Pathways to Self-Reliance in Combat Aircraft
A Strategic Roadmap for India's Aeronautical Sector

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This article outlines a strategic roadmap aimed at achieving self-reliance in India's aeronautical sector by 2047, focusing on building indigenous capabilities in advanced combat aircraft, propulsion systems and unmanned systems. The roadmap addresses India's current challenges such as reliance on imported engines, extended development timelines and limited private sector involvement, by proposing actionable solutions to foster a sustainable and competitive aeronautical industry. Key recommendations include the establishment of autonomous institutions, such as a dedicated aeronautical university and Aeronautics Technology Parks within defence corridors, to drive research, training and development efforts. Additionally, the article advocates for continuous feasibility studies and a phased approach to engine development, allowing India to gradually build a comprehensive ecosystem for next-generation aircraft. The roadmap also underscores the importance of enhancing public–private partnerships (PPPs) and forming strategic collaborations with technologically advanced Asian nations to complement India's capabilities while reducing dependence on Western partnerships. These partnerships would enable joint projects in Artificial Intelligence (AI), stealth technologies and high-altitude testing, accelerating India's progression in aeronautical innovation. Through structured

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reforms, targeted investments, and the alignment of government, industry and academia, the proposed initiatives aim to position India as a globally competitive player in aeronautics, aligning its strategic defence goals with long-term economic and technological independence. This comprehensive approach is intended to advance India's vision of self-reliance, reinforcing its role as an innovator and exporter in the global aeronautics market by 2047.

Keywords: *Self-Reliance, Combat Aircraft, India's Aeronautical Sector*

Introduction

India's ambition to achieve developed nation status by 2047 is closely tied to self-reliance in critical defence technologies, particularly in the aeronautical sector, where global leadership increasingly demands innovation, agility and indigenous capability.[1] While projects like the Light Combat Aircraft (LCA) Tejas and the Advanced Medium Combat Aircraft (AMCA) represent significant milestones in indigenous aircraft development, challenges remain in several key areas. Dependence on foreign-made engines, protracted development timelines and limited private sector involvement underscore the need for a more cohesive approach to research and development (R&D), industry collaboration and policy reform to drive sustained progress.[2]

India's journey in combat aircraft design began in earnest with the HF-24 Marut in the 1960s, a project that symbolised an early commitment to indigenous capability but highlighted the challenges of independent production in a technologically demanding sector.[3] Since then, India has evolved its approach, balancing international collaborations with local development initiatives. However, the current landscape of defence and aeronautical technology underscores an urgent need for structural changes to expedite innovation, streamline bureaucracy and deepen integration between government entities, industry leaders and academic institutions. This article offers a strategic roadmap to strengthen the sector by emphasising advanced combat capabilities, such as sixth-generation manned fighter jets, unmanned stealth bombers and Unmanned Combat Aerial Vehicles (UCAVs).[4]

A phased, comprehensive approach is essential to transform India's aeronautical capabilities. Key elements include the establishment of new, agile institutions focused on fast-tracking ambitious aeronautical projects, as well as dedicated Aeronautics Technology Parks within defence corridors to facilitate cutting-edge research, testing and industry–academia collaboration.[5] These parks would foster an environment where private sector firms, start-

ups, MSMEs and academic institutions can actively participate in solving critical industry challenges, from propulsion systems and stealth technologies to AI-driven simulations and flight control. This article emphasises the importance of a dedicated aeronautical university modelled on leading international institutions to develop a sustainable talent pipeline equipped for next-generation challenges.[6]

Recognising the importance of global partnerships, the roadmap also explores collaboration with technologically advanced Asian nations, such as South Korea, Japan and Taiwan, whose economies and innovation ecosystems align with India's goal of regional self-reliance. These partnerships serve as a counterbalance to Western reliance, providing resilience in areas prone to sanctions and export restrictions. Furthermore, structured Public–Private Partnerships (PPPs) and Special Purpose Vehicles (SPVs) will enable private firms to leverage their agility and innovative potential while contributing directly to India's national defence goals.[7] These efforts, supported by the 'Make in India' initiative, are expected to enhance India's attractiveness to foreign investors and encourage global technological transfer without compromising India's strategic autonomy.

To streamline high-level coordination, this article proposes the creation of an Aeronautics Commission or a Defence Technology Council for Aeronautics, with direct reporting to the Prime Minister, ensuring that aeronautical R&D aligns with national defence priorities.[8] This central body would facilitate rapid decision-making, ensure accountability and oversee critical projects and collaborations.

