiring centres adopt shared-ownership models that lower costs for small and marginal farmers.

The role of drones in *crop health mapping and monitoring* is proving equally transformative. Equipped with high-resolution cameras, NDVI (Normalised Difference Vegetation Index) sensors, and

AI, drones can detect early signs of disease, pest infestation, and water stress. For example, State governments are also advancing agricultural drone use. Maharashtra, for instance, is advancing agricultural drones through partnerships and sugarcane pilots like with the World Economic Forum's Centre for the Fourth Industrial Revolution to apply remote-sensing indices like NDVI, while Tamil Nadu is establishing a common drone testing centre to scale adoption under its Aerospace and Defence Policy.

The aerial seeding capacities of drones also extend beyond agriculture to environmental management, where large-scale afforestation campaigns utilise drones for inaccessible forest areas, accelerating ecosystem restoration with minimal on-ground human intervention.

As drone-generated data begins integrating with AgriStack and other digital agriculture platforms, it will support more accurate crop insurance, subsidy management, and policy design.

Disaster Management: Saving Lives Through Rapid Response



Drones are growing to be effective assets in disaster and emergency response. A study paper on ‘Use Cases of Drones in Disaster Management’ published by the Department of Telecommunications (DoT) in 2024 highlights that drones provide “timely outcomes and precise data collection,” making them vital tools for saving lives and reducing damage.

Drones are contributing to *search and rescue operations*, offering rapid reconnaissance in areas inaccessible to ground teams. During the 2013 Uttarakhand

floods, authorities deployed UAVs to survey areas inaccessible to ground teams; in the 2024 Andhra Pradesh floods, the state and National Disaster Response Force (NDRF) used drones to deliver food, water, and medicines in inundated localities, easing helicopter demand and speeding relief. In post-disaster assessments (e.g., Kerala 2018), aerial technologies including drones and satellite SAR (synthetic-aperture radar) produced high-resolution maps that guided damage assessment and resource planning.



Logistics: Transforming Last-Mile Delivery



Source: eds technologies

Rise in consumer demand for quick commerce and the pressure to streamline supply chains are accelerating the use of drones in logistics. Drone-based *package delivery* helps overcome traffic delays, lower operational costs, and reduce emissions, making logistics more efficient. Citing Fortune Business Insights, DoT in its paper notes that the global drone package delivery market was projected to grow from about USD 1.52 billion in 2021 to USD 31.19 billion by 2028, a CAGR of roughly 53.9%. India is also exploring heavy-lift platforms capable of transporting large cargo over long distances.

Drones are reshaping *healthcare* delivery as well. Enabled by the Ministry of Civil Aviation's liberalised Drone Rules, 2021, Indian pilots and programs such as ICMR's i-DRONE and Telangana's

Medicine from the Sky, have shown that drones can safely transport temperature-sensitive medicines, vaccines, diagnostic samples, and even blood components to remote areas, reducing travel time and improving access.

In *food and e-commerce* delivery, drone testing has shown promising results for rapid point-to-point transport of meals and groceries. Early trials demonstrated that hybrid drones can carry light payloads at high speeds over short distances, highlighting the potential for hub-to-hub delivery networks. Other pilots assessed the use of drones for replenishing inventory between dark stores and customer pickup points, indicating that drone-enabled logistics could soon complement traditional delivery models in dense urban areas.

Infrastructure and Surveying: Enhancing Asset Management



Drones are also being utilised for infrastructure monitoring and maintenance in India by enabling faster, safer, and more cost-effective inspections than traditional methods. Major agencies have institutionalised their use, streamlining workflows, improving data accuracy, and reducing risks in challenging environments. National Highways Authority of India (NHAI), for instance, mandates monthly drone surveys and is rolling out analytics through its Data Lake/Data Analytics and Management System (DAMS), while Indian Railways has formal guidelines for UAS-based mapping and bridge inspection.

In *pipeline inspection and monitoring*, drones help identify vegetation encroachment, structural defects, and other

mechanical issues in real time. Equipped with RGB and thermal sensors, they provide one of the quickest forms of non-destructive testing, supporting more efficient maintenance schedules, reducing asset downtime, and enhancing worker safety. Similarly, *power line inspection* has become more effective with UAVs mounted with infrared and thermal imaging systems. These enable early detection of hotspots, cracks, wire damage, and insulator failures, making maintenance forecasting more reliable and cost-effective. As India's power transmission network continues to expand, drone-based inspections offer significant benefits strengthening reliable and cost-effective forecasting across the transmission network.

Surveillance and Monitoring: Enhancing Observational Capabilities



Source: droneuniversities

Drones are significantly advancing India's surveillance and monitoring systems by providing real-time, high-resolution data across diverse terrains. Their agility and precision support border management, infrastructure oversight, and environmental monitoring more efficiently than traditional methods. These systems are increasingly being integrated into national efforts to strengthen observational capacity, particularly in weather forecasting and coastal security.

In *weather forecasting and atmospheric monitoring*, the India Meteorological Department (IMD) is evaluating drones for upper-air observations and has formed an inter-departmental committee to study the approach, including experimental drone-based radio sounding on a No Cost No Commitment basis with industry and academia. Traditional balloon launches rarely allow radiosonde recovery, limiting reuse and the deployment of more advanced sensors; while drones can carry comparable payloads (around 200 grams), enable recovery,

and support side-by-side comparisons up to roughly 5 km altitude. The Ministry of Earth Sciences (MoES) is establishing a Thunderstorm Testbed in East India and plans to procure drones for pre-storm boundary-layer monitoring and post-event damage assessment, with the goal of generating higher-resolution upper-air data from remote areas and improving forecast skill.

In *coastal surveillance and monitoring*, drones are augmenting India's coastal security and fisheries enforcement with real-time aerial monitoring. Odisha has begun drone surveillance along its 480-km coastline using night-vision-equipped platforms that relay continuous feeds to coastal control centres and support marine police patrols out to 12 nautical miles. Maharashtra has introduced AI-enabled drone surveillance across its 720-km coastline, monitoring up to 12 nautical miles in seven coastal districts and streaming evidentiary video to curb illegal fishing and strengthen maritime security.



The drone ecosystem

The drone industry today spans a wide spectrum of models, broadly categorised as Drones-as-a-Service (DaaS), Drones-as-a-Product, and Drones-as-a-Platform. Purchasing drones as standalone products remains the simplest model, but the service-based approach is increasingly important, especially in fields such as healthcare and agriculture, where users often lack the expertise to operate or maintain drones. DaaS providers bridge this gap by offering end-to-end support, which is accelerating adoption in both public and private sectors.

In parallel, the platform-based model refers to hardware–software ecosystems designed for modular upgrades, analytics integration, and programmable missions through open APIs or development kits.

This allows users to customise drones for advanced applications, including automated data collection, cloud processing, autonomous flight, and AI-enabled analysis.

Drone data platforms complement these models by converting raw hardware-generated data into actionable insights through cloud-based or AI-driven processing. Service and platform models are also converging: integrated solutions now offer custom delivery, inspection services, and real-time data analytics in a single package. Together, these approaches enable flexible and scalable adoption, positioning drones not just as tools or products but as dynamic service and data infrastructures responding to evolving market demands.

With researchers developing new systems and subsystems, policymakers shaping governance frameworks, and government agencies promoting penetration into remote and underserved regions, the drone ecosystem continues to expand. Policymakers, in particular, carry the dual responsibility of enabling innovation while preventing misuse, which requires regulatory frameworks to evolve continuously in response to technological progress and shifting application patterns.

India's academic ecosystem has responded proactively to this growth. The Indian Institutes of Technology have launched specialised programs to build a skilled workforce: IIT Kanpur has introduced a master's program in unmanned aerial systems, while IIT Madras offers an online UAV-focused program open to learners of

all ages, independent of traditional entrance examinations, and driven solely by interest in the field.

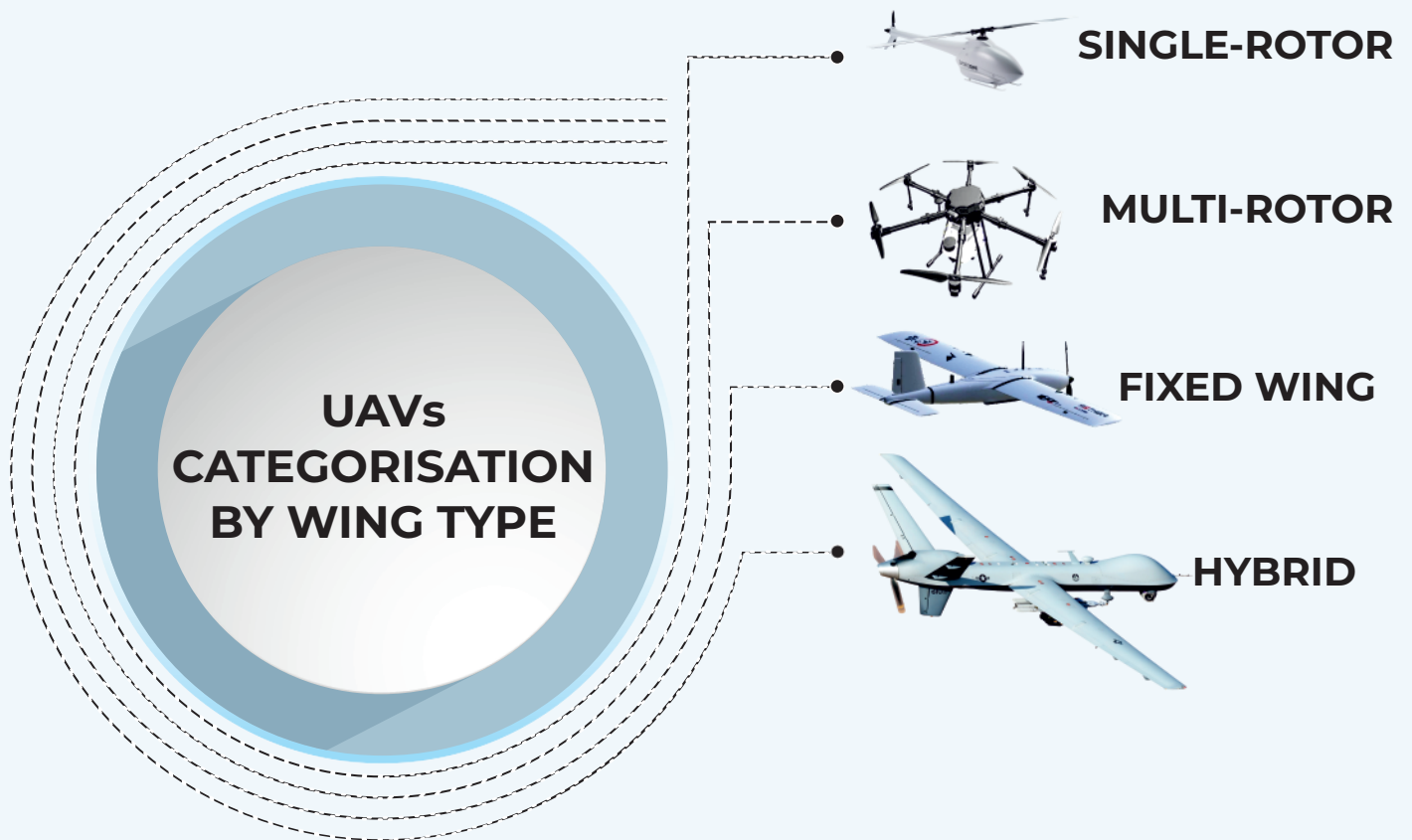
As drone use cases multiply, demand for payload design, manufacturing, and integration is rising, creating new industrial opportunities across sectors. From a defence standpoint, the need for indigenous software, chips, and navigation systems has become critical, given global cyber vulnerabilities and the risk of drone hijacking. Ensuring domestic control over components and subcomponents is equally vital during emergencies, where supply chains may be disrupted. Continuous innovation and expanding data analytics capabilities are expected to reveal new drone applications, further reinforcing drones as integral to India's technological and economic landscape.

India's drone sector spans defence and civilian applications and, under coordinated adoption, could lift GDP by roughly 1% through productivity gains in areas like agriculture and public services. The opportunity extends from manufacturing airframes to critical subsystems including motors, magnets, avionics, sensors, cameras, batteries, and propellers, backed by enabling policy, even as localisation of electronics remains a priority. Capturing this growth will require large-scale skilling and upskilling to build a workforce for operations, maintenance, and design-to-manufacture roles.

TYPES OF

UAVS





India's Drone Decade:

From Policy Uncertainty to Global Ambition



Mr. Piyush Srivastava, IES

*Senior Economic Adviser,
Ministry of Civil Aviation*

The past decade marked a period of significant transition for India's drone ecosystem. The country transitioned from a near-blanket civilian UAS ban in 2014 to a permissive, digitally enabled regulatory

approach that opened large parts of airspace and later introduced trust-and-verify tooling and pivoted to domestic manufacturing incentives. A detailed timeline highlighting key milestones of this evolution is shared below:



Source: MoCA

Date	Regulatory Document	Objective	Remarks
7th October, 2014	Public Notice	(Prohibited civil use of UAS). To understand the system and provide appropriate safety requirements	Case-by-case exemptions/ no objections were provided to Government entities to utilise drones based on the risk assessment of the intended operations
27th August, 2018 effective from 1st December, 2018	CAR Section 3, Series X, Part I under Rule 15A of the Aircraft Act, 1934	To regulate civil use of drones: Digital permission for No-Permission, No-Takeoff (NPNT) conceptualised	Registration and UAS operator permit were mandated. Paperless, digital permissions through DigitalSky platform. Display of airspace map (zones) was critical requirement for NPNT concept.
12th March, 2021	The Unmanned Aerial System (UAS) Rules, 2021	To regulate civil use of drones, the entire drone ecosystem and future technological provisions	72 services, 25 forms (applications), autonomous, swarm drones, etc. rules regulated supply chain, import, R&D, testing sites, training organisation, drone ports, Unmanned Traffic Management Service Providers (UTMSP) etc. Repealed by the Drone Rules, 2021 after backlash from industry including R&D & educational institutions.
25th August, 2021	The Drones Rules, 2021	To regulate civil use of drones – trust based approach	Type certification, registration, remote pilot certification, Remote Pilot Training organisation (RPTO) authorisation, free R&D, insurance

The reforms were complemented by the Production Linked Incentive (PLI) Scheme for Drones and Drone Components in September 2024, the ban on import of fully built drones to encourage indigenous manufacturing and the liberalisation of export policy to support global market access. The PLI offered time-bound incentives linked to domestic value addition—computed as a percentage of eligible value added—to Indian

manufacturers of drones and specified components, with a capped multi-year outlay, relaxed value-addition thresholds to widen MSME/start-up participation, and eligibility covering critical sub-systems (airframes, propulsion, avionics, communications, sensors/payloads, safety systems, and software), thereby nudging localisation, scale, and export readiness across the supply chain.

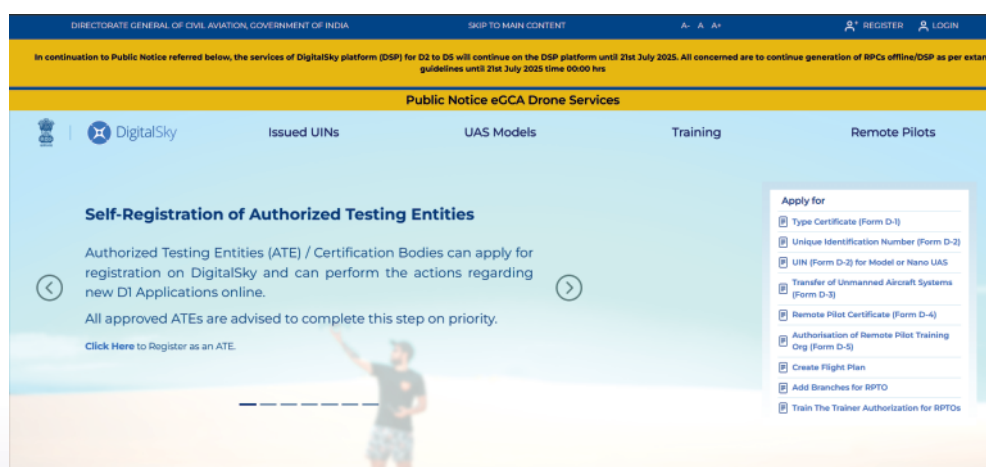
These initiatives were further enhanced by the establishment of a unified regulatory framework that simplified permissions, boosted ease of operations, and incentivised investment in drone manufacturing.

This comprehensive approach laid the foundation for a collaborative ecosystem involving government bodies, academia, and industry stakeholders.

The Ministry of Civil Aviation (MoCA) has enabled a digital backbone through the DigitalSky platform, for drone operations, ensuring transparency, traceability and ease of compliance, stability, innovation, and self-reliance.

DigitalSky is the national single-window portal operated by India's aviation regulator for end-to-end unmanned aircraft governance covering registration of drones and operators, unique

identification, remote pilot licensing, automated flight permissions, and an interactive airspace map that demarcates green, yellow, and red zones for "No Permission, No Takeoff" compliance. It also acts as the data backbone for Unmanned Aircraft System Traffic Management (UTM), publishing dynamic airspace advisories, synchronising flight intents and approvals, and storing flight logs to enable transparency, traceability, and real-time oversight for both civil users and law-enforcement agencies. Together, these measures created a predictable and growth-oriented environment for industry development. Further, the collaboration with central ministries, state governments, academia and industry has led to a sharp rise in certified drone models, training organisations, and licensed pilots. The "Drone Decade" period has thus begun as an era defined by policy.



DigitalSky portal as of November, 2025.

India's Vision: **Becoming a Global Drone Hub by 2030**

The vision of making India a global drone hub by 2030, announced by the Hon'ble Prime Minister, reflects a national resolve to transform India into a global leader in the design, manufacturing, and deployment of drone technology. This ambition aligns with the call for Atmanirbhar Bharat, emphasising indigenous capability, innovation and integration with global value chains.