To summarise, the roadmap laid out in this article provides a robust foundation for elevating India's aeronautical sector. Through targeted investments, policy reforms and strategic alliances, India can transition from a defence importer to an exporter, thereby achieving a self-reliant and globally competitive aeronautics industry by 2047. This approach aligns India's defence needs with its long-term vision for economic and technological independence, positioning the nation to lead in advanced aeronautics and secure its place on the global stage.

The Current State of the Aeronautical Sector in India

India's aeronautical sector has achieved significant milestones, notably the development of the LCA Tejas and the sanctioning of the Advanced Medium Combat Aircraft (AMCA) CCS project in 2023.[9] These accomplishments reflect the nation's commitment to self-reliance in aerospace technology.

However, persistent challenges remain, including technological dependencies, reliance on imported engines, extended development timelines and limitations in research and development (R&D) infrastructure.[10]

An Overview of Existing Capabilities

India's aeronautical advancements have been primarily driven by institutions such as the Aeronautical Development Agency (ADA), Hindustan Aeronautics Limited (HAL), National Aerospace Laboratories (NAL) and the Defence Research and Development Organisation (DRDO). The LCA Tejas programme, led by ADA, established a strong foundation for indigenous combat aircraft development, demonstrating India's capacity to design and produce multi-role fighter jets.[11] The AMCA project, aimed at creating a fifth-generation stealth fighter, signifies India's ambition to reduce reliance on foreign platforms and enhance its indigenous capabilities.[12]

In the unmanned systems domain, initiatives like the GHATAK UCAV reflect efforts to develop autonomous, stealth-capable deep-strike platforms.[13] However, progress in this area underscores the need for advancements in artificial intelligence (AI), stealth technology and propulsion systems—critical areas for maintaining competitiveness in the global aerospace industry.[14]

Identified Gaps and Challenges

Despite these successes, India's aeronautical sector faces several key challenges:

- *Technological Dependency*: A significant portion of critical components, including high-performance engines, avionics and sensors, continues to be sourced internationally.[15] This dependence elevates costs and introduces strategic vulnerabilities, especially in geopolitically sensitive situations. Developing reliable, domestically sourced alternatives is an urgent priority.[16]
- *R&D and Infrastructure Gaps*: While ADA, DRDO, NAL and HAL have driven key projects, the current R&D ecosystem lacks essential infrastructure, such as specialised AI test labs, dedicated aeronautical universities, Aerospace Technology Parks within defence corridors, and an Indian Air Force Research Laboratory (IAFRL) equipped for the exponential growth of next-generation combat aircraft technologies and development infrastructure. These gaps—alongside limited private sector involvement, a lack of rapid commercial prototyping facilities and insufficient collaborative spaces—hamper innovation in critical domains like AI, propulsion and autonomous systems.[17] This article will explore

these infrastructure and ecosystem deficiencies in detail and propose strategic solutions to address these challenges, essential for enhancing India's global competitiveness.[18]

- *Lengthy Development Timelines*: Extended timelines from project initiation to completion pose a significant barrier. For instance, the AMCA project underwent internal study for nearly 18 years before receiving full CCS sanction in 2023.[19] Slow decision-making processes, prolonged feasibility studies and an overemphasis on current-generation aircraft development have delayed progress on next-generation platforms. To mitigate these delays, adopting parallel feasibility studies for future aircraft while simultaneously executing ongoing projects is essential.[20]
- *Absence of Specialised UCAV Development Organisations*: India lacks a dedicated organisation on the scale of ADA or HAL focused solely on UCAV development. To address this gap, an autonomous organisation, modelled after ADA but not under DRDO, should be established under the proposed IAFRL. As the primary user of UCAV systems, the Indian Air Force (IAF) is best positioned to lead and manage such an organisation, ensuring alignment with operational requirements and minimising delays commonly associated with DRDO-led projects. This entity should directly report to the Prime Minister's Office (PMO), mirroring ISRO's governance structure, to foster innovation and streamline decision-making.