To realise this vision, the Ministry of Civil Aviation has implemented a multi-dimensional strategy built on reform, investment and capacity building. Regulatory simplification through the

Drone Rules, financial incentives under the PLI Scheme and initiatives such as *Drone Shakti* have together enabled the creation of a strong domestic base for both manufacturing and services. The focus has been on promoting design-led growth, encouraging exports and integrating drones into diverse applications.

With these continued efforts, India's success is increasingly evident. The country is well on course to become a significant global contributor in drones, components, software, and Drone-as-a-Service solutions by 2030.



Next-gen drones enhancing India's mapping, surveillance, and delivery systems.

The Civil Aviation Ministry's approach integrates policy with promotion. The PLI Scheme and coordination with ministries such as agriculture, defence and disaster management have ensured alignment across government functions. Through these measures, India's drone ecosystem is evolving into a comprehensive network of manufacturers, operators, researchers, and service providers. By coupling simplified regulation with targeted support for domestic capability, the country is nurturing an environment conducive to both entrepre-

neurship and safety-driven growth. These measures project a mature, standards-driven framework that provides clarity, predictability and confidence to all participants in the ecosystem. The core approach of the strategy is to promote rapid adoption of drone use while prioritising safety, security and indigenisation through a "promote-and-regulate" posture. India's drone strategy is anchored in a forward-looking policy framework that prioritises innovation while maintaining operational safety and accountability.



Sabal 20 Drone



Skyrath Agriculture Drone

India and the **Global UAV Ecosystem**

Across the world, drones are reshaping economies and redefining industrial processes. The United States, China and the European Union have emerged as leaders in drone adoption, integrating UAVs into logistics, surveillance, agriculture and urban management. India has recognised the strategic importance of developing its own strong UAV base.

MoCA's approach combines self-reliance with global engagement. The ban on import of fully built drones, coupled with incentives for component production, ensures that Indian companies focus on indigenisation and capability development. At the same time, export liberalisation and international collaboration are enabling Indian firms to access and compete in global markets.

The Government is also playing the role of market maker by creating demand through more market creation via public sector use-cases (similar to drone didi scheme),

export facilitations through released SCOMET (Special Chemicals, Organisms, Materials, Equipment and Technologies) incentives, PLI and ease-of-doing-business measures for startups and MSMEs.

The Civil Aviation Ministry, in coordination with partner departments, has launched several programs to promote research, innovation and entrepreneurship. Government-supported initiatives such as Drone Shakti, NIDAR (National Innovation Challenge for Drone Application and Research) and technology development schemes have strengthened collaboration between academia, start-ups and established enterprises. This dual focus on domestic growth and global integration has made India an increasingly visible player in the UAV sector. The country's efforts to align with global aviation standards and to collaborate with international stakeholders also underscore its commitment to responsible leadership in unmanned aviation.



Source: Hindustan times

Hon'ble Prime Minister Narendra Modi during a live drone demonstration conducted by 'Namo Drone Didis'.

Continuing the momentum, the road ahead is focused on consolidation, scale and global leadership. MoCA aims to deepen research capabilities, strengthen domestic manufacturing and build interoperability with global standards. Priority areas include the establishment of common testing facilities, development of drone corridors and deployment of Beyond Visual Line of Sight (BVLOS) norms and development of Unmanned Traffic Management (UTM) systems to enable safe and scalable operations. MoCA is also focusing on promoting exports and expanding India's global footprint in

drone manufacturing. Policy interventions will continue to support export-ready products and streamline procedures to enhance competitiveness.

India's ability to combine innovation with public purpose makes its drone ecosystem significant. With continued focus on policy refinement and capacity expansion, India can consolidate its place as a global hub for drone manufacturing and services. The Ministry of Civil Aviation remains committed to ensuring that India's "Drone Decade" delivers on its promise of innovation, economic growth and technological self-reliance.





Source: autoevolution

Economic and Industrial Dimensions of India's Drone Ecosystem



Smit Shah
President,
Drone Federation India

Over the past decade, India has rapidly emerged as one of the world's fastest-growing drone ecosystems, shaped by regulatory reforms, technological advancement, and increasing public-private collaboration. What began with restrictive, experimental guidelines has evolved into a structured national mission supported by digital platforms, targeted

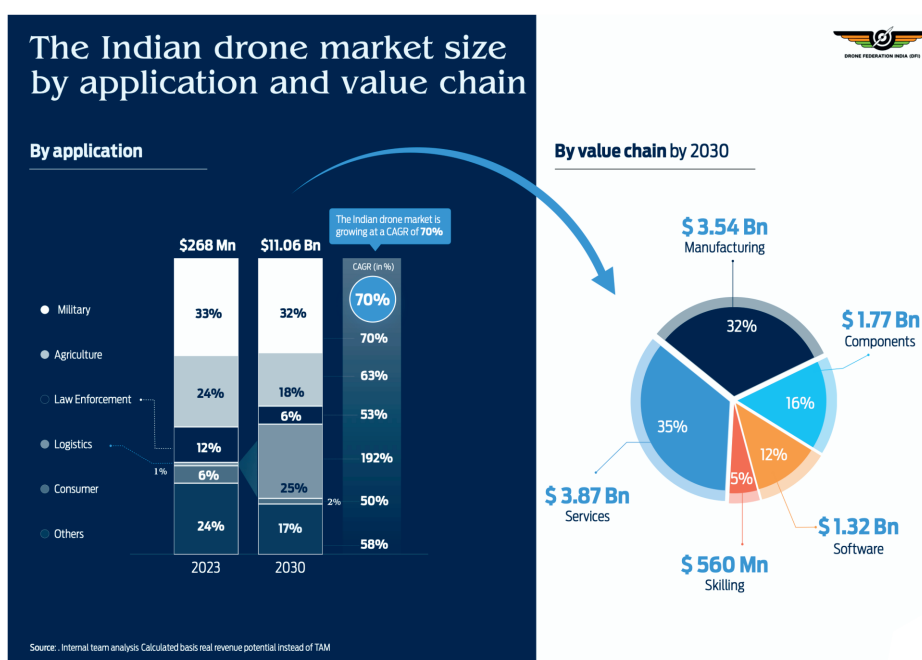
incentives, and a strong innovation culture. Today, the drone ecosystem includes manufacturing, software and analytics, service delivery models, regulatory systems, and sector-specific applications, reflecting India's broader transition towards a self-reliant, technology-driven economy with reduced import dependence. This momentum is also underscored through various



Source: millenniumpost

market trends and reports. An EY assessment projected that India's drone and component manufacturing industry could reach USD 23 billion by 2030, significantly boosting national production capabilities. A separate projection by MarketsandMarkets estimated that the Indian drone sector may grow from about USD 0.47 billion in 2025 to USD 1.39 billion by 2030, corresponding to a compound annual growth rate of around 24.4 percent. Mordor Intelligence placed the global drone market at nearly USD 90 billion by 2030, depending on the inclusion of defence, services, and payloads. Grand View Research valued the market at USD 73.06 billion in 2024 and projected it to reach roughly USD 163.6 billion by 2030, with a compound annual growth rate of about 14.3 percent between 2025 and 2030. Even partial realisation of the projected potential would support India's broader economic ambition of becoming a USD 5-trillion economy. This expansion is driven by improvements in drone autonomy, better battery performance, advanced sensing technologies, high-bandwidth connectivity

like 5G, and increasingly powerful onboard AI systems. These enablers are translating into measurable impact across Indian industries. Grand View Research also reported that industrial applications accounted for more than 58 percent of global hardware revenue in 2024. In India, major national programmes for roads, railways, smart cities, and urban development are benefitting extensively from drones, given their advantages in safety, cost, and time efficiency. One of the most transformative developments is occurring in the services and analytics layer of the ecosystem. Drones have become high-quality data-collection platforms capable of gathering imagery, LiDAR (Light Detection And Ranging), and thermal data. When processed through AI-driven analytics, they enable integrated solutions that combine hardware, software, and data services. This shift from a hardware-centric model to platform-based and analytics-driven services is expanding revenue opportunities and creating new roles in software engineering, cloud systems, and digital enterprise services.



India's Drone Ecosystem: Strengthening Value Chains and Employment

With applications spanning numerous sectors, drones are emerging as a catalyst for new employment opportunities across a wide and interconnected value chain. Opportunities span component design, manufacturing, system integration, data analytics, piloting, maintenance, inspection services, certification, training, and exports. This landscape includes both hardware and software domains, creating an ecosystem of technical and operational roles. Importantly, the decentralised nature of drone manufacturing and services has allowed Tier II and Tier III cities to emerge as hubs for assembly, analytics, and operations, placing capabilities closer to end-user industries.

Micro, Small, and Medium Enterprises (MSMEs) are increasingly contributing to sub-components, software modules, and analytics services, helping build a distributed industrial base that aligns with national objectives such as Make in India, supply-chain resilience, and export readiness. The ecosystem is supported by several enablers, including component manufacturing, platform assembly, AI and software development, service-delivery models, testing and certification facilities, and export pathways. Together, these components connect research and development with commercial deployment.

India's transition from an import-heavy model to one anchored in domestic production is strengthening strategic autonomy and improving value capture. Policy measures

such as the Production Linked Incentive (PLI) scheme have accelerated this shift. With an outlay of ₹120 crore and relaxed value-addition norms of 40 percent, the scheme encouraged localisation, scaling, and export-led growth.

However, despite the progress, some structural gaps remain. India continues to rely on imported sensors, propulsion systems, and avionics, constraining domestic value addition. Regulatory frameworks for Beyond Visual Line of Sight (BVLOS) operations, dense urban deployments, and Unmanned Traffic Management (UTM) are still evolving.

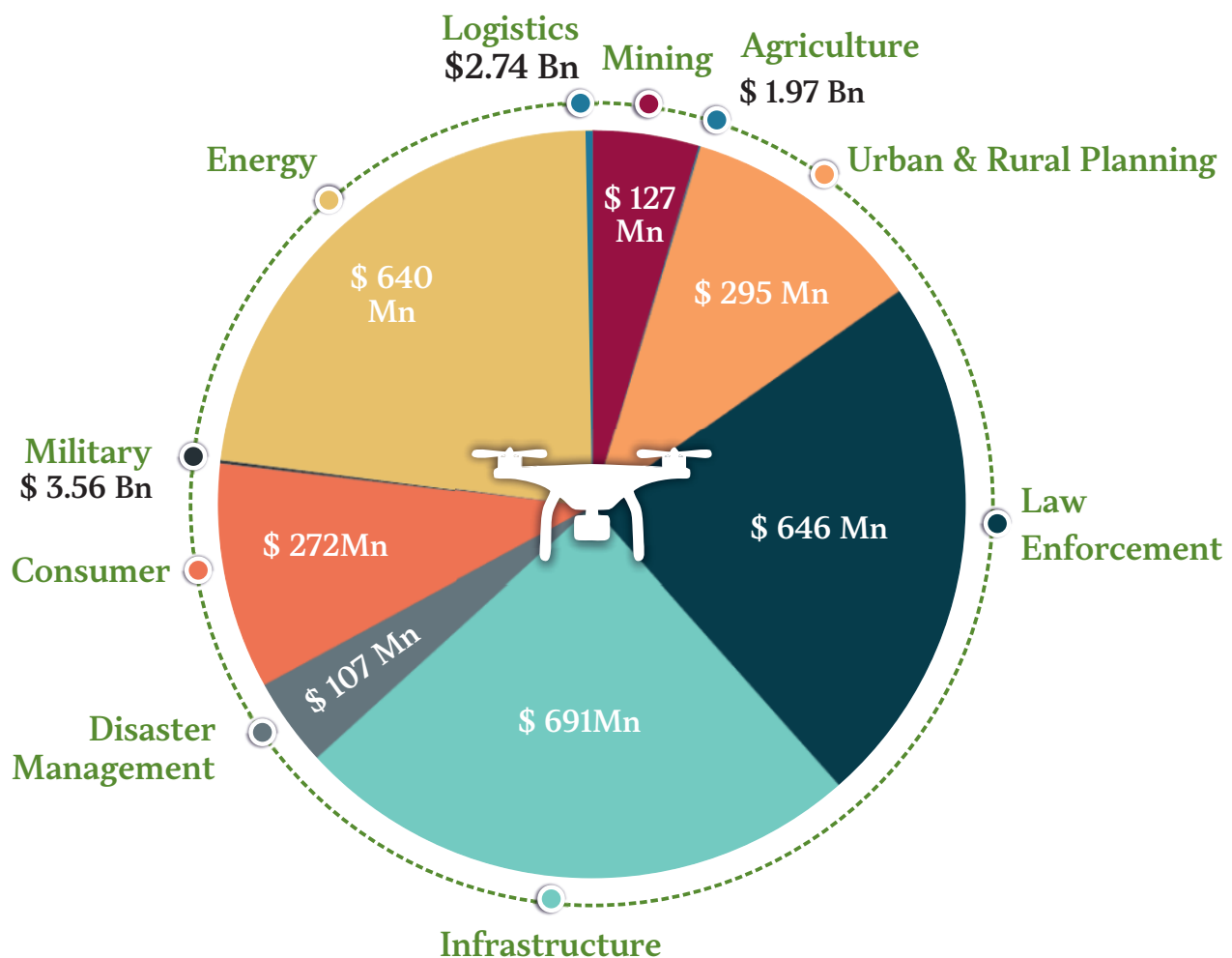
Expanding testing facilities, certification infrastructure, and financing mechanisms will be crucial for sustainable growth. Even so, liberalised regulations, domestic manufacturing incentives, import restrictions on fully built drones, and growing government demand are reducing operational costs and enabling rapid innovation. Drone-as-a-Service (DaaS) models and international partnerships are further integrating Indian enterprises with global value chains.

The global drone industry is on a steep upward trajectory, and studies indicate that the Asia-Pacific region is expected to be the fastest-growing market as regulatory regimes stabilise and technological innovation accelerates. In India, the growth trajectory is reinforced by digital regulatory systems, import curbs on ready-built drones, targeted

incentives through the PLI scheme, and mission-driven deployment across agriculture, infrastructure, and public services. Together, these factors position India to

strengthen its industrial ecosystem and expand exports of cost-effective drone solutions tailored for the Global South.

Drone Market Overview



According to our report (Indian Drone Landscape), the drone market spans a wide range of sectors, with the military segment leading at \$3.56 billion, followed by agriculture at \$1.97 billion.

Commercial and public-sector applications also show strong adoption, including infrastructure, law enforcement, energy, and urban

and rural planning. Emerging segments such as consumer drones, mining, and disaster management further demonstrate the growing diversification of drone use across industries. The visual above maps the economic landscape of drone adoption across major sectors, showcasing how these applications translate into market value.

Scaling India's Drone Economy

India's drone economy is now on the verge of broad-based expansion. Manufacturing is poised to scale from a few thousand units today to potentially hundreds of thousands annually, supported by deeper localisation of components and rising export competitiveness. At the same time, the services segment, which includes mapping, inspection, monitoring, and delivery, is expected to become the central driver of economic value. As hardware gradually commoditises, value will increasingly shift toward recurring service and analytics-based models.

India is also well positioned to become a leading exporter of affordable and reliable drone solutions, particularly for developing nations. As the ecosystem matures, employment opportunities will continue to grow across engineering, piloting, data science, logistics, and maintenance,

contributing to a diverse and inclusive workforce.

In the years ahead, innovation will remain central to shaping competitive advantage and future development. Indigenous intellectual property, advanced software platforms, sensor development, and AI-enabled analytics will play a critical role in helping India capture higher margins and strengthen technological sovereignty. For the country, the drone sector represents a strategic lever for boosting manufacturing, expanding services, creating jobs, and enhancing export competitiveness.

As India advances towards 2030, the national priority remains clear - building a resilient domestic value chain, enabling widespread drone deployment across priority sectors, attracting sustained investment, and positioning the country as a global leader in drone technology.





Image Credits: Licensed stock visuals.

From R&D to Runway:

R&D ecosystem of UAVs in India

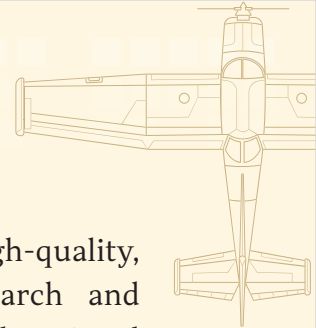
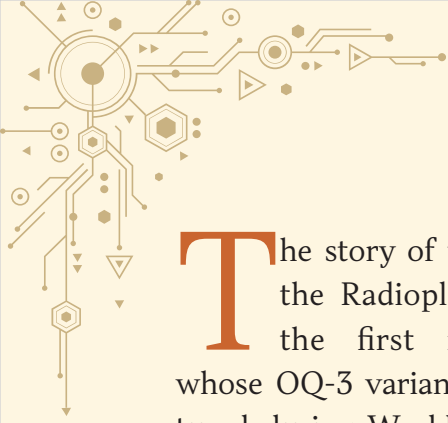


Vivek Kumar

Scientist,
Office of the Principal Scientific Adviser
to the Government of India



AI-generated illustration



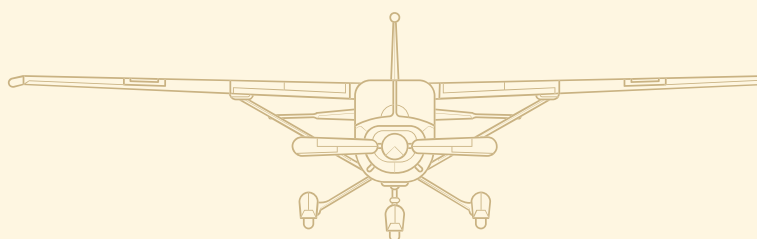
The story of the drones begins with the Radioplane OQ-2, which was the first mass-produced UAV, whose OQ-3 variant was widely manufactured during World War II (WWII). Since then, the world witnessed jet powered surveillance drones and medium-sized tactical UAVs (Cold War), and drones like MQ-1 Predator and MQ-9 Reaper that expanded military reach (2000s). The 2010s brought an explosion of quadcopters such as the DJI Phantom and Parrot AR, making drones accessible to the public and spawning industries in mapping, agriculture, and emergency response. These advancements, no doubt, are the result of extensive Research and Development (R&D) in UAV and associated technologies in the past few decades. R&D remains the backbone of innovation, and in the 2020s, it continues to drive advancements in AI-powered delivery and swarm systems, as well as medium and high-altitude long-endurance drones. Cutting-edge platforms such as the Lockheed Martin Vectis and the Airbus Barracuda represent the most advanced and futuristic developments in unmanned aviation. Reports also indicate that some nations are developing mosquito-sized micro-drones designed for covert military missions, reflecting rapid progress in micro-robotics and drone miniaturisation technologies.