  The development of this new organisation should draw on the expertise and input of established entities such as ADA, HAL and DRDO, much like how new IITs are supported by older, well-established IITs. The organisation should be staffed with handpicked talent from the IAF, ADA, HAL, DRDO, ADE, NAL, the academia and private sector to create a highly skilled and diversified team. The director of this body could be drawn from either the private sector or the IAF, leveraging their operational expertise and innovative approaches. Such a structure would combine the agility of private sector innovation with the operational focus of the armed forces, providing a robust platform for advancing India's UCAV programmes and achieving self-reliance in unmanned systems development, thus avoiding delays in projects that usually occur with DRDO-led initiatives. This innovative framework is being proposed to break this bureaucratic structure.[21]
- *Private Sector Engagement*: Despite initiatives to increase private sector involvement, its role in defence manufacturing remains limited.[22] Current policies have yet to unlock the full innovation potential of private firms,

which could accelerate development timelines and reduce reliance on public sector undertakings (PSUs).[23]

- *Prolonged Focus on Fourth Generation Aircraft*: India's continued emphasis on 4+ generation aircraft such as the LCA Tejas, has impeded its transition to fifth and sixth-generation platforms, limiting its ability to keep pace with global advancements.[24] To address this, it is recommended that several dedicated teams be formed within established design houses such as ADA, HAL, NAL and DRDO. These teams should be relieved from routine, non-innovative tasks associated with ongoing CCS projects, allowing them to focus exclusively on futuristic designs that match or surpass international standards.

  Additionally, innovative tasks can be assigned to teams within the proposed IAFRL and design centers in academia, leveraging their unique strengths and fostering collaboration. These dedicated teams, supported with equal priority and resources, would have the freedom to innovate without being constrained by existing projects. By ensuring such focused efforts, India can accelerate next-generation aircraft development, achieve breakthrough innovations and maintain long-term competitiveness in the global aerospace arena.[25]
- *Engine Development Deficiencies*: The absence of an engine development organisation with proven experience in certifying and deploying domestically produced engines for operational test flights and indigenous aircraft remains a significant weakness in India's aeronautical sector.[26] Despite the Gas Turbine Research Establishment (GTRE) operating for over four decades, it has yet to achieve certification and operational deployment of an indigenous engine. One approach to address this deficiency is through collaborations between Indian private sector firms and established foreign engine manufacturers, creating joint ventures aimed at developing certified engines in India. Initially, this approach could focus on civilian aircraft engines, gradually progressing to combat aircraft engines. A recent example of such collaboration is the partnership between Tata Advanced Systems Limited (TASL) and Airbus to produce the C295 military transport aircraft within India, which included establishing a Final Assembly Line in Vadodara in 2024.[27] The next phase of such collaborations should focus on the indigenous design and development of both engines and aircraft. This model provides an alternative path for the private sector to engage in certified engine manufacturing, complementing GTRE's efforts and accelerating India's journey towards self-reliance in critical engine technologies.[28]

Service Involvement

The involvement of the Indian Armed Forces is critical in shaping the operational requirements of future combat air systems.[29] While the Services provide valuable feedback, their integration into the R&D process should be deepened. Establishing dedicated research initiatives, such as the proposed IAFRL, could enhance this collaboration and ensure that new technologies align with the operational needs.[30]

Assessment of Existing Organisations

India's key aeronautical organisations—ADA, HAL, NAL and DRDO—have played pivotal roles in advancing the nation's aerospace capabilities.[31] The successes of the LCA Tejas and AMCA projects demonstrate the potential of these institutions. However, to meet future challenges, these organisations need to evolve by adopting streamlined management practices, improving accountability, and fostering stronger collaboration with private industry and academic institutions.[32]

To overcome bureaucratic constraints and ensure the agility required for next-generation projects, the establishment of a new, autonomous body akin to ADA is essential. Unlike ADA, which operates under DRDO's control and has inherited bureaucratic limitations, this new organisation would be designed to foster greater autonomy and innovation. Its structure would prioritise private sector partnership, mirroring HAL's early role in ADA's formative years but with modern emphasis on private enterprise as the driving force. This entity would recruit programme directors and senior administrators from both government and private sectors, drawing on expertise from ADA, HAL, DRDO, NAL, the academia and private aerospace firms. Such a composition would introduce a new level of operational efficiency and flexibility, distinguishing it from ADA's current framework. The involvement of the private industry as a major partner would provide the innovation and efficiency needed to fast-track technological advancements and secure India's competitive edge in aerospace development.[33]

Desired State of the Aeronautical Sector in India

Achieving a self-reliant and globally competitive aeronautical sector is a strategic imperative for India as it seeks to bolster its defence capabilities and reach 'developed nation' status by 2047.[34] The envisioned future includes advanced indigenous capabilities across a wide range of combat air systems, from next-generation manned aircraft to sophisticated unmanned platforms.

This vision comprises the development of fifth and sixth-generation fighter aircraft, operationally relevant UCAVs, and integrated manned–unmanned teaming systems.[35] To drive these innovations, a robust R&D ecosystem is essential—one that includes dedicated research institutions, Aeronautics Technology Parks, a specialised Aeronautical University and the proposed IAFRL. These elements, coupled with private sector collaboration and rapid prototyping capabilities, would bridge existing technological gaps by enabling continuous development, expediting the transition from research to deployment, and integrating cutting-edge advancements into India's defence infrastructure.[36]

Vision for 2047: Self-Reliance in Advanced Combat Air Systems

The strategic goal is to achieve self-reliance in the development, production and deployment of advanced combat air systems. This requires building a comprehensive ecosystem for design, testing and manufacturing, supported by a domestic supply chain for critical technologies such as engines, avionics and stealth materials.[37] By 2047, India aims to position itself not only as a consumer but also as a key innovator and exporter of advanced combat aircraft technologies.[38]

Indigenous Fifth- and Sixth-Generation Aircraft Development

Current efforts include the development of the LCA Mk-2 and the Twin Engine Deck Based Fighter (TEDBF), both classified as 4.5+ generation aircraft. While these platforms are equipped with advanced avionics and capabilities, they lack full stealth features such as stealth materials and enclosed weapon bays, which are critical for fifth-generation classification. The absence of these features may pose challenges to their acceptance by the armed forces, particularly for the TEDBF. Given that the Advanced Medium Combat Aircraft (AMCA) project will incorporate full stealth features, including low radar cross-section (RCS) technology through shaping and stealth coatings, it is highly probable that the Indian Navy will demand similar stealth capabilities in the TEDBF once it becomes operational.

To ensure alignment with future operational requirements, it is imperative that any aircraft project sanctioned after the AMCA project includes full stealth features. Without these advancements, such platforms risk rejection by the services due to evolving operational standards and the increasing importance of stealth in modern warfare. Moving beyond AMCA, future development must focus on sixth-generation aircraft, integrating advanced technologies such as artificial intelligence (AI), directed energy weapons,

adaptive engines and enhanced stealth features to maintain competitiveness on the global stage.[39]

Globally, countries like the USA, France, the UK and Japan are progressing on sixth-generation platforms, integrating AI and advanced stealth technologies.[40] India must align its trajectory with these developments to remain competitive. Drawing on past successes like the LCA Tejas, India can build resilience and innovation to leapfrog into sixth-generation aircraft, accelerating progress through collaborative ventures with friendly nations.[41]

Development of Operationally Relevant UCAVs and Manned–Unmanned Teaming Systems

The desired future includes a versatile fleet of UCAVs tailored to India's strategic needs. Projects like the GHATAK UCAV, integrated with advanced AI and manned–unmanned teaming (MUM-T) strategies, will provide India with autonomous strike capabilities, deep penetration missions and real-time battlefield adaptability.[42] However, limitations of the uncertified Kaveri dry engine, particularly in range and payload capacity, hinder the ability of Indian UCAVs to meet global performance standards set by advanced systems such as Russia's Okhotnik UCAV (The National Interest), China's GJ-11 Sharp Sword (Defence Agenda), and the US X-47B (Popular Science), each of which utilise engines surpassing the specifications of the Kaveri dry engine. The current approach by the government and DRDO emphasises UCAV designs constrained by the Kaveri dry engine's specifications, resulting in operational limitations.

To overcome these constraints, India should consider establishing a new, autonomous organisation akin to ADA, focussed on developing high-performance UCAVs independently or in collaboration with DRDO-ADE's UCAV programme. This new organisation could explore alternative engine solutions and pursue international collaborations with friendly countries (BRICS or Asian) to secure the advanced propulsion technology required to meet the capabilities demonstrated by global UCAV competitors. However, such collaborations are challenging due to the classified nature of UCAV developments and the reluctance of nations to share sensitive technologies. Systems like HAL's Combat Air Teaming System (CATS), which aligns with MUM-T concepts, represent a critical step towards integrating AI-driven swarm technologies.[43] Expanding such projects, along with scaled flight competitions for swarm drones sponsored by the defence services, will foster innovation and help India remain globally competitive in unmanned combat capabilities.[44]

Strengthening R&D and Innovation Ecosystems

Achieving the desired future requires bolstering India's R&D ecosystems. Establishing advanced technology centres within leading universities such as the Indian Institute of Science (IISc) and Indian Institutes of Technology (IITs), specifically focused on manned and unmanned combat aircraft systems, will drive research in AI, stealth, propulsion and digital engineering.[45]

Furthermore, the creation of a dedicated aeronautical university, like the Indian Institute of Space Science and Technology (IIST) for space research, will nurture specialised talent for future aircraft programmes.