India is also steadily building capacity in this space, with expanding R&D infrastructure, targeted government support, university courses and specialised degrees. The growing industry-academia opportunities

further encourage high-quality, application-driven drone research and innovation. Some of the educational institutions that are involved in R&D on drones include: Indian Institute of Science (IISc) Bangalore, Indian Institute of Technology (IIT) Bombay, IIT Kanpur, IIT Madras, Defence Institute of Advanced Technology (DIAT) Pune, International Institute of Information Technology (IIIT) Hyderabad, Anna University, and many more besides the labs of Defence Research & Development Organisation (DRDO) and Council of Scientific & Industrial Research (CSIR).

India is entering a decisive phase in the evolution of unmanned systems, where the frontier of research is no longer defined by incremental upgrades but by highly specialised, state-of-the-art breakthroughs that only a handful of advanced laboratories can attempt. These efforts are strategically significant for India's aspirations in the next generation of defence preparedness and high-value manufacturing. By investing in such frontier-level research, India is laying the foundation for sovereign capability in critical technologies related to UAVs.

This article highlights significant R&D efforts from some of these institutions and labs that hold immense potential and promise. The following initiatives represent the most sophisticated strand of drone R&D currently underway in the country, combining deep-technology experimentation, high-precision engineering and cross disciplinary science.



CSIR-NAL and the Stratospheric Dream



Dr. L. Venkatakrishnan

*Program Director - High Altitude Platform
Chief Scientist, Experimental Aerodynamics Division
CSIR-National Aerospace Laboratories*

At the National Aerospace Laboratories in Bengaluru, scientists led by Dr. Venkatakrishnan are attempting something that until recently sounded almost utopian - a solar-powered aircraft that can fly autonomously at an altitude of 20 kilometres for three months without landing. The High-Altitude Platform (HAP) project seeks to combine the persistence of a satellite with the versatility of an aircraft. When equipped with payloads, these aircraft become High-Altitude Pseudosatellites capable of significant impact on strategic area of ISR, battlefield communications, and border security, in addition to 4G and 5G telecommunication solutions, GPS enhancement, weather, disaster, and environment monitoring.

The full-scale version of the CSIR-NAL HAP would have a wingspan almost equal to a commercial airliner, but the

weight of a conventional motorcycle. The entire energy of flight and payload has to be generated by solar photovoltaic cells and stored in batteries for the night. CSIR-NAL has already demonstrated its capabilities by successfully designing the propeller, airframe and integration of the subscale version which holds India's altitude record for a UAV, having reached 7.5km above sea level on 11 May 2024. With the goal being complete indigenisation to prevent technology denial, work has commenced in multiple domains, some of which include low Reynolds number aerodynamics for high altitude flight; low weight carbon-based materials for the airframe; very high energy density lithium batteries; high efficiency flexible solar cell technology; high performance BLDC electric motor design and payloads that have low size, weight and power requirements without compromising performance.



Source: CSIR-National Aerospace Laboratories

IIT Kanpur and the Power of Vertical Lift



Dr. Abhishek

*Professor,
Department of Aerospace Engineering,
Helicopter and VTOL Laboratory,
Indian Institute of Technology Kanpur*

The Helicopter and VTOL Lab at IIT Kanpur was established by Prof. Abhishek in 2011 to pursue research in the domain of Vertical Take-Off and Landing (VTOL) capable Uncrewed Aerial Systems (UAS), as this field is still at an early stage in the country. This state-of-the-art lab is equipped with 3D motion capture system, high end 3D printers, rotor testing facility, gust wall facility etc. and has been created with funding support from MeitY, Govt. of UP, DST, Hindustan Aeronautics Limited (HAL), Defence Research and Development Organisation (DRDO), Army Design Bureau (ADB), Prabhu Goel Foundation, and Fund for Improvement of S&T infrastructure (FIST) of DST.

Over the past decade, the lab team's research has delivered several firsts,

including logistic UAVs such as Sabal-20 and Sabal-50 that can carry twenty to fifty kilograms at altitudes above 5,500 metres, a crucial advantage for the Indian Army's high-altitude operations.

The Sabal-50, qualified in trials conducted by the Northern Command earlier this year, is arguably the world's first electrically powered heavy-payload variable-pitch quadrotor, offering twice the energy efficiency of comparable systems. The laboratory's journey has also seeded entrepreneurship. EndureAir Systems Pvt. Ltd., a start-up incubated from Professor Abhishek's research group, now supplies high-performance surveillance and logistics drones to the armed forces.



Source: knocksense

IITM Pune and the Sky as a Laboratory



Dr. B. Padmakumari

*Scientist-F & Project Director,
Atmospheric Research Testbeds,
Indian Institute of Tropical Meteorology
Ministry of Earth Sciences (MoES)*

While some drones are designed to deliver goods, others are built to deliver knowledge. At the Indian Institute of Tropical Meteorology, Pune, under the Ministry of Earth Sciences, drones are being used to study the lower atmosphere with unprecedented precision. The Lower Atmospheric Research using Unmanned Aerial Systems (LARUS) Facility is India's first initiative to develop an instrumented UAV dedicated to atmospheric and climate research.

The fixed-wing platform carries a suite of miniaturised sensors measuring aerosols, clouds, turbulence, radiation, and meteorological parameters. Its real-time data telemetry and lightweight design allow vertical profiling of the atmosphere at fine spatial and temporal resolutions that were previously impossible with balloons or manned aircraft. The early field campaigns have already revealed layers of light-absorbing aerosols that influence

solar radiation and boundary-layer dynamics, deepening our understanding of regional climate processes. The team is now working on a hybrid version that can cover larger areas and longer durations, transforming how India monitors its own atmosphere.

This work underscores a quiet revolution that drones are no longer only machines of defence or delivery, they are becoming tools of discovery. By merging aeronautics with atmospheric science, IITM is giving India an indigenous capacity for atmospheric monitoring that will feed directly into weather models and climate resilience strategies.



Source: The indian express

IIT Delhi and Intelligence on the Edge



Dr. Manan Suri

*Professor,
Department of Electrical Engineering
Indian Institute of Technology - Delhi*

If aerodynamics defines flight, intelligence now defines autonomy. At IIT Delhi, Professor Manan Suri's group is pushing the limits of onboard intelligence through neuromorphic and edge-AI hardware. Their research into nonvolatile memory devices and in-memory computing is applicable for drones that can think faster and consume far less power, a very crucial requirement for endurance missions where every milliwatt matters. The team has shown PoCs (proof of concepts) that achieved on-board hyperspectral image classification with over ninety-one percent accuracy using very low energy levels via specialised

accelerators. Neuromorphic computing concepts developed in the lab can help classify pixels in microseconds, enabling drones to interpret scenes in real time. Complementing the research, the start-up CYRAN AI Solutions (spinoff from the same lab) develops indigenised geospatial AI tools that fuse electro-optic, multispectral, and radar data for remote-sensing applications. Some of the start-up innovations can also help with AI based navigation support for drones. Together, the lab and the start-up represent a full stack of innovation, from semiconductor devices to operational drone intelligence and applications.



Source: Indiatimes

IIIT Hyderabad and the Robotics Frontier



Dr. K Madhava Krishna

*Professor and Researcher,
Robotics Research Center,
IIIT-Hyderabad*

At the Robotics Research Centre of the International Institute of Information Technology (IIIT), Hyderabad, the spirit of experimentation meets the precision of engineering. The centre's portfolio spans agricultural, industrial and defence applications, each demonstrating how robotics can extend human capability.

The centre is working on vision-based autonomous navigation that allows UAVs to map and avoid obstacles using only onboard cameras, as well as on fault-tolerant control systems that maintain stability even after motor failure. Its

hybrid flapping-wing robots, inspired by birds and insects, combine stealth, agility, and endurance, while a spin-off company, Arka Aerospace, has developed Elasticopter – the world's first shape-changing drone that adjusts its frame to suit payloads and missions. Another start-up, Energy Lab, is creating computer-vision algorithms that let UAVs navigate GPS-denied environments using only cameras and inertial sensors. These developments together reflect a new wave of Indian robotics research that prizes adaptability, autonomy and resilience.



Source: Guidance Forever

IISc Bengaluru and the Intelligence of Design



S. N. Omkar

*Chief Research Scientist,
Guidance & Control,
Indian Institute of Science, Bengaluru*

At the Indian Institute of Science (IISc), Bengaluru, interdisciplinary innovation under Professor S. N. Omkar brings together aerospace engineering, artificial intelligence, and bio-inspired design. His ecosystem of three laboratories (the Micro Aerial Vehicle Lab, the Computational Intelligence Lab, and the Biomechanics Lab) works in tandem to translate cross-domain research into advanced unmanned systems and intelligent flight technologies.

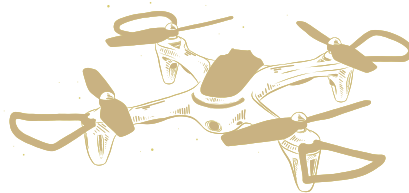
The group has produced an impressive range of UAV systems - modular air-

frames that can be rapidly assembled, amphibious drones that operate from land and water, and tethered copters for continuous surveillance. The HyTRAV hybrid vehicle unites vertical take-off with fixed-wing efficiency, while the Eye-in-the-Sky system employs deep learning to detect violent activity through pose estimation and behaviour analysis. Other projects extend beyond aerospace include AI frameworks first developed for drones that are being adapted for healthcare diagnostics and educational content creation.



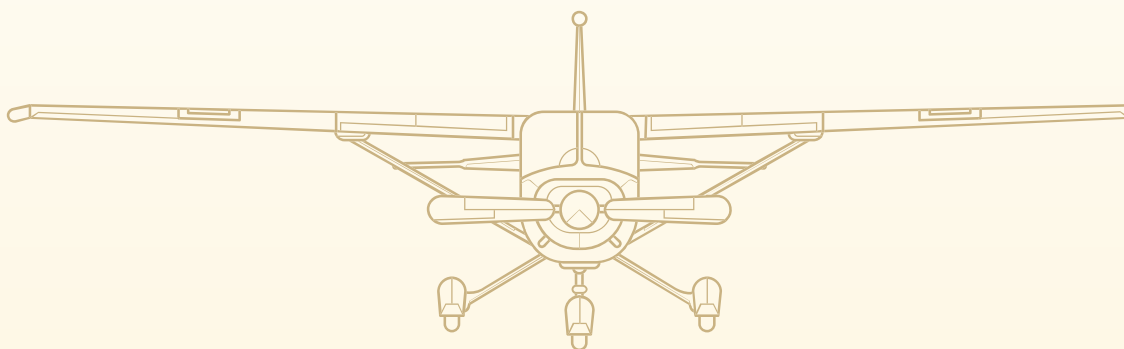
Source: The Indian Express

The Path forward



On 3rd November 2025, Hon'ble PM launched Rupees One Lakh Crore Research, Development and Innovation (RDI) Fund. This is set to energise R&D in deeptech, strategic areas like drones by financing high-risk, long-cycle research, from advanced aerodynamics and propulsion to AI-driven autonomy and sensor integration, that typically struggles to attract private capital. By bridging the gap between academic innovation and industry deployment, it will accelerate India's progression from experimental drone prototypes to globally competitive indigenous technologies.

The Government has advanced R&D through time-bound national missions, expanded funding, and a sustained emphasis on indigenous innovation, underlining that India is meeting this moment with a clear vision. These measures are intended to enable India's scientific community to pursue progress with purpose and urgency. As with most emerging technologies, the outlook for drones spans multiple scenarios and warrants careful assessment. India has its own vision for the future, and the best way to predict the future is to build it.



Hon'ble Prime Minister launches the ₹1 lakh crore Research, Development and Innovation (RDI) Fund to boost India's deeptech and strategic sectors.



RDI

Research Development & Innovation



Hon'ble Prime Minister launches the RDI Fund

Deeptech companies in UAVs



Rohit Gupta

*Chief Technology Officer,
Office of the Principal Scientific Adviser
to the Government of India*



India stands at an inflection point in aerial technology. What began as a niche set of hobbyist platforms and bespoke military systems has matured into an ecosystem where deeptech companies imagine, build and operate whole classes of capability. These firms do not merely assemble flying machines. They write the software that makes flight useful, design sensors that read the earth in new ways, and stitch together data pipelines that turn raw imagery into decisions for farmers, mine managers and disaster responders. In doing so, they are changing how government programmes are delivered and how national problems are solved.

AI-generated illustration.

Startups have been the proving ground for ideas that scale. Small teams move fast, fail early and iterate with the urgency that large institutions often cannot match. That agility translates into field proven systems that can be adopted by states and by industry. When a national mapping programme needs rapid, accurate land data, or when a health ministry needs last mile delivery in difficult terrain, it is often the nimble company that supplies the tested solution. This pattern of innovation, demonstration and adoption is the backbone of an indigenous drone ecosystem that is finding purchase across India. Recent security operations have shown the strategic role that domestic capability can play when national resilience is tested. Operation Sindoor brought that reality into stark relief by demonstrating integrated response architectures where indigenous systems were central to detecting and denying hostile aerial threats and to protecting critical infrastructure. India's drone ecosystem has grown rapidly over the past decade. What began as a small

cluster of firms in 2014 gained significant momentum after 2020, expanding into hundreds of active startups and companies by 2024. This article profiles a selection of some such ventures as case studies, showcasing their technical innovations, their evolution over the years, and the broader maturation of the national drone landscape. These stories demonstrate endurance, trusted autonomy, resilient supply chains, interoperable standards, and the availability of accessible test facilities. They also highlight how supportive certification pathways and shared infrastructure are enabling scalable outcomes and reducing barriers for emerging players. The story of deep tech in drones is both practical and strategic. It extends beyond sensors and software to questions of technological sovereignty, skilled employment, and national preparedness. It encompasses missions that enhance lives today and capabilities that help secure the future. The following pages present startups whose successes offer valuable insights and concrete ideas to guide the journey ahead.

Founded in 2013 and headquartered in Bengaluru, Aereo (formerly Aarav Unmanned Systems) has grown with a simple yet transformative mission - to equip enterprises and governments with AI-powered, high-precision aerial data that enables safer, more sustainable, and data-driven decision-making across sectors such as mining, infrastructure, and urban and rural development. Over the years, the company has built an integrated ecosystem of indigenous drone platforms and the Aereo Cloud, an AI-driven geospatial analytics suite that converts raw aerial data into actionable business intelligence. This platform supports high-accuracy mapping, monitors planned versus actual project performance, and strengthens safety and environmental compliance. Further, with the Aereo Go mobile app connecting field operations to cloud-based analytics, decision-makers can access critical insights in real time. All Aereo drones meet DGCA Type Certification norms and deliver survey-grade accuracy with volumetric errors within $\pm 2\%$. Aereo has mapped over 150,000 sq. km and digitised more than 3,700 mines across India, Brazil, and Africa. Through its contribution to the SVAMITVA Scheme, mapping over 60,000 villages, the company has supported land record modernisation and property rights for millions. Organisations such as Tata Steel, Hindalco, Coal India, UltraTech, the Survey of India, and multiple state departments work with Aereo. With a strong manufacturing base capable of producing over 100 drones a month, backed by active R&D and global collaborations, Aereo now serves 60+ enterprise customers across four continents and stands among India's leading exporters of AI-powered aerial intelligence.

- **Production capacity (units/month):** 100 Drone Systems per month
- **ISO / certifications:** ISO 9001:2015, ISO 27001, DGCA Type Certification
- **Major partners:** Datamine Group-UK, SEED Group-Dubai
- **Clients:** 60+ across India, Brazil, Australia & Africa
- **R&D spend (% of revenue) or labs:** ~12% of annual revenue invested in R&D
- **Patents:** 10 approved



Vipul Singh
Co-founder & CEO

“India's drone ecosystem is evolving from flight to foresight. At Aereo, our vision is to turn every aerial survey into continuous, AI-powered intelligence for a safer planet.”

This Bengaluru-based drone technology company started in 2012 with the mission of developing innovative and reliable end-to-end drone solutions that transform aerial data into actionable intelligence. Over the years, Asteria has grown into a full-stack drone technology company, develops customised drone solutions using its in-house hardware design, software development, and manufacturing capabilities. It is a subsidiary of Jio Platforms Ltd., bringing together startup agility and enterprise-strength execution. Asteria's VTOL platform, the AT-15 VTOL is engineered for high-altitude operations at 20,000+ ft, offering advanced day-night surveillance, AI-enabled target detection, and artillery fire correction. The A200-XT multirotor, designed for rapid deployment, supports seven swappable payloads, enabling inspections, close-range surveillance, and survey-grade mapping. All Asteria drones operate on a common proprietary Mission Control Software that ensures intuitive, secure, and safe operations. With over 750 drones deployed across defence, homeland security, GIS, oil and gas, agriculture, construction, and mining, Asteria has monitored 30,000+ km of oil and gas pipelines, mapped 5,000+ villages under SVAMITVA, and digitised 5,000+ farms for crop science research. More than 600 of its systems are in service with the Indian Army. Asteria operates a manufacturing facility capable of producing over 2,000 drones annually, supported by R&D in autonomy, sensor fusion, and analytics. With 100+ clients and expanding global partnerships, the company is now entering smart cities, industrial inspections, and international markets, advancing its vision of delivering trusted, high-precision aerial intelligence for a rapidly evolving world.

- **Production capacity (units/year):** 2000+ units per year
- **ISO / certifications:** ISO 9001:2015 certified
- **Major partners:** Academia, educational institutes, think tanks & OEMs from India & across the world.



Neel Mehta
Director &
Co-founder

“ At Asteria, we envision a future where indigenous drone innovation drives strategic advantage - empowering defence and enterprise sectors while shaping India's global leadership in aerial intelligence. ”

EndureAir Systems began in 2018 with a small group of engineers envisioning a new generation of aerial robotics built specifically for India's environment. The founders focused on platforms that could lift heavier loads, fly longer, and operate reliably in high-altitude, all-weather conditions. The team rapidly specialised in VTOL and variable-pitch rotor technologies, a choice that allowed their UAVs to carry payloads of up to 100 kg while maintaining stability, maneuverability, and endurance. The drones were built for the complexities of real missions like ship-deck landings at sea, logistics sorties in the mountains, persistent surveillance in extreme weather, and swarm-enabled navigation for tactical operations. At the core was an indigenous autonomy stack designed for resilience and smart navigation. Eventually, the company introduced a suite of flagship products including SABAL, a heavy-lift logistics UAV that became a standout for its combination of VTOL, variable-pitch technology, and all-weather reliability. VIBHRAM, an electric unmanned helicopter, extended mission endurance for long-range ISR operations, and ALAKH, a nano FPV drone, addressed the need for agile, close-range tactical and swarm missions. As SABAL production scales, plans for an air-ambulance UAV by 2028 are also advancing. With a facility for both prototype development and scaled manufacturing, in-house testing, an R&D pipeline, the team continues to push boundaries in rotorcraft design, ship-deck landing systems, autonomy, and swarming. With 10 granted patents and more on the way, today EndureAir works with the Indian Army, Navy, Air Force, NDRF, DRDO, Delhivery, Adani Cement, BEL, and L&T Defence, among others, deploying its platforms across logistics, utilities, disaster response, and defence.

- **Production facility:** 40,000 sq. ft. design & production unit
- **Payload capability:** Up to 100 kg on selected platforms
- **Environmental performance:** Wind resistance up to 45 km per hour on qualifying platforms
- **Certifications:** AS9100 aerospace certification
- **Patents and publications:** 10 granted patents; 50 plus technical publications



Rama Krishna
Co-founder & CEO

ideaForge Technology Limited



<https://ideaforgetech.com/>

ideaForge's journey began in 2007, with a group of ambitious IIT graduates, and has evolved today to be ranked third, globally as dual-use drone player. Over 18 years, ideaForge has built a reputation for high performance, reliable, autonomous, and resilient UAVs that operate in the toughest environments, completing more than 800,000 successful missions. From its earliest prototypes to its present-day platforms, the company has remained vertically integrated, with in-house design and development and indigenous manufacturing. This approach has enabled ideaForge to build proprietary technologies such as the BlueFire Autopilot system, one of the world's smallest and lightest when developed in 2007-08. With more than 95+ global patents across UAV subsystems and autonomy software, ideaForge has steadily expanded its indigenous portfolio to include multi-rotor systems like NETRA and the Q-Series, as well as fixed-wing VTOL hybrid platforms such as SWITCH and ZOLT. SWITCH is the only UAV in its class certified by Directorate General of Quality Assurance (DGQA) as "Fit for Indian Military Use." Additionally, both SWITCH and Q6 carry NATO Stock Numbers (NSN). ideaForge serves the Armed Forces, central armed police organisations, state police forces, and several enterprise users. Its UAVs support ISR missions, border security, disaster response, and village-level mapping under the SVAMITVA Scheme, while also enabling global enterprises in infrastructure inspection and asset monitoring. With a production capacity of over 10,000 units per month and partnerships with global players like Qualcomm and FLIR, the company is expanding internationally. Backed by deep localisation, strong R&D, and new products such as Flyght Cloud and Flyght Docks, ideaForge is contributing strongly to India's drone ecosystem, enhancing national security, public safety, and enterprise efficiency.

- **Production capacity (units/month):**
10,000+
- **ISO /Certifications**
AS 9100D | ISO
9001:2015 | ISO
27001:2022 | DGCA
Type Certification
- **R&D spend (% of revenue) or labs:**
20%+ of revenue
- **Patents:** 95+ (granted & pending)
- **Global Reach:**
Presence in the US.
Other geographies through reseller partners.



Ankit Mehta
CEO &
Co-founder

“Our journey reflects India's spirit of indigenisation and persistence - engineering drones that strengthen national security and enable industries to operate smarter, safer, and more autonomously.”

Roter Precision Instruments Private Limited



 <https://www.apiroter.com/>

Roter Precision Instruments has spent nearly nine decades in the surveying industry. Roter delivers advanced mapping platforms such as Total Stations, GNSS systems, LiDAR scanners, mobile mapping solutions, photogrammetry tools, and 3D modelling technologies. The company has been in the forefront of manufacturing unmanned systems that have been field proven for various mapping payloads.

In 2018, the company introduced India's first fixed-wing eVTOL drone, developed with an indigenous autopilot and firmware. It remains the only DGCA type-certified platform capable of carrying a diverse range of payloads, including multispectral and LiDAR sensors, as well as oblique and high-resolution cameras. Recently, Roter expanded its portfolio by launching India's first helicopter drone and a versatile multi-copter system, and an AI driven fully autonomous drone, all strengthened by in-house advancements in battery management, AI, robotics, and geospatial software. Built to international standards, the company's equipment is certified by accredited laboratories, underscoring its engineering rigour. With domestic manufacturing capabilities and a scalable production capacity ranging from 50 to 5,000 units per month, the company continues to receive consistent support under the PLI scheme.

Roter's drones' power some of India's most ambitious mapping missions including SVAMITVA, NAKSHA, Digital Twin of Smart Cities, large-scale mining surveys, military mapping and even complex 3D models such as the LOD2 reconstruction of Trichy Airport. Its work in the Ken River with WII Dehradun earned a special mention from the Prime Minister in Mann ki Baat. Roter's platforms have even mapped concealed voids inside Himalayan mountains for the Indo-Bhutan PHPA II dam project.

Roter continues to serve India's growing demand for precision mapping and unmanned Air & Ground systems.

- **Employee strength:**
200
- **Production -capacity (units/month):**
Model dependent from 50 to 5000 units/ month
- **ISO / certifications:**
IS 16046 (Part 2)/IEC62133-2:2019
IS 9000 Part 2&3
IS 9000 Part 4 / IEC 60068-2-78:2012
IEC 60068-2-27
IEC 61000-4-3:2020 / IS 14700
IEC 60068-2-13: 2021
IEC 60529:1989 + A1:1999 + A2:2013
- **Major Clients:**
Survey of India, ISRO
NRSC, NESAC, IITs,
Military Survey & Private Surveying Companies



Mr. Sajid Mukhtar
Chairman & Managing Director
Roter Group

“Our vision is to empower India's skies with intelligent, reliable, and homegrown drone technologies through innovation while leveraging on existing strengths.”

Sagar Defence Engineering Pvt. Ltd.



 <https://www.sagardefence.com/>

Sagar Defence Engineering's began in 2015 with a simple but ambitious belief that the future of India's maritime and defence capability would be shaped by unmanned and autonomous systems operating seamlessly across sea, air, and land. Founded by Capt. Nikunj Parashar, Mridul Babbar, and Lakshay Dang, the company set out to build mission-oriented platforms and autonomy stacks that could strengthen national security while reducing risks to personnel in high-stakes environments. From its early days in a small workshop, Sagar Defence focused on developing core autonomy technologies that could transform both new and existing systems. Its breakthrough came with GENISYS, a self-learning command-and-control module that enables remote, semi-autonomous, and fully autonomous navigation. This platform-agnostic autonomy layer soon powered a family of unmanned systems, including autonomous surface vessels, underwater vehicles, maritime spotter drones, and heavy-lift cargo UAVs capable of operating in challenging conditions. The company also began demonstrating how weaponised swarm boats could coordinate across domains, hinting at the future of naval warfare. Some of its most notable milestones include the Sagarmala Parikrama, a long-range autonomous voyage from Mumbai to Thoothukudi, which showcased the endurance and reliability of its surface vessels. Demonstrations aboard INS Vikrant further cemented the company's credibility in India's defence ecosystem. With growing collaborations involving international industry partners, the Indian Navy, and national research organisations, Sagar With more than 40 patent filings and multiple national awards, the company plans to expand into waterfront manufacturing to scale production of maritime autonomous platforms.

- **Production capacity (units/month):** 30
- **Patents:** Company states over 40 patent filings across related technologies
- **Major partners / collaborations:** Indian Navy stakeholders, international industry partners, and national research organisations
- **Focus Areas:** Defence, maritime security, and export-oriented autonomous systems



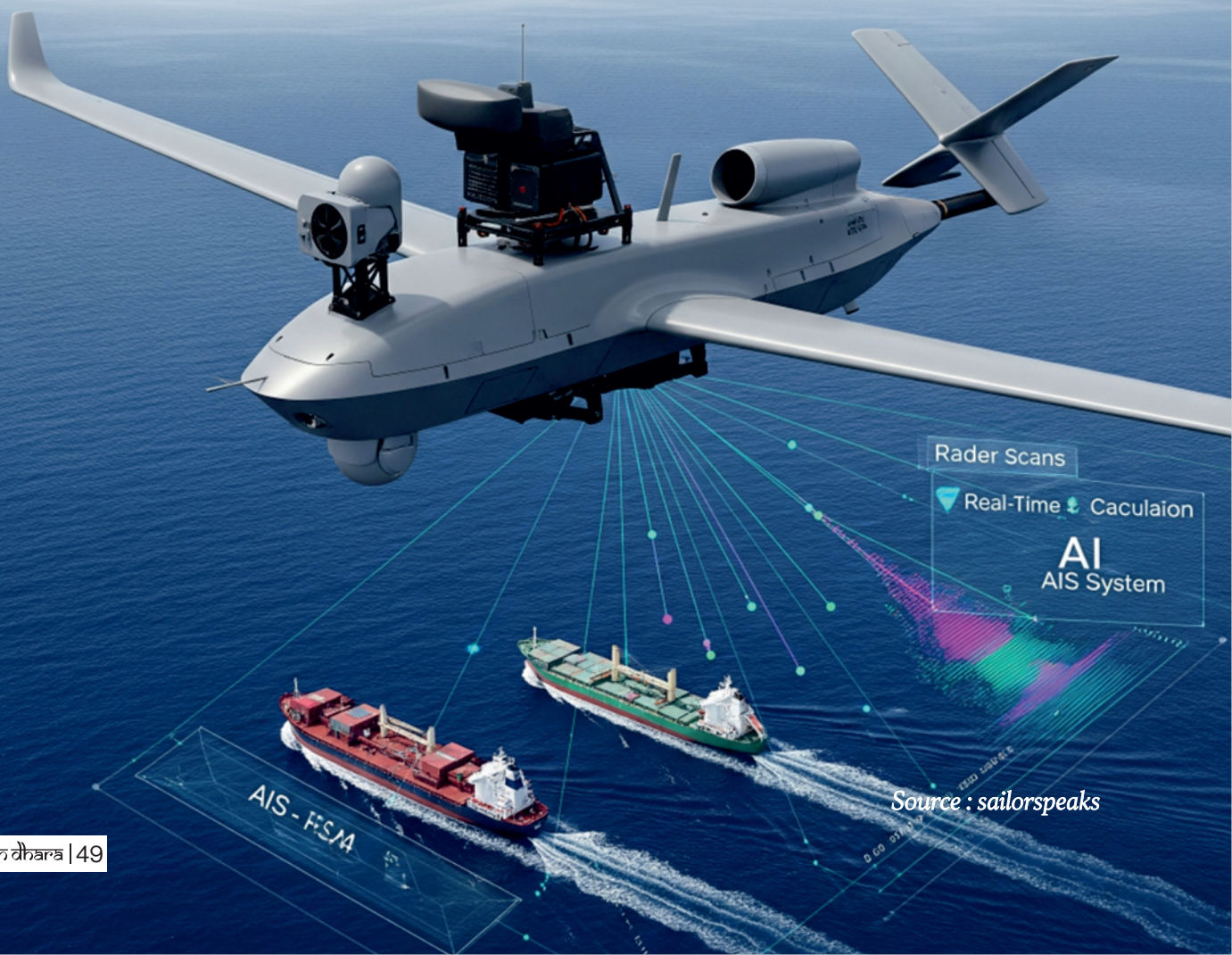
Capt. Nikunj Parashar
Co-founder & CEO

The Technology Sovereignty Imperative for India's UAV Ecosystem



Arnav Bhasin

Policy Fellow,
Policy Analytics and Insights Unit,
Office of the Principal Scientific Adviser
to the Government of India



Drones are a classic case of a technology evolving from being an additional integration to a necessary enabler. Globally, drone technologies have been growing rapidly. This growth is also evident in the case of India by the projections of the drone industry becoming an \$11.06 billion market by 2030, showcasing a nearly 70% CAGR as shared in the Indian Drone Landscape report by the Drone Federation India (DFI). It is important to note that drones are not limited to the ones we see in the sky; they can be utilised in all three mediums - water, land and in the air. Nevertheless, the aerial drones or the unmanned aerial vehicles (UAVs) form the most widely focused category of drones. UAVs have become a vital asset across sectors, ranging from defence and logistics to agriculture and healthcare.

While the UAV market is growing at a commendable rate, specific areas within the UAV technology

value chain require continued efforts to establish a sovereign UAV ecosystem. A sovereign UAV ecosystem entails the capacity to build and govern UAV technologies independently, without dependence on a single source. This shouldn't be confused with a 100% domestic value chain, as the globally interconnected supply chains of critical technologies make it prudent to diversify our partnerships with key international players.

The prospect of technology sovereignty is especially important in times when technology is used as a tool for leverage, as seen through the recent case where the energy company, 'Nayara', lost access to its technology infrastructure overnight, prompting focus on the use of sovereign technologies.

For India to realise its ambition of becoming a global drone hub, it needs to secure the critical systems that power the UAV vision.



Key Considerations for Technology Sovereignty

Given the cross-sectoral applications of UAVs, it is crucial to analyse the ecosystem from technological, economic and national security angles to ensure a more comprehensive understanding of the current state of sovereignty.

I. Systemic Technological Dependencies

For understanding the UAV system, the different components can be segregated by criticality. The table below lists UAV components according to three levels of criticality:

The three-tier classification of a UAV

1



Tier 1: Flight-Critical Subsystems

Description: Systems whose absence, failure or compromise can cause loss of control, unsafe operations or inability to complete or safely terminate the flight.

Technological Subsystems:

- Flight Control Units
- Primary Communication
- Propulsion (for multicopters)

2



Tier 2: Mission-Enabling Subsystems

Description: Systems that determine mission success and operational capability, but allow for degraded operation or safe recovery procedures if they fail.

Technological Subsystems:

- Power Management Systems
- Structural and Mechanical Systems
- Propulsion (for fixed wing systems)

3



Tier 3: Mission-Execution Subsystems

Description: Systems that enable mission-specific functionality without affecting basic flight safety.

Technological Subsystems:

- Sensors and Payload Systems
- Artificial Intelligence and Autonomy Stack

India's UAV technology ecosystem shows systemic vulnerabilities that cascade across criticality tiers. A disruption in any one tier can compromise the entire UAV's operations. Across different tiers of criticality, the United States and China are the top contributors to intellectual property (IP). For the most critical components like the flight controller units and navigation systems, India's contribution as an inventor country stands at 50 patents (as per data collected from Lens.org) compared to the United States' 1,243 patents. This low share in IP is compounded by the heavy reliance on imports for critical components - approximately 39% of flight controllers and 50% of communication systems

are sourced from international suppliers, primarily China, the United States, and the European Union (as reported by EY in 'How India can become the Drone Hub of the World by 2030'). This dependence extends to subsystems like propulsion, power management and sensors, which have nearly 75% import dependence.

A siloed approach for these issues may lead to deeper concerns like strategic dependency (a one-sided dependency on a country/supplier) and a stunted development of the domestic industry. Hence, achieving sovereignty requires simultaneous development across all criticality tiers instead of siloed approaches focused on individual subsystems.

II. IP ownership and control

India's UAV IP landscape shows innovation without resulting in ownership and commercialisation. This stems from issues in IP jurisdictional preferences and in translating innovations into industry-relevant products. Across the UAV subsystems - from flight controllers and communication to sensors and payloads - India's rank as an IP inventor country is notably stronger than its rank as an IP owner country. For example, India ranks at the 9th position of IP inventor countries for the subsystem of sensors and autonomy but holds the 15th position in the case of countries owning the IP. Vulnerabilities also exist in jurisdictional preferences - most patents with India as a priority jurisdiction are filed with the foreign IP offices and their jurisdictions, like the United States [107 patents] and World Intellectual Property Organisation (WIPO) [99 patents], as shown in Graph 1. *[The patents in the previous sentence refer to patents with priority jurisdiction or application filing jurisdiction noted as India.]*

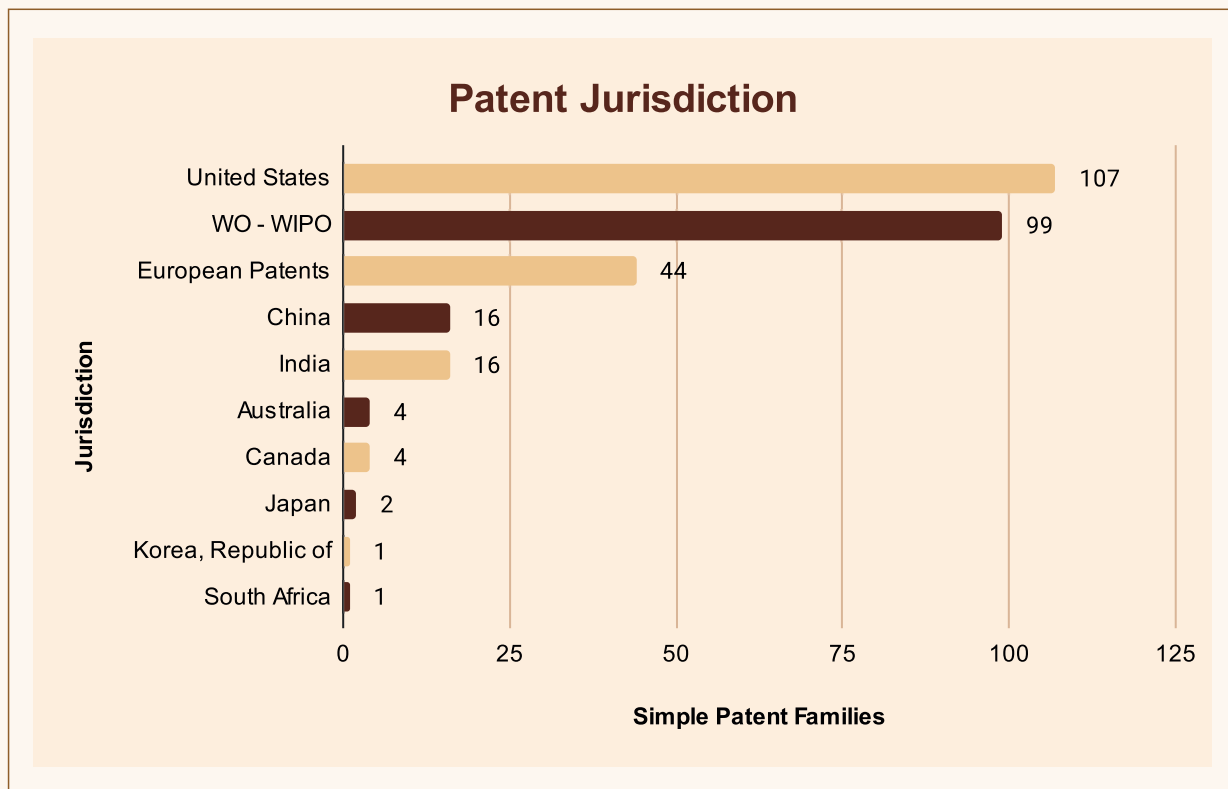
This points towards a pattern of preferring international patent protection rather than

domestic consolidation. By contrast, IP from China is majorly owned in the country itself, as seen from more than 47,000 patents being filed for ownership domestically (as shown in Graph 2). The pattern in China's case is to consolidate technological capabilities domestically.

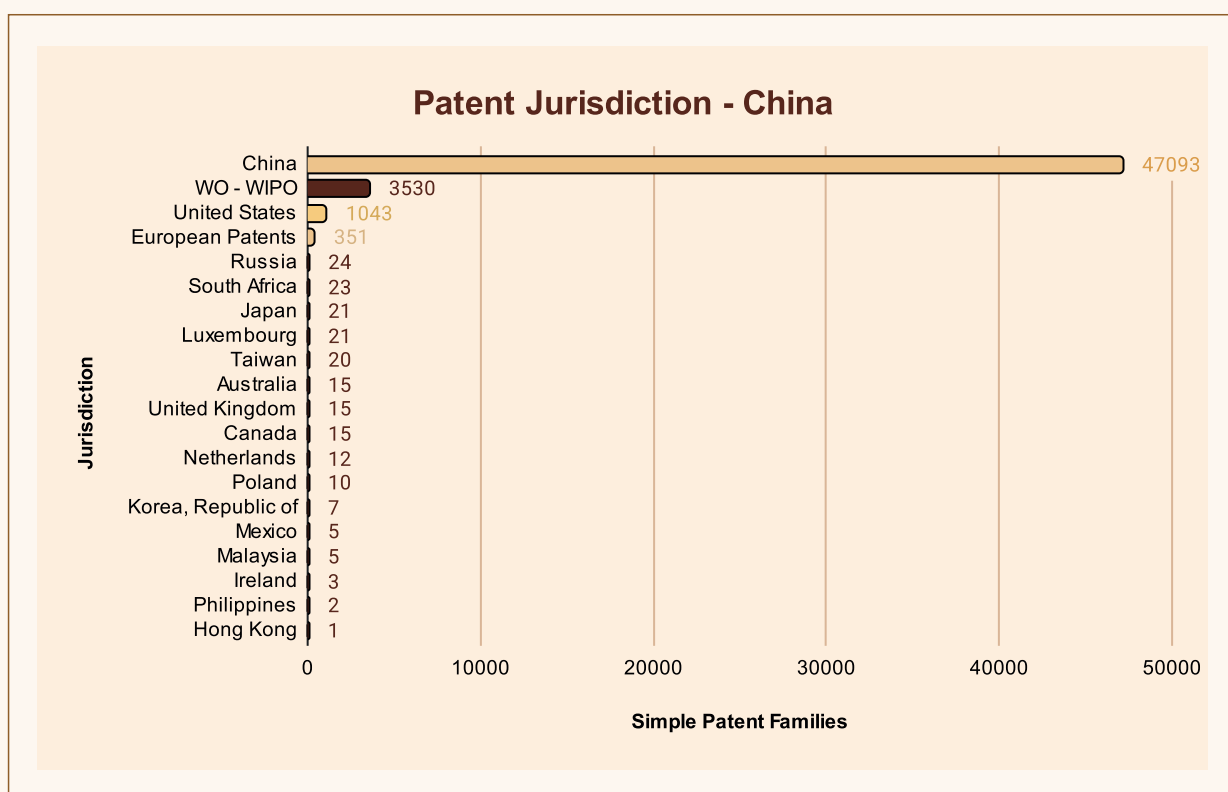
This contrast highlights a strategic reality - from a sovereignty perspective, retaining jurisdictional mandate and control over IP in the country is of equal, if not greater, strategic importance than the aggregate volume of domestic IP ownership. Currently, the Indian UAV ecosystem shows limitations in both jurisdictional and aggregate aspects, as indicated by India's relatively low share of 0.57% in granted patents and 4% in research publications. Multiple impediments to sovereignty are hence prevalent here: the low aggregate values, a skewed focus on applications and software by the published patents, and the jurisdictional preferences. A path towards sovereignty would require a push for domestic IP inventions focused on core technologies, along with facilitating IP ownership within the country.



AI-generated illustration.



Graph 1: Patent Jurisdiction - India | Source: Lens.org (Date accessed: 02/09/2025)

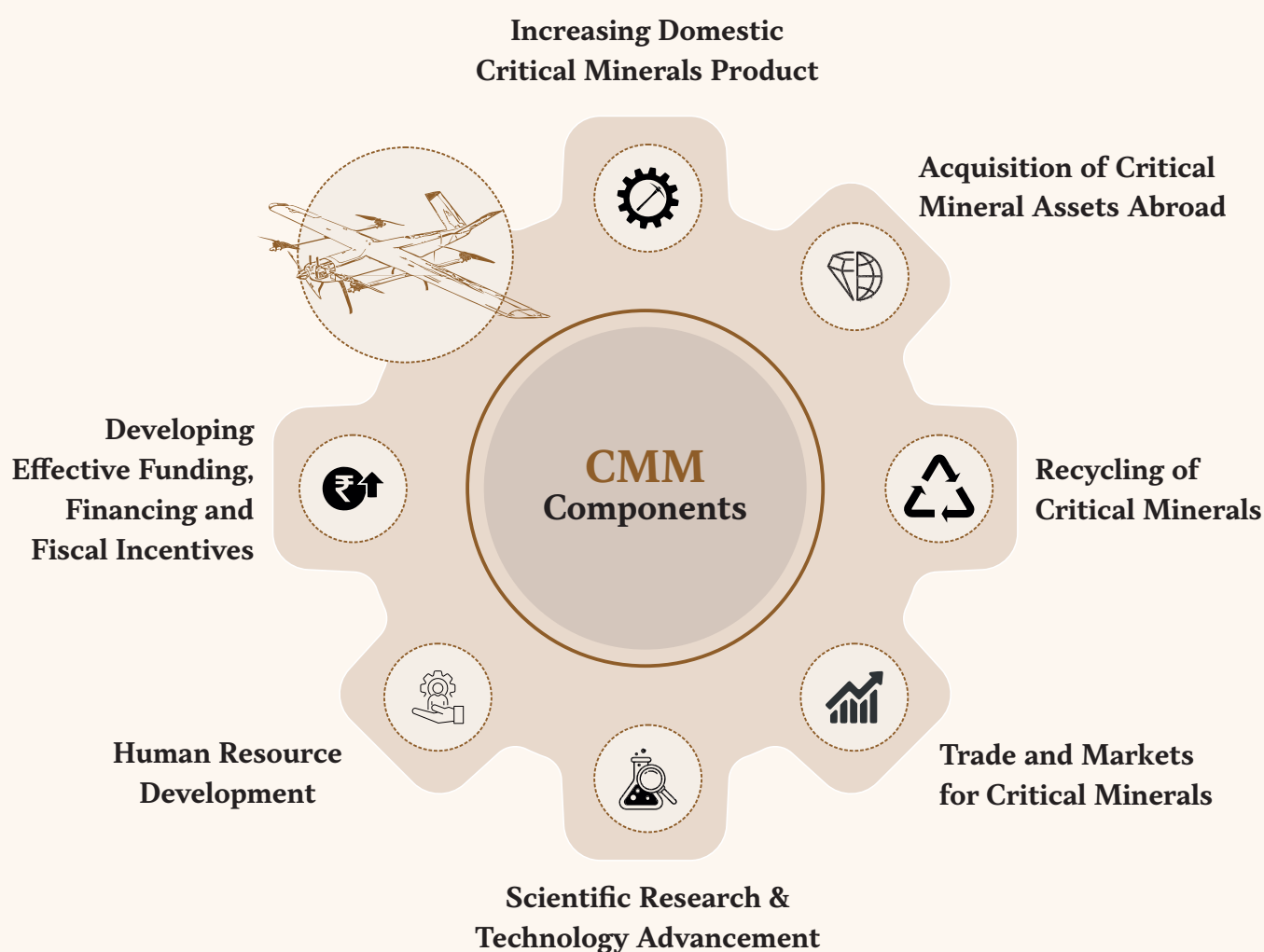


Graph 2: Patent Jurisdiction - China | Source: Lens.org (Date accessed: 02/09/2025)

III. Raw Material Dependency

The UAV ecosystem is import dependent for various upstream inputs like lithium (batteries), carbon fibre (airframes) and rare earths (propulsion). The presence of import dependency at the input stage, combined with the import dependencies that already exist at the subsystem stage points towards its systemic nature. The imports being majorly sourced from countries like China and the United States highlight the potential disruption this heavy dependence can cause, as seen during the recent export curbs by China for rare earths.

The supply chain vulnerabilities prevalent at the raw material level highlight a critical sovereignty constraint - a lack of domestic capacity. This issue is even more prominent as compared to component/subsystem level dependencies, because material dependencies require longer-term investments in extraction, processing and refinement infrastructure. The mandate of the National Critical Mineral Mission (CMM) for domestic and international exploration could fill this gap going forward.



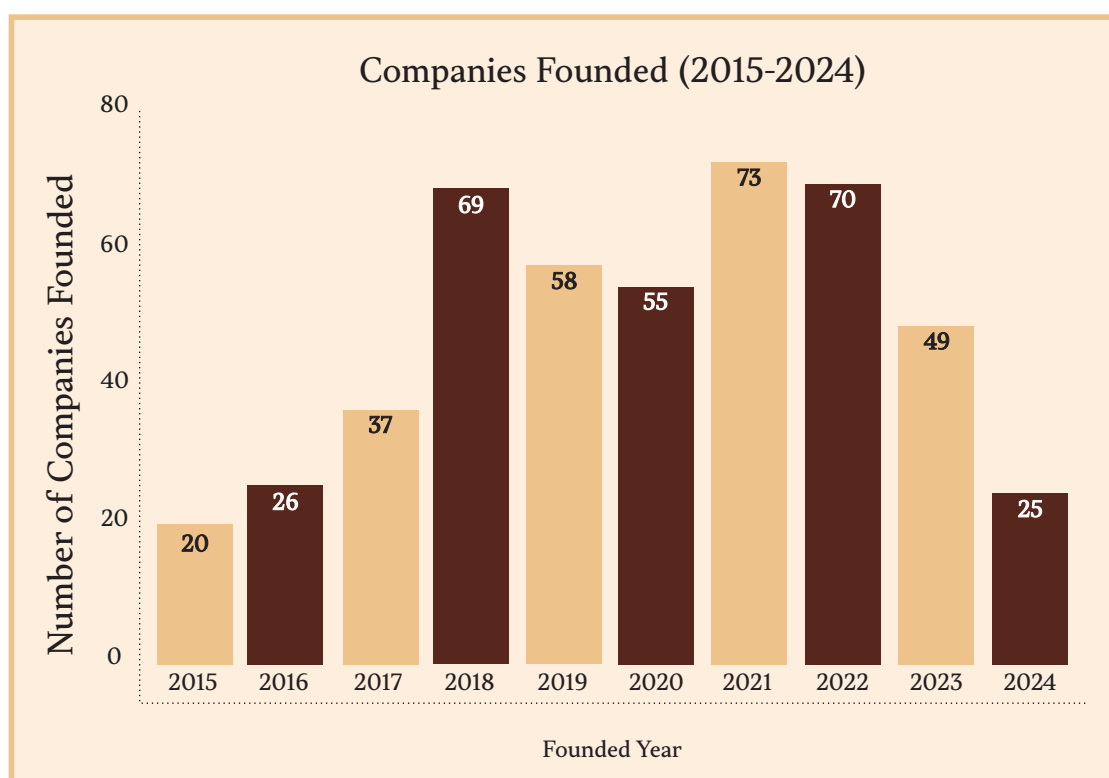
Source: PIB

IV. Technology translation - Startup and Investments

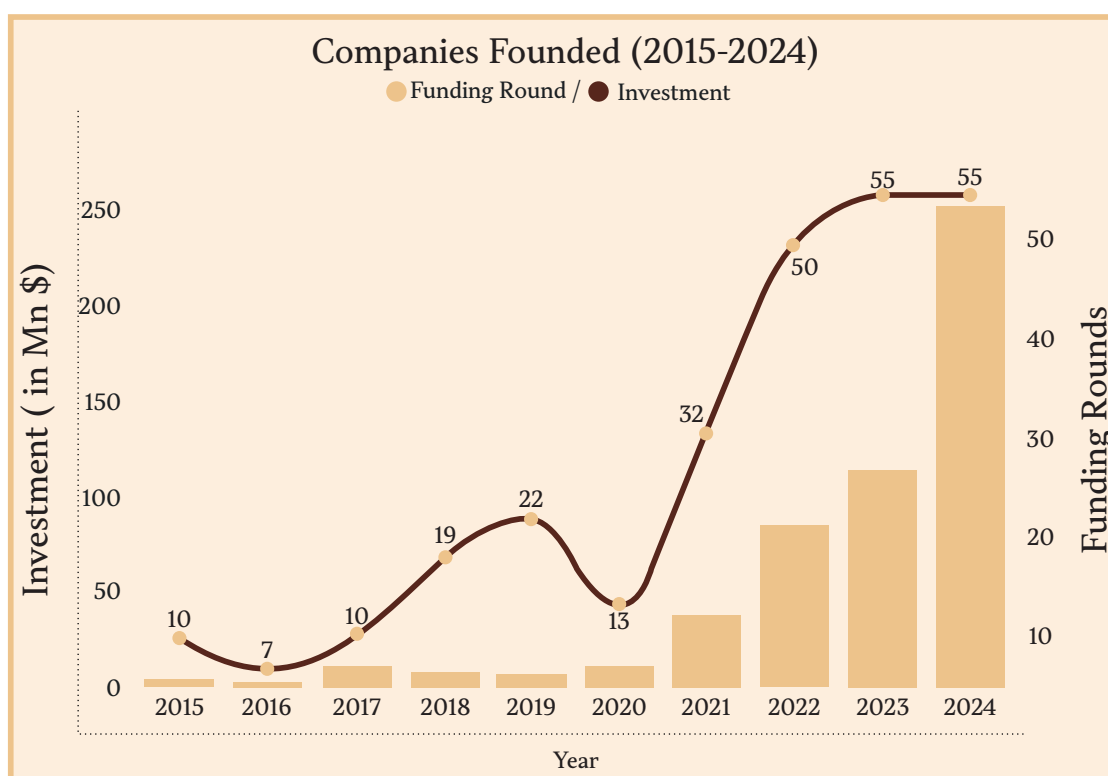
The industry relevance of Indian IP can be measured through analysing the startup and investment trends of the UAV technology ecosystem. The startup landscape has shown rapid growth over the past decade, hinting at the possibility of growing market confidence and policy maturation. Nevertheless, the concentration of market activity in application areas rather than core technology points towards a limited depth of domestic innovation. Over the past decade, around 500 startups were founded, with the highest being founded in 2021 (73 startups). This growth trend correlates with funding as well - from

around \$10 million in 2015 to more than \$50 million in 2024 (with a higher growth trend seen after 2021), as noted by Tracxn (shown in Graphs 3 & 4). The uptake in both funding rounds and investments coincides with the launch of the Drone Rules 2021, which aided market confidence.

An indicator for domestic capabilities and IP relevance can be the percentage of components that are domestically produced. The top 10% of UAV manufacturers are over 70% indigenous, while the bottom 50% are under 30% indigenous, according to DFI's Drone Landscape report.



Graph 3: Companies Founded (2015-2024) | Source: Tracxn (Date accessed: 08/09/2025)



Graph 4: Investments in UAVs in India | Source: Tracxn (date accessed - 06/09/2025)

This suggests that larger and more established startups have a higher tendency to have manufacturing capabilities in-house, while the smaller ones are mostly dependent on foreign IP or imports. This leads to a two-level formation:

The smaller, first tier comprises large companies that are technologically self-reliant largely with indigenous capabilities.

The larger second tier comprises smaller and newer companies that focus on assembly or services. These firms have limited indigenous capabilities and rely on foreign IP for operations.

The focus on applications may be an indication that startups are opting for quicker commercial viability through lower capital needs in the initial phases. However, this perpetuates the already nascent manufacturing capabilities in critical UAV technologies, thereby hindering longer-term sovereignty. Creation of cyclical dependency could also take place - the limited domestic capabilities lead to continued imports, which in turn disincentivise investments in indigenous manufacturing capabilities.

V. Convergence across sectors

Building domestic capacity could be catalysed by exploring convergence opportunities with other sectors. For example, the electric vehicle sector, with its projected ₹ 3.4 lakh crore investment by 2030, is already focusing on lithium-ion batteries and rare-earth magnets that are directly applicable to drones, as shared in Colliers' report 'EVs in India: Renewed Vigour in Electric Mobility'. Dedicated UAV production lines within the manufacturing facilities would reduce import dependence and leverage the new infrastructure to develop specialised UAV capabilities. Similarly, carbon fibre, which is essential for UAV airframes, is demanded by the aerospace

and wind energy sectors. Another convergence could be found with India's ongoing efforts to progress quantum sensing technologies through the National Quantum Mission (NQM). Enabling UAVs with indigenously built quantum sensors could improve their sensing capabilities, especially for military use cases. The ongoing initiatives under the Bharat 6G vision could also act as convergence opportunities for the UAV industry, enabling them to have reliable and real-time communication systems. Through convergence, we can address value chain constraints without UAV-specific investments lacking economies of scale.

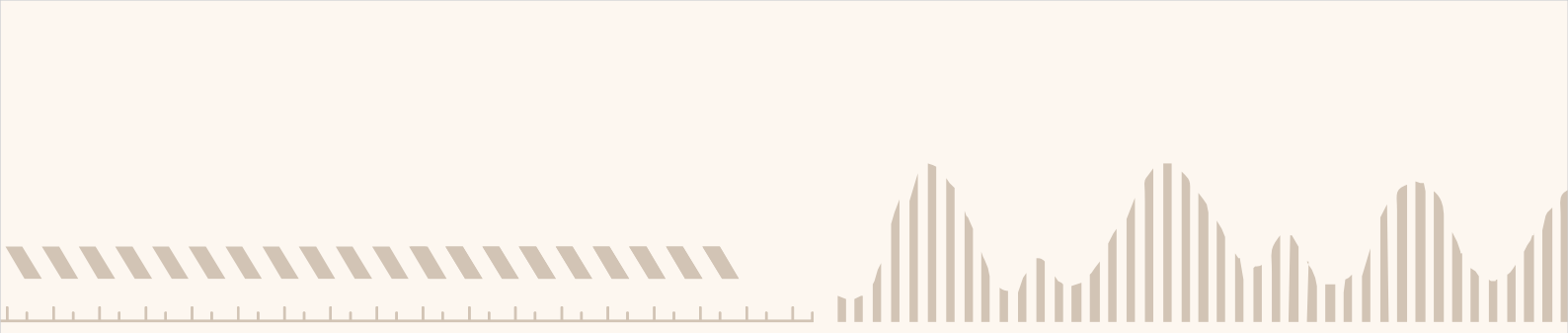
VI. Policy and Regulatory Framework

Regulations concerning drones have evolved over the past decade - from restrictions in 2014 to the liberalised drone rules of 2021 and to the Civil Drone Bill of 2025 (in draft stage currently). The opening up of 90% of the Indian airspace as 'green zones' by the 2021 rules led to a consistent growth in the number of startups being founded in this area.

Another crucial aspect for policy is testing and standardisation. UAV testing is crucial for improving innovation and policies. A regulatory sandbox is one such approach which is beneficial for both the industry and regulators, as it helps make real-world data

available for data-backed decisions and policies. The current lack of formal sandboxing regulations may hinder testing and innovation for commercial drones. At the global level, the International Standards Organisation (ISO), through a dedicated committee, is developing technical standards for UAVs. The International Civil Aviation Organisation (ICAO) is developing the overarching regulatory framework for UAV integration into the global airspace. Through the Bureau of Indian Standards (BIS), India is also participating in the global standard setting by being a full member of the ISO committee.





The Indian UAV ecosystem has come a long way in the past decade. It has seen a growth of startups, investments, knowledge intensity, as well as evolution at the policy level. However, heavy import dependence and IP translation challenges can hinder technology sovereignty in this critical area. The push for technology sovereignty in this space is not only a strategic imperative but also a tremendous economic opportunity that covers both the defence and

civilian domains. With the market for UAVs projected to reach \$11.06 billion by 2030, achieving sovereignty will have positive externalities ranging from strategic independence to positive economic contributions through use cases in precision agriculture, logistics and disaster management. By targeting the specific vulnerabilities, we can ensure that drones are not just assembled in India, but are also designed and engineered in India.





Image Credits: Licensed stock visuals.

Understanding the

National Security Implications of

UAV use cases

In conversation with

**Dr. Samir V. Kamat, Secretary,
Department of Defence R&D
and Chairman, DRDO**



In an exclusive interview for *Vigyan Dhara*, Dr. Samir V. Kamat, Secretary - Department of Defence R&D and Chairman - DRDO, shared insights with Rohit Gupta, Chief Technology Officer (CTO), OPSA on India's UAV capabilities, the evolving nature of air warfare, and the critical role of indigenisation in building a robust national drone ecosystem. As the country advances its strategic priorities in unmanned systems, Dr. Kamat also discussed DRDO's focus areas, public-private partnerships, and lessons from recent tactical operations.

The Evolution of Air Warfare and Emerging Technologies

Q: What will the future of air warfare look like in the next 10 to 20 years, particularly with advances in materials, sensing, and networking technologies?

Dr. Samir Kamat: The nature of air warfare is changing dramatically, as evidenced during Operation Sindoor. We no longer witness close combat scenarios. The Air Force is transitioning toward a paradigm where long-distance capabilities are employed to engage ground-based targets. Gradually, there will be a shift toward greater utilisation

of unmanned platforms in air warfare.

The future will also feature manned-unmanned teaming systems, wherein a set of unmanned aircraft operate alongside a manned aircraft, functioning as a system of systems to accomplish mission objectives. We are moving from an era characterised by close combat requiring dog-fighting skills to an era where air platforms serve primarily as mechanisms to deliver warheads to their desired locations with very precise strikes at far-off, stand-off distances.



AI-generated illustration

Q: In an AI-driven era, how much human oversight is both necessary and practical to ensure effective responses? What verification and governance frameworks should guide the operation of automated swarms and similar systems?

Dr. Kamat : There is an ongoing effort at the United Nations to develop rules and regulations for lethal autonomous weapon systems. However, allowing AI to make such decisions raises profound moral and ethical concerns. In contemporary conflicts, we already see a growing shift toward autonomous decision-making. In my view, a human should remain in the loop before any final decision to launch a weapon is made. Yet, given current trends, unless global consensus is reached at the UN level, the use of autonomous systems in weapon deployment is likely to continue expanding.

Q: No discussion on drones is complete without referencing the Russia–Ukraine conflict. What operational lessons from this experience are relevant to India’s defence sector?

Dr. Kamat : We have already applied several of these lessons during Operation Sindoor, where our services employed UAVs and drones with considerable effectiveness. In that sense, many insights from the Russia–Ukraine war have already been internalised. What we must now focus

on is building comprehensive supply chain capability within the country. The government has taken steps in this direction through the PLI scheme. Once we strengthen this foundation, combined with our strong system integration capabilities, we will be well positioned to manufacture any type of drone indigenously.

Q: Ukraine’s experience has highlighted the value of local industry and rapid improvisation in drone warfare. How can India strengthen its domestic capabilities so that units can adapt quickly to changing payload and mission requirements in the field?

Dr. Kamat : This is an area our industry will need to build further. At present, we are not as agile as Ukraine has shown itself to be. Much of this rapid innovation, however, occurs in wartime, when technological development and adaptation naturally accelerate. In peacetime, regulatory processes and testing requirements slow the introduction of new technologies. I am confident that if India were to face a similar situation, innovation would advance rapidly out of necessity. But in peacetime, replicating what is happening in Ukraine is challenging, and this pattern is consistent throughout history. During the Second World War, for example, numerous technologies emerged quickly because extensive testing was bypassed. In contrast, peacetime demands a complete validation cycle, which inevitably slows innovation.

Indigenisation Strategy and Public-Private Partnerships

Q: How does DRDO plan to partner with commercial innovators and start-ups while protecting sensitive technologies?

Dr. Kamat : Today, we have a policy to treat the private sector and public sector equally. Our partnership decisions are based on criteria other than whether an entity is private or public, except in the case of our strategic systems. For all tactical weapons, we do not differentiate between the private and public sectors. However, we have certain norms in place to ensure that the technology developed remains within the country.

Q: What role should commercial innovators and start-ups play in developing a national drone ecosystem?

Dr. Kamat: Start-ups and the private sector are currently playing a significant role in the drone ecosystem. Today, we possess very good system integration capability when it comes to drones, which resides mostly in the private sector and particularly with start-ups. Moving forward, we must ensure that the entire supply chain

involved in manufacturing drones also becomes indigenised. Considerably more effort is required in this area. The Ministry of Civil Aviation's PLI scheme encourages domestic manufacturing of subsystems and components which go into making a drone. The private sector and MSMEs (Micro, Small and Medium Enterprises) can play a pivotal role in indigenising these subsystems.

Q: Is DRDO playing any role in the indigenisation of critical drone

Dr. Kamat : Currently, DRDO's focus is on larger UAVs - specifically, Medium Altitude Long Endurance (MALE) and High Altitude Long Endurance (HALE) UAVs. In the domain of smaller drones, DRDO provides assistance with whatever technologies we have developed. We are not engaged in developing smaller drones ourselves because the capability in the industry is very good today. We collaborate with numerous start-ups to utilise their drones, either to weaponise them or to employ them for specific DRDO applications.



Q: How does DRDO balance the dual-use nature of drone technology between civilian benefits and military applications?

Dr. Kamat : The civilian applications of HALE and MALE are quite limited; they are predominantly for military applications. It is the smaller drones where dual use exists, and that is not a space where we are actively engaged. Military drones require certain characteristics that civilian drones do not. They must operate in environments where GPS can be denied and function in an electronic warfare-tense environment. These characteristics are essential for military drones, and these are technologies we already possess. We are working with start-ups and MSMEs to assist them in upgrading the drones they manufacture to military grade.

Q: Are there successful examples of technology transfer between the civilian and defence sectors in drone space?

Dr. Kamat : We work with drone manufacturers, though I do not wish to name specific companies. We have the ability to design ammunition that can be integrated on platforms such as helicopters and aircraft. We are transferring this knowledge to enable drone manufacturers to integrate this ammunition on their platforms. This is one example where many of the weaponised drones that our tri-services are now procuring from the private sector involve DRDO's close collaboration with those companies to facilitate the weaponisation process.

Q: What are the top strategic priorities for UAVs for DRDO?

Dr. Kamat : As mentioned, our focus is on HALE and on developing an unmanned combat aerial vehicle (UCAV) - essentially, a remotely piloted strike aircraft. Our emphasis is on these categories of UAVs.

Q: Do you foresee any shifts in these priorities over the next 5 to 10 years?

Dr. Kamat : I don't think so because these systems will take approximately five years to build. These are areas we have recently initiated, and my estimation is that we will require five to seven years to build this capability. Therefore, I do not foresee any change in the next 5 to 10 years. Beyond that timeframe, given how rapidly technology is changing, we will need to reassess as the years progress.

Q: Which UAV capabilities are most critical for national security, and where do current gaps suggest opportunities for private-sector solutions?

Dr. Kamat : Today, we have good system integration capability, but our supply chain is not indigenous. That represents a vulnerability. As witnessed in recent conflicts, the numbers of UAVs required for sustained warfare are substantial. With today's production capability, we would not be able to sustain prolonged conflicts. Therefore, we need to build indigenous capability for subsystems and scale up our production. Supply chain and subsystems are the critical areas.

Operational Effectiveness and Counter-Drone Systems

Q. How would you summarise the role of unmanned vehicles during Operation Sindoor?

Dr. Kamat : They played a very critical role. UAVs were used for Intelligence, Surveillance, and Reconnaissance (ISR), as loitering munitions, and for providing necessary information to enable weapons to be launched at precise positions. Not only UAVs, but counter-UAV systems also played a very effective role.

Q: Operation Sindoor demonstrated the strategic integration of layered air defence systems and electronic warfare countermeasures. What worked best in detecting and defeating enemy drones? Are there gaps that remain in electronic warfare or kinetic defence?

Dr. Kamat : We have what is known as a D4 system, which is a layered defence. It comprises a radar with a

range of 6 to 8 kilometres, which hands over to an electro-optic system that then tracks the drone. Following this, we have a soft kill option which is an Electronic Warfare Device (EWD) and also a hard kill option which is a laser-based system that can destroy the drone. This system functioned very effectively during Operation Sindoor.

We are also developing high-power microwave-based counter-UAV systems, which will be more effective against swarms. Laser-based systems require precise pointing and can only tackle one drone at a time, whereas high-power microwave systems can neutralise a swarm of drones simultaneously. I would note that the D4 system had limited deployment because these systems are just being inducted into service. However, many of the soft kill systems were already inducted and have proven to be very effective.



Source: timesofindia

Q: From a cost perspective, are non-kinetic approaches more economical than kinetic approaches?

Dr. Kamat : Yes. Laser-based systems have a very low cost per shot, although the initial system cost is higher. Gun-based systems for very small drones will also be highly effective, and we are developing those solutions to reduce costs.

Missile-based systems are very costly and should not be employed against smaller drones. They should be reserved for MALE and HALE type systems. For low-flying UAVs, missiles are an overkill because the cost of the drone is much less than the cost of the missile used against it. For these threats, non-kinetic means are the optimal approach.



Q: Any closing thoughts on the future of the drone ecosystem in India, and any message for start-ups and MSMEs?

Dr. Kamat : What the start-ups and MSMEs have achieved in the last five years is truly significant. Today, we have the capability to design any type of drone within the country, and our structural manufacturing capability is also excellent.

Where we need to focus is the power systems, flight control systems, on-board computers, avionics, batteries, and gas turbine engines or internal combustion engines for these platforms. These are components we must prioritise over the next three years to ensure we have control over our supply chain.





Scan the QR
to watch the
entire interview

AI-generated illustration

Unmanned Horizons: The Indian Air Force and the Future of Unmanned Airpower



Air Vice Marshal Ashish Singh, VM, VSM
ACAS Ops (Remote)

This article is curated based on insights shared by Air Vice Marshal (AVM) Ashish Singh in response to a set of questions and examines the Indian Air Force's (IAF) growing integration of Unmanned Aerial Systems (UAS). It highlights the evolving synergy and distinctions between manned and unmanned platforms, the transition shaping modern airpower, and the IAF's indigenisation efforts to nurture a vibrant ecosystem for UAS innovation in India.



Source: [airpowerasia](http://airpowerasia.com)

Unmanned Aviation : A Brief Contextual History

The air domain is the newest physical domain of both warfighting, as well as transportation; it's barely a century old, as compared to land and maritime domains. The evolution of airpower represents an ongoing paradigm shift, with much still unfolding. In terms of its impact on civilisation, we are currently living in the “age of airpower,” though this may only be recognised in hindsight, much like the age of sail. Stockholm International Peace Research Institute (SIPRI's) data from 2018–2022 notes that aircraft accounted for nearly 50 percent of total arms exports by the world's ten largest suppliers. Airpower thus remains highly valued, and unmanned technology marks a significant milestone in its evolution. It's an evolution within a larger revolution.



V-1 flying bomb on display at Imperial War Museum

Unmanned aviation's first widely useful role has been Intelligence, Surveillance and Reconnaissance (ISR), mirroring the early trajectory of manned flight. In case of manned aviation, the first recorded case is from 1794 when the French prevailed in the

Battle of Fleurus as a General observed the battlefield from high above, achieving victory by superior observation. Similarly, in recent decades, the most significant role of UAS has been in ISR, even though their earliest, and still ongoing, use was primarily for target practice. The Germans used the V1 and V2 guided missile weapons offensively for psychological effect in World War II (WWII). The Americans used it for reconnaissance during the Vietnam war. The Israelis used it innovatively for decoy and DEAD (Destruction of Enemy Air Defences) missions in the 1982 Bekaa Valley conflict. The US changed the norms of armed UAS usage when they armed a Predator in 2001 and started to carry out decapitation strikes against terror.

Its role in the CSFO (Counter Surface Force Operations) was highlighted in the Azerbaijan-Armenia conflict. The ongoing Ukraine -Russia conflict has seen the evolution of multiple roles by both militaries that have arguably not been 'air-minded.' In the CSFO role, one notable shift it demonstrates is that it enables smaller forces to hold ground or

prevent an enemy's advance, hence addressing a long-standing limitation of airpower, which traditionally could not hold territory. Its ramification is that airpower (manned or unmanned) enables a reduction of standing armies, especially in defence of static lines. Deterrence against invasion can be achieved with smaller standing armies, and if it fails, 'denial' of enemy land objectives through airpower is possible. This war has also seen its use in coercive roles via what is traditionally called Strategic Bombing. There is little conceptual difference between the Strategic Bombing Campaigns of WWII and the target sets being attacked via UAS in this conflict today – population, energy and infrastructure. The Israeli vs Iranian use earlier this year is interesting. Both sides used it in a different conceptual manner. The Israelis used it in seamless amalgamation with manned airpower, enabling the best of both to be applied synergistically in a 'denial plus decapitation campaign' focussed on military/strategic targets. In contrast, the Iranians have used it less effectively in a stand-off retaliatory mode, clubbing it with other unmanned vectors like rockets and missiles, in a largely 'punishment' mode. These examples reiterate the lessons of airpower that clear conceptual doctrine drawn from historical lessons i.e. coherent air strategy, wins out over any quantitative buildup or application of airpower whether manned or unmanned. Coming to the example of Operation Sindoor; both sides had airpower (manned and unmanned), one side used it (both manned and unmanned) synergistically to attain war objectives in line with its doctrine, the other attacked incoherently, with nothing to show for its manned/unmanned offense.



India's Unmanned Air Power Trajectory

IAF has a Capability Development Perspective Plan 2047 and UAS are a large part of that plan. Earlier this year, the IAF formulated a conceptual 'UAS Vision and CONOPS' (Concept of

Operations) document to guide future development, distinguishing between immediate needs and long-term goals. Circumstances demand a rapid expansion of our UAS fighting

potential, to the tune of more than 30 units in short measure and more later, as the future technologies we are investing in, bear fruition. We see this as an indispensable facet of airpower that we will nurture to its full potential.



*The ALS-50 loitering munition.
Source: Tata Group*

The IAF has invested in various facets of unmanned aviation from more than two decades ago. It was not just ISR, but roles like DEAD, Unmanned Strike, Target practice and special roles. Our force structure reflects our priorities - driven by the offensive value of airpower and the centrality of targeting and intelligence. These missions require control of the air, which in turn depends on suppressing

enemy air defences, both on the ground and in the air. Effective targeting also depends on strong ISR capabilities. This is why we have invested in above capabilities. In recent years, this investment has expanded significantly. The creation of a dedicated 'Remote' sub-branch headed by a two-star officer, establishment of a Weapons Systems School for training unmanned cadets, and a UAS School for operational training underscore this shift.

While unmanned aviation can theoretically perform most functions of manned aviation, its utility must be guided by cost/benefit considerations. The IAF prioritises unmanned missions that are Dangerous, Dull, Dirty, Impossible, and Efficient (DDDIE). Unmanned systems are invaluable for reducing human risk during high-threat operations. Some missions that manned aircraft cannot undertake, such as flying inside buildings or beneath foliage, or performing stand-in jamming, are now made possible due to smaller platform sizes of unmanned systems.

Efficiency becomes another key factor. Long-endurance ISR systems, for instance, offer cost-effective peacetime surveillance. A 2021 U.S.

Congressional Budget Office study found the U.S. Air Force's RQ-4 Global Hawk to have 17 percent lower lifecycle costs than the U.S. Navy's P-8. However, other studies show that in strike roles, platforms like the MQ-9 Reaper can cost more and offer lower survivability than manned aircraft such as the F-16. Hence, the optimal approach is to combine manned and unmanned capabilities to maximise effectiveness while minimising risks.

UAS are getting simpler to operate as computers execute many jobs which need human skills. For example, larger UAS which needed external pilots to land, now land automatically. Training for tactical tasks has become faster and simpler, broadening the demographic of operators to include airmen, women, short-service personnel, and even reservists. The IAF Vision and CONOPS document also records this, and will use these guiding tenets to shape future organisational structures and policies. On the other hand, the complexity of warfighting at the operational and strategic level will only grow more complex and that requires air-mindedness in training. It will become even more important to ensure airpower training and education for higher levels of warfare that does not neglect the lessons of Airpower Doctrine. The IAF system has catered for this by its overview of the continuum of training between Air Force Academy (AFA), Weapon Systems School (WSS), School of UAS, as well as higher education at courses like Higher Air Command Course (HACC). However, UAS also raise questions about airspace management or command and control mechanisms in war.

Airspace management for unmanned aviation must follow the same foundational principles as general aviation. Agencies such as the IAF and Airports Authority of India (AAI) already have defined roles and are evolving rules to integrate unmanned systems. Larger Unmanned Aerial Vehicles (UAVs) currently file flight plans and are integrated with existing airspace networks, such as the IAF's Integrated Air Command and Control System (IACCS),

which already interfaces with AAI. The challenge lies in integrating smaller UAVs into systems designed primarily for manned aircraft. However, efforts are underway to transition from notification-based operations to real-time tracking and to develop an Unmanned Traffic Management (UTM) system compatible with diverse UAV platforms.

In airpower application, offence and defence cannot be separated. As the entity responsible for Air Defence of the nation, we apply the same core principles whether addressing manned or unmanned threats and whether executing area or point defence. We are investing in both procurement and indigenous development of C-UAS capabilities across the spectrum from enhanced detection to a range of neutralisation options, including hard-kill, electronic warfare, and directed energy systems. Close collaboration with industry and DPSUs aims to align operational concepts with fielded systems.

Globally, the counter-UAS mission faces two persistent problems. First, legacy air-defence systems are optimised for larger (manned) platforms and struggle to detect very small UAS. Second, the cost of neutralisation is often calibrated to expensive manned targets; against cheap, small drones the expense of countermeasures can exceed the value of what is being neutralised. Nevertheless, the decision to engage depends on the opportunity cost of failing to eliminate an imminent threat. Air defense technology is working to tackle this new factor.

Innovation, Indigenisation, and the Flight Ahead

While general costs of UAS are lower than comparable manned platforms, so are the performance characteristics and safety/reliability. Foreign platforms push up costs and impose time penalties in logistics of maintenance. This will reduce as the IAF's plan of Made in India UAS fructifies. We plan to rely on greater measures on domestic industry for complex maintenance, while simultaneously ensuring simpler forward maintenance for availability in war. Lifecycle costs promise to be lower for low end platforms; it may not be so for platforms like Unmanned Combat Aerial Vehicles (UCAVs) depending on factors like how many operators / maintainers each platform needs, accident rates etc. Given the rapid evolution in this domain, our procurement and HR policies

may need change to cater for faster procurement, faster regulatory clearances, fast obsolescence and replacement, as well as faster upgrade cycles. Many UAS capabilities we want are available in the Indian market, and can be inducted fast, but the human resource we need will take longer to induct and train, due existing policies.

The IAF's first major initiative toward indigenising UAS was the launch of the Mehar Baba Competition in 2018 as a technology development platform, preceding programmes like iDEX. The first edition focused on Swarming technologies based on Humanitarian Assistance and Disaster Relief (HADR) scenarios. An investment of ₹ 16.5 Cr on the competition resulted in total orders for all participants exceeding



Source: PIB

The Indian Air Force (IAF) organized the Mehar Baba Competition-II (MBC-II) in 2022, aimed at developing a swarm drone system to detect foreign objects on aircraft operating surface

₹2000 crore, besides generating employment for hundreds of engineers. The second edition concluded in 2024. This year, the IAF is launching two new editions: one focused on island logistics and the other on distributed radar systems. These R&D initiatives create ripple spinoff benefits.

Recognising aviation as a dual-use domain, the IAF is determined to avoid the historical dependence on imports that has characterised both civil and military aviation. For instance, airlines are projected to import one aircraft per week over the next decade (GE Aerospace, October 2025). The IAF is aligning with the Hon'ble Prime Minister's vision to make India a global drone hub - serving both defence and civilian sectors. For instance, the IAF plans to develop a hydrogen-based medium-altitude heavy-lift airship, advancing the National Green Hydrogen Mission while enabling spin-offs in civilian logistics. Similarly, the High-Altitude Pseudo Satellite (HAPS) programme is expected to yield benefits in communications and other industries.

To foster innovation, the IAF continues to engage with industry and academia through seminars and initiatives like Mehar Baba - not merely to share procurement plans but to encourage creative problem-solving. It is also providing industry access to test ranges and expert guidance to support indigenous development. An Aerospace University could further strengthen this ecosystem by combining public investment in testing infrastructure with private innovation and research. The IAF can contribute significantly to this effort through its skilled human resources and aviation expertise. This could be the kernel

around which an innovative aviation ecosystem could grow – an Aerospace Hub based on UAS.

Future UAS will see an increase in autonomy, Artificial Intelligence (AI), swarming, endurance and speed. One problem UAS face is the umbilical cord of connectivity with the human controller on the ground. As systems proliferate in numbers and increase in range, the bandwidth for data will tend to run out. This is especially true of SATCOM based long range capability. Increased dependency on Space communications will make Space a future Centre of Gravity (CoG) for aerial warfare outcomes. The way out is to increase the degree of UAS mission autonomy so as to reduce data flow, saving it for the most essential human intervention. This autonomy will in turn need machine intelligence. Therefore, AI in both piloting, as well as other mission subsets, will need to increase. AI will also be essential for accelerating decision-making, which is critical in the air domain, where the tempo of warfare is significantly faster than in the other two physical domains.

Swarming is also expected to grow in importance. Swarms harness the power of coordinated teams and, among other advantages, can function as a form of collective or distributed intelligence, thereby reducing the computing load required on each individual system. Conversely, AI will be essential to control large swarms, as there will be a limit to how many machines a single human can control simultaneously. Yuval Noah Harari credits the rise and dominance of Homo Sapiens to the ability to cooperate on the largest scales

possible. Swarm behaviour holds the potential to do the same for machines when they act in concert towards warfare.

While most proponents prefer speed, endurance has its own advantages. Long loiter UAS can dominate battlefields and create better situational awareness. This especially holds good for missions like Suppression of Enemy Air Defence (SEAD), where the mere presence of an enemy UAS deters AD systems from opening up. Long loiter also sharpens 'orientation', the key aspect of the OODA loop. Technology continues to increase aerodynamic and

energy efficiency towards increasing endurance, for both large (HAPS) and smaller machines. This development will happen in parallel with increase in speed – not just physical speed, but of decision speed. Both speed and endurance can translate to larger reach.

Looking ahead, indigenisation will broaden our capabilities across ISR, Electronic Warfare (EW), strike, mobility, logistics, and even casualty evacuation i.e. every civil/military role of airpower; and we are cultivating a military–industrial–academic ecosystem to sustain innovation.



MQ-9B SkyGuardian, a derivative of MQ-9 Reaper

Source: aerotime

Swarming with Small Drones:

A Game changer



The conduct of tactical and operational warfare, and indeed the battlefield scenario, has been fundamentally redefined by the advent of UAVs. Lower acquisition costs, reduced Electromagnetic (EM) signatures, and the ability to operate at very low altitudes have made them highly effective in modern conflict zones. When employed in coordinated formations, these systems can degrade the efficiency

of conventional air defence mechanisms.

Furthermore, these systems create an asymmetric cost-exchange ratio, where inexpensive UAVs can impose disproportionate economic and strategic costs on high value assets. From a defence perspective, drones have emerged as a persistent, distributed and adaptive aerial threat, requiring the evolution of new paradigms to counter them.



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From Remote-Controlled Drones to Swarming Systems

Remotely operated First Person View (FPV) drones have been commonly used as weapons of choice in almost all recent major conflicts, such as the Nagorno-Karabakh war, the Ukraine- Russia conflict, the Middle-East conflict and Operation Sindoor. In their 2025 study for the French Institute of International Relations, Vincent Turret examined how mass drone warfare represents a potential military revolution, fundamentally changing how forces engage in combat.

While these systems have demonstrated reasonable success, they

remain vulnerable to electronic warfare measures such as communication and GNSS (Global Navigation Satellite Systems) jamming. To counter these vulnerabilities, some platforms have incorporated limited onboard autonomy, typically restricted to predefined route following, collision avoidance, and end-game target acquisition. However, increasing autonomy often comes at the cost of size, complexity, and expense, making such systems more susceptible to interception by conventional air defence systems.

Against this backdrop, drone swarms have emerged as a new and transformative threat. By leveraging the sheer number of smaller, inexpensive, and minimally capable platforms, swarms can overwhelm even the most advanced defence systems.



Understanding **Swarm Dynamics**

In 2004, researchers Marco Dorigo and Erol Sahin defined a swarm of robots as “a large number of relatively simple, physically embodied agents, designed such that a desired collective goal-directed behaviour emerges from local interactions among agents, and between agents and the environment.”

The effectiveness of a drone swarm, therefore, does not arise from individual drones but from their collective behaviour, where the whole is greater than the sum of its parts. A group qualifies as a swarm only when coordinated, goal-driven behaviour emerges from the decentralised interactions of many simple agents.

Drone swarms represent a significant leap from current state-of-the-art multi-agent systems (MAS), where each drone is individually capable of executing complex missions. It is important to distinguish swarming from other group dynamics that may appear similar:

- **Synchronised flying:** As seen in drone light shows, where formation and movement are rigid and predetermined.
- **Flocking:** As seen in bird formations, which are loosely coordinated and usually led by one or few individuals.



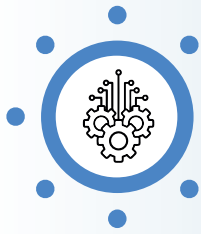
Source: Botlabs Dynamics

3,500 indigenous drones light up the Raisina Hills during rehearsals for Beating the Retreat ceremony 2023

Key attributes of **Swarming**

The fundamental characteristics and attributes defining a swarm are:

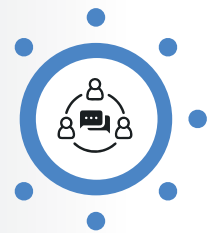
Minimally Capable Platforms



Individual drones in a swarm are intentionally “simple” and typically incapable of executing a mission individually. They are equipped with minimal sensing, computing and communication capabilities for localisation and environmental perception. This minimalist approach creates an asymmetric advantage, making swarm systems extraordinarily cost-effective against even the most advanced individual manned and unmanned systems.

Local Communication

Drones in the swarm communicate exclusively with their immediate neighbours, either directly or through the environment (Known as stigmergy). The communication could be opportunistic and need not be continuous in nature. Individual decision-making on the platforms does not require global awareness at highest fidelity; only necessary information is shared among neighbours, thereby conserving communication bandwidth. Information that isn't relevant beyond the immediate neighborhood is naturally attenuated, while essential data can be abstracted and propagated further as needed.



Emergent Behaviour



One of the principal differentiators of a swarm is that the local interactions of the simple drones evolve to form what is called emergent behaviour, where local interactions among simple drones evolve into sophisticated collective actions. Research by Melanie Schranz and colleagues in 2020 documented various swarm robotic behaviors and their current applications, demonstrating how emergent behavior is directed toward achieving overall mission goals through the coordinated actions of individual platforms. Evolving and adaptive behaviours makes them flexible to handle different environments and tasks dynamically increasing mission survivability against hostile actions. them flexible to handle different environments and tasks dynamically increasing mission survivability against hostile actions.

Decentralised Control

Another key differentiator of a swarm system is that there is no centralised command and control unit. The collective behaviour of the swarm results from a composition of the local decisions made by individual drones in the swarm. This provides exceptional operational resilience and robustness, since there is no single point of failure that can be targeted. Decentralisation and local communication make the system scalable, i.e. swarms can maintain their function while changing their size.



*[The above-mentioned characteristics and attributes have been outlined in the 2018 book *Swarm Robotics: A Formal Approach* and in the 2020 research papers *Swarm Robotic Behaviours and Current Applications*; and *Frontiers in Robotics and AI* by Springer M. Schranz, M. Umlauf, M. Sende, W. Elmenreich.]*

Autonomy in **Swarming**

To be effective in an EW-contested battlefield environment, each platform in the swarm would have to be autonomous, with the key components of such autonomy being:

- a) **Localisation**, which enables each drone to determine its own position, orientation and speed in the environment. In a contested environment where GNSS signals are denied or degraded through spoofing, swarm drones need to rely on collective localisation, where positional data shared among neighbours is used to create and maintain the spatial awareness.
- b) **Perception**, which involves interpreting the environment using sensors mounted on the platform. Thomas Schmickl's 2007 research on collective perception in robot swarms demonstrated how individual platforms with limited fields of view can share perceptual information to create comprehensive environmental awareness.

Opportunistic propagation of individual perceptions among neighboring drones creates shared situational awareness, allowing the swarm to react to evolving battlefield dynamics.

- c) **Navigation Planning**, which requires each drone to generate collision-free trajectories through cooperative path planning with its neighbors while maintaining focus on the overall mission goal.
- d) **Mission Planning**, which encompasses several sophisticated tasks. Drones must supplement their current operational state with situational awareness of the dynamic environment and neighboring platforms. They identify possible secondary objectives that support primary mission goals and evaluate feasibility. Finally, they plan and execute basic low-level actions within their capability to realise mission objectives in cooperation with neighboring platforms.

A swarm with heterogenous capability is shown in Figure 1 below, depicting the dynamic nature of operations. A supporting aspect of autonomy is deriving a cohesive situational picture of the swarm's operational state from sporadic inputs from individual

platforms. This includes tracking progress toward primary and secondary mission objectives, and assessing the capability and capacity currently available in the swarm to successfully achieve these objectives.

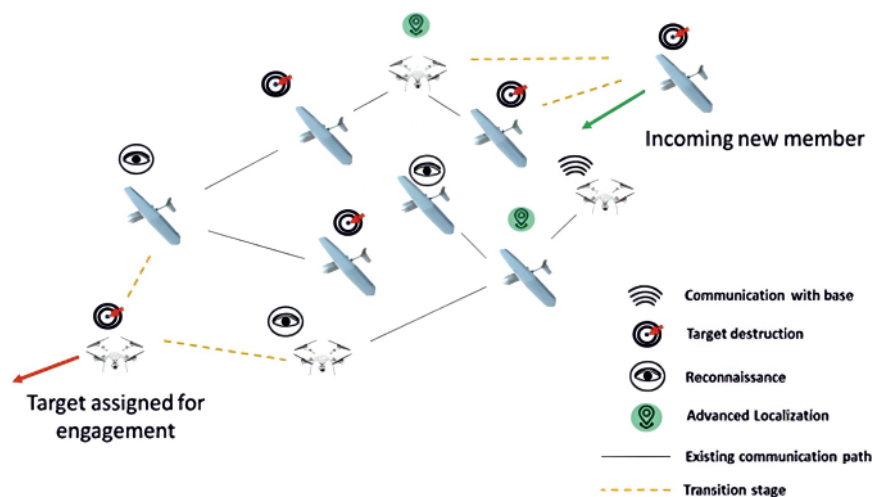


Figure 1: Swarm with heterogenous capabilities showing dynamic nature of team composition during missions.



For representational use only

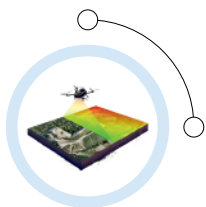
Source: Open source visual

Applications of Swarming

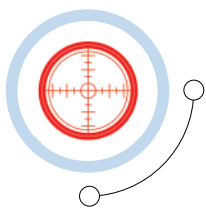
In their 2025 analysis of AI-driven drone swarms, Johnson, Williams, and Hoover highlighted the transformative potential of swarming for future battlefields. The possible operational applications include:



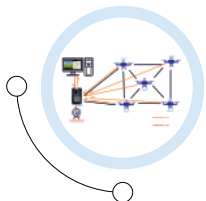
Deploying coordinated, resilient for tactical surveillance, reconnaissance and kinetic operations



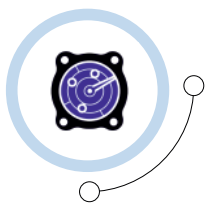
Rapid and resilient surveillance and near-field photogrammetry of enemy areas and vulnerable points for 3D model construction, useful in special operations



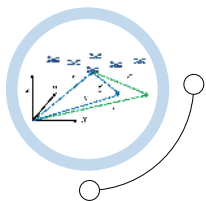
Combat missions employing munitions to locate and destroy specific targets while countering enemy defences.



Creation of ad-hoc aerial networks in support of ground operations for relaying communication and PNT data.



Acting as decoys that collectively mimic the radar cross-section of larger aircraft



Functioning as collective “super sensors,” such as synthetic aperture radar (SAR) systems, through coordinated use of onboard radio frequency components.

Challenges and the way forward

In their comprehensive 2025 review published in the Journal of Engineering and Applied Science, Yusuf Alqudsi and Mustafa Makaraci identified significant challenges that must be addressed before drone swarms can be operationally deployed. AI-based systems are essentially non-deterministic when operating in a continuous, non-discretised domain. It is essential to establish guarantees of safety, security, robustness, resilience, reliability and trustworthiness, especially in the context of combat environments. This will require a continuous and sustained cycle of technology development and infusion. Mika Lehto and Bill Hutchinson, in their 2021 presentation at

the International Conference on Cyber Warfare and Security, emphasised that new operational paradigms must be evolved to effectively employ such systems, including logistics and maintenance, especially considering the rapid evolution of technology, and shortened obsolescence horizons.

Operational deployment will also need the integration of these systems into a Command and Control (C2) grid, with situational awareness across the echelons. While this is well understood for manned and small groups of unmanned platforms, new concepts will need to be evolved to effectively employ and visualise swarms in a C2 grid.

Swarming drones mark the transition from individual platform warfare to collective, intelligent systems capable of overwhelming traditional defenses. Existing conventional defence mechanisms, including counter-drone systems, are ill-matched to meet the threat posed by these swarm systems. Centre for Artificial Intelligence and Robotic (CAIR) has established leadership in AI-based perception, localisation and autonomous navigation, through extensive in-house R&D, academic and international collaborations. The technology has been instantiated and customised for a range

of physical platforms, in partnership with industry. CAIR is now engaged in developing and establishing swarming in military operational contexts. Confronting the challenge posed by swarms demands a fundamental rethinking of military operational concepts and tactics. Ultimately, future forces can counter the threat only by adopting the same principles that empower it - the only effective defence against a swarm will indeed be another swarm. A swarm-on-swarm engagement restores symmetry, allowing equivalent resilience, adaptability and speed of operations.

Cybersecurity, Safety & Ethics of UAS



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Unmanned Aircraft Systems (UAS), commonly referred to as drones, are increasingly being deployed in a wide range of industrial and commercial applications. Their widespread adoption reshaped the war dynamics, as seen in recent conflicts, where UAS are integrated as a core component for military strategy. Despite their growing use, the security dimension of UAS operations has not received adequate attention. It is required to have comprehensive regulations, standardised testing, and certification processes for UAS to mitigate cyber threats. It is, therefore, imperative to develop a thorough understanding of the cybersecurity challenges associated with UASs, as well as to adhere to safety protocols and ethical guidelines during their operation.



Cyber Security

Cyberattacks have the potential to disrupt vital drone operations, putting crucial law enforcement and data-gathering missions at risk. UASs in the hands of adversaries could present avenues for cyberattacks, with UASs themselves serving as “cyber weapons” intended to deliver malicious content or enable kinetic impacts.

Studies on attack categorisation of drones indicate that UAS is a major victim of cybersecurity threats such as denial of service, spoofing, attacks on remote control and Wi-Fi networks. Also, UAS itself is being used as cyber weapon in certain cases.

Threat Model

The cybersecurity threat model for UAS is described in many literatures, and the threat model can be classified into Confidentiality, Integrity and Availability. Confidentiality threats are unauthorised access to information by intercepting the information where the drone, Ground Control Station (GCS), and communication link are the victims.

Threats to the GCS are software-based viruses, malwares, trojans, keyloggers, etc. with hacking being the major threat to drones. Confidentiality of the communication links can be compromised by any of the network attacks, such as hacking, eavesdropping, spoofing and protocol attacks.

Threats to Integrity can be either by the modification of existing information during transit or while in storage, or the fabrication of new information. The threats include jamming, compromising the signal integrity and capturing the signal. Signal integrity can be compromised by distortion or a decrease in the signal-to-noise ratio. Fabricating information can be done by the use of malicious code or existing subroutines of the system by finding and exploiting vulnerabilities in the firmware of the system once the attacker has acquired some information about the system. Threats to availability can be either by jamming or denial-of-service attacks which may lead to flooding or buffer overflow.

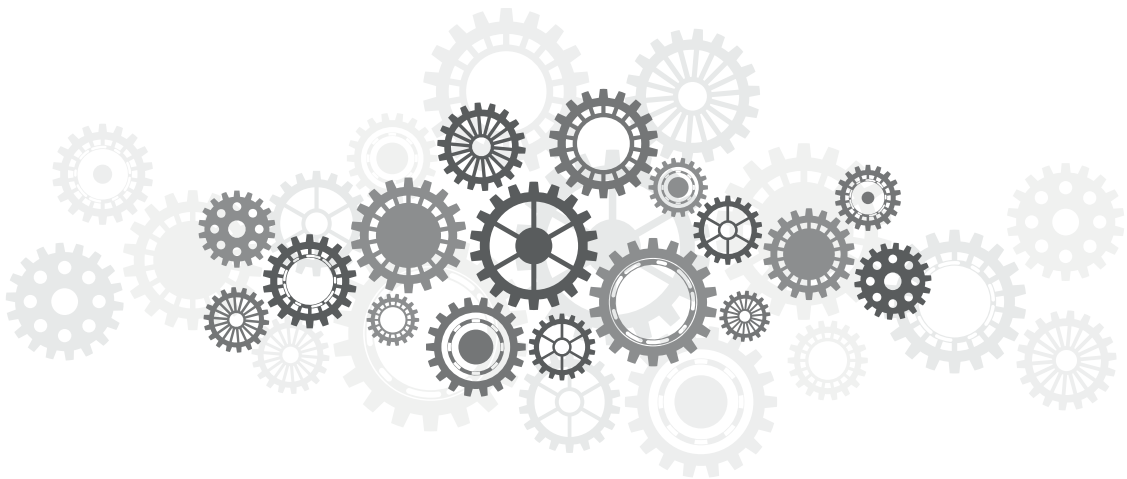
Safer UAS design mechanisms

Countermeasures to these threats must be a high priority for UAS designers. Best practices include incorporating secure by design principles and through intrusion detection and prevention systems with digital signatures for data links and firmware updates, strong hashing mechanisms to ensure authenticity, and robust encryption to maintain confidentiality.

Research on the use of AI and ML techniques for network communication are being carried out to identify various types of intrusions and attacks. Malware detection techniques are being used to detect any malware in drones. Similarly, research must be carried out for prevention of injecting hardware trojans to the critical components of the UAS. Many researchers propose the use of Blockchain technology to be used for the communication links for authenticity.

For safe hardware and software for the UAS, a Root-of-Trust mechanism can be

used so that a secure boot flow can be implemented by digitally signing and verifying all stages of the boot loading sequence. Firmware tamper detection and avoidance by the Power-On Self-Test feature can be used to verify the firmware integrity. Similarly, the checksum of the system firmware, logs, etc. can be used to detect any unauthorised update. During firmware update or any flight parameter change, the digital signature of the UAS manufacturer must be verified by the flight module for authenticity. Since autonomous drones are more susceptible to GPS spoofing attacks, mechanisms for authentication and implementation countermeasures for detection and avoidance of the same are required. Multiple GNSS (Global Navigation Satellite System) can be used for switching to another receiver when an attack on any of the GNSS receivers is detected. AI-based GPS intrusion detection mechanisms are also being developed and explored.



Counter-UAS measures against adversarial drones

Various techniques are being tried across the globe as countermeasures against an adversarial UAS like RADAR, Radio Frequency (RF) analysers, and Audio/video surveillance, to detect and use jammers, spoofing, LASER, projectiles etc., to destroy the adversarial drone. The main challenge for the C-UAS mechanism is to distinguish between legitimate and illegitimate UASs. The strategies for the C-UAS technology must be selected based on the nature and payload of the UAS, and by ensuring a low level of false positives and false negatives with less response time.

The Government of India has published a UTM policy framework, so that stakeholders may come up with innovative ideas to refine the policy further. The C-UAS methods need more research and innovations to make it more affordable, accurate and real-time.

Opportunities need to be created for innovation towards devising C-UAS methods that require more research to make it more accurate, real-time and affordable. With the extreme growth in demand for drones and cases related to its misuse, the Government is evolving a strategy for developing C-UAS technologies by supporting them legally and financially by safeguarding airspace, communication spectrum and civil rights.

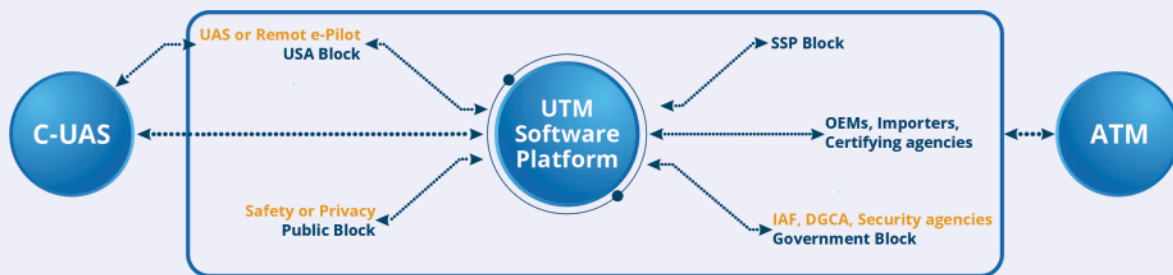


Image Credits: Licensed stock visuals.

UAS Traffic Management (UTM) and related Standards

It is envisaged that **managing UAS traffic will be a herculean task in the coming years**. It will be required to manage UAS traffic in line with Air

Traffic Management (ATM). Since the current ATM is not designed for unmanned systems, **a modern, separate, software-based UTM must be evolved to allow stakeholders to communicate with each other**, to separate a UAS from a manned aircraft and other UAS and to provide awareness of UAS airspace to stakeholders.



UTM Concept

The objectives of the UTM policy framework of India are to allow identified stakeholders to seamlessly communicate with each other, assist in separating unmanned aircraft from other manned and unmanned aircraft and to provide situational awareness of very low level (VLL) airspace to concerned stakeholders. The framework consists of a proposed UTM architecture. **The UTM architecture is primarily divided into** Digital Sky Platform, UTM Service Providers,

UAS Supplementary Service Providers, UAS, Remote Pilots, Government stakeholders and the general public. Each component provides specific user interfaces and APIs for stakeholders to interact with the UTM ecosystem and perform their primary functions while ensuring the safety and security aspects related to UAS operations in India. A few important global standards related to UTM are ISO 23629, IEEE 1939 and ASTM F3411-19 & F3442-20.

Safety and Ethics

Ethical and safety measures need to be followed by a user to obtain a license, check the regulations by referring to the live Digital Sky Platform, and be aware of the challenges in flying a drone in a specific environment and climate. It is also critical to perform pre-flight checks by inspecting the critical components like battery, propellers, GPS, and sensors and ensure that firmware is up-to-date. While operating the drone, the pilot must respect the privacy of others by not capturing images or videos without consent. In case of an emergency, the pilot must be equipped to land the drone safely by using the “Return to Home” feature. To fully understand these responsibilities, it is important to have a basic understanding of the legal framework governing UASs in India.

The Drone Rules 2021 are pertinent to all the civilian drones operated in India. The classification of UAS based on the weight is from

Nano (<250 g) to Large (> 125Kg). All the UAS in India should be certified by the Quality Council of India (QCI) or an authorised testing entity on behalf of Directorate General of Civil Aviation (DGCA). The Indian airspace is classified into “red”, “yellow” and “green” zones.



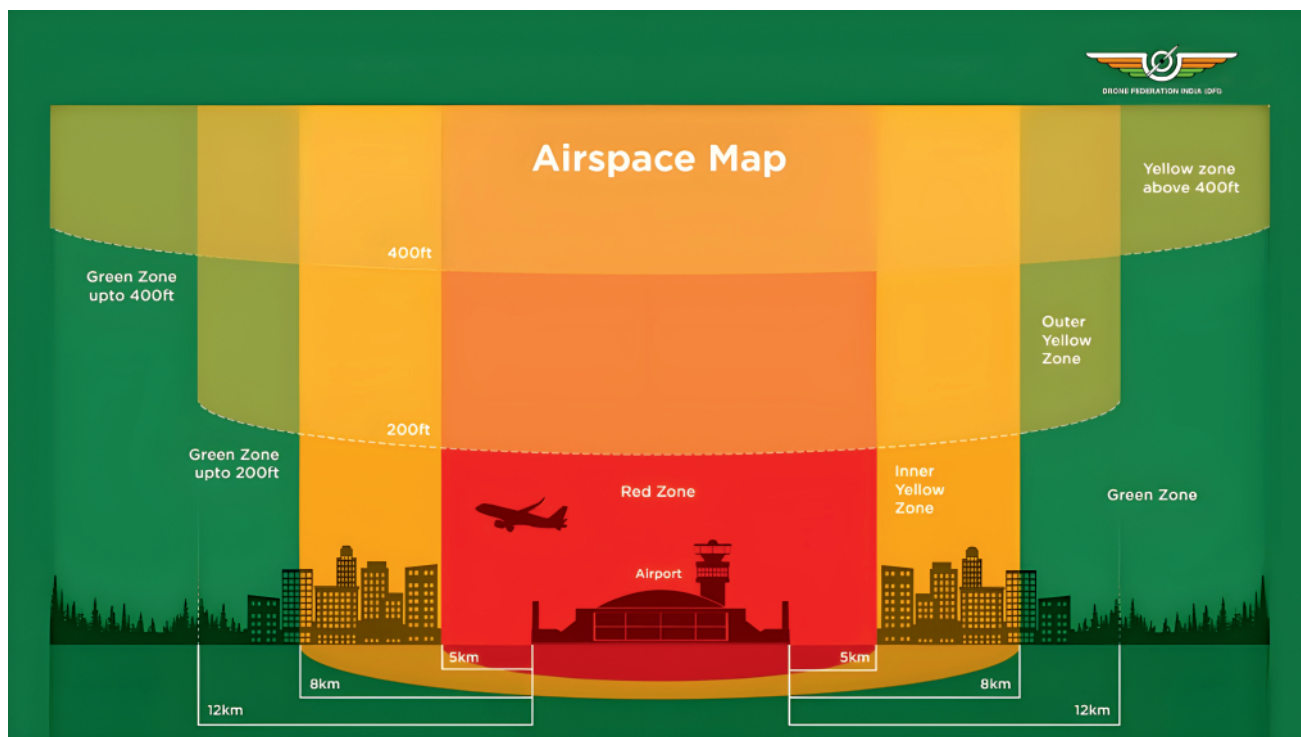
The “red zone” refers to airspace where drone operations are permitted only with authorisation from the Central Government



The “yellow zone” indicates restricted airspace requiring permission from the air traffic control authority;



The “green zone” includes areas up to 400 feet (120 meters) in height that are not designated as red or yellow, where drone operations are allowed without special permissions.



The UAS must also be registered by any user on the Digital Sky Platform to obtain a Unique Identification Number (UIN) for registering new UAS, transferring the ownership of an existing UAS or for the de-registration of a permanently lost or damaged UAS. The user must obtain a valid remote pilot licence

before operating a UAS. The user should complete training and pass the necessary tests from an authorised remote pilot training organisation. As per the Digital Sky Platform, the Government of India has issued 14,015 Remote Pilot Certificates and 34,700 UINs.

As India's drone ecosystem expands across defence, agriculture, infrastructure, and public services, the sector is now entering a phase where scale must be matched with safety, reliability, and regulatory clarity. Several initiatives, from liberalised drone rules to investments in manufacturing and R&D, have accelerated adoption. However, for the industry to realise its full potential, a set of structural, technological, and regulatory priorities must be addressed. Realising the importance of drone security, SETS on its 24th Foundation Day held on 25 June 2025, conducted a panel discussion titled, "Drone Security: Current Trends and Challenges" involving experts from academia and startups & industry as panel members who deliberated on the challenges and way forward.

Moving forward, some of the key challenges and opportunities that need attention include the effective implementation of UTM policy and a more nuanced classification of drones based on user intent, terrain, payload type, and risk level. Strengthening domestic capabilities through indigenisation and standardisation of autonomous navigation algorithms and critical components, such as flight controllers, autopilot software, sensors, batteries, and power modules, will be essential. Ensuring secure operations will also require the integration of Post-Quantum Cryptographic algorithms, Zero Trust Architecture, and platform-agnostic communication systems. Creating a robust testing ecosystem, supported by dedicated UAS sandboxes, will help designers prototype and validate more reliable systems. Simultaneously, pilot licensing frameworks must evolve so that skill requirements are clearly differentiated between recreational flyers and certified operators. Finally, expanding access to decentralised, DGCA-recognised training and licensing centres will be crucial for building a competent workforce that can support the sector's continued growth.



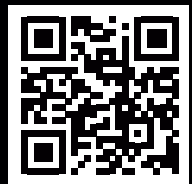
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