A critical institution, the proposed IAFRL, modelled after the US Air Force Research Laboratory (AFRL), will focus on next-generation aerospace platforms and align R&D efforts with operational needs.[46] Additionally, Aeronautics Technology Parks are envisioned to foster collaboration between the government, private industry, start-ups and academia, translating breakthroughs into practical applications more rapidly. Although India already has designated defence corridors, these specialised technology parks would serve as hubs for aeronautical development, located strategically within defence corridors where existing flight test centres, runways and aircraft fabrication facilities are available. To support the growth of the aeronautics sector and position India as a leading aircraft producer and exporter, one Aeronautics Technology Park could be established in each defence corridor, as well as in key locations such as Bengaluru and near the Chitradurga flight test centre. This approach would ensure economic viability by leveraging existing infrastructure and attracting investments from both the public and private sectors.[47] Integrating digital engineering tools like a National Design & Simulation Tools Archive will streamline rapid prototyping and testing, reducing development timelines. Strengthening these R&D ecosystems will ensure India's aeronautical sector can meet its future defence needs and position itself as a hub for advanced aeronautical technologies.[48]

Roadmap to Achieve the Desired State

Achieving the desired state of India's aeronautical sector requires a coordinated and strategic approach that integrates government, industry, academia and the defence services.[49] This roadmap outlines essential steps to build a self-reliant and globally competitive aerospace industry by 2047. Key initiatives include structural reforms, advancement of research and development (R&D), enhancement of private sector involvement, and formation of strategic international collaborations—all aimed at overcoming current challenges and

realising India's future vision.[50] Notably, the monograph "India's Quest for UAVs and Challenges"[51] by Gp Capt RK Narang emphasises the importance of establishing dedicated organisations for UAV development, fostering public–private partnerships and enhancing indigenous capabilities to reduce dependence on foreign technologies.

Additionally, the MP-IDSA monograph titled "Unmanned Aerial Vehicles in China: Options for India"[52] by R.K. Narang highlights the need for a robust R&D ecosystem and strategic collaborations to advance India's UAV programmes. Incorporating these insights, along with the roadmap suggested in this article for the aeronautics sector, will be crucial for advancing future aircraft developments and achieving a self-reliant and globally competitive aeronautical sector by 2047.

Establishing a High-Level Defence Technology Council for Aeronautics

A critical element of the roadmap is the creation of a High-Level Defence Technology Council for Aeronautics, overseen by a committee approved at the highest levels of government.[53] This council would drive long-term strategic planning, oversee the execution of recommendations and monitor progress on aeronautical initiatives. Reporting directly to the Prime Minister, the council would ensure that national defence objectives are aligned with advancements in aeronautical technology. A similar concept, an Aeronautics Commission, was proposed by Gp Capt RK Narang in his book *India's Quest for UAVs and Challenges*, underscoring the importance of a high-level governing body to steer aeronautical development and integration. Such a council or commission is essential to coordinate efforts across agencies, support policy alignment and provide the strategic oversight necessary to advance India's aeronautical ambitions.

The council's primary responsibilities would include coordinating efforts among stakeholders such as ADA, HAL, NAL, DRDO, private industry and the armed forces.[54] It would also guide the formation of new autonomous bodies designed to fast-track future aeronautics projects, driving innovation and addressing emerging challenges, as the existing organisations will be busy trying to meet the ongoing CCS projects. Additionally, the council would streamline project approvals and shorten development timelines, thereby overcoming delays experienced in programmes like the AMCA project sanction.[55]

This council would prioritise both immediate and long-term goals, with a particular focus on accelerating technological advancements and

implementing structural reforms. It would ensure that the roadmap remains adaptable, maintaining a view to achieve self-reliance in aeronautics.

Strengthening Research and Development (R&D) Capabilities

The roadmap proposes the creation of new autonomous bodies and the IAFRL to address evolving technological challenges.[56] While ADA and HAL have played significant roles in indigenous combat aircraft development, future challenges require specialised entities focused on emerging technologies with the involvement of all stakeholders including the services.

Despite the significant achievements of the ADA in developing the LCA Tejas and the AMCA project initiatives, the organisation faces considerable bureaucratic challenges and resource constraints. These limitations impede its ability to manage multiple advanced projects concurrently.[57] A notable instance of this is the transfer of the UCAV project from ADA to the Aerospace Development Establishment (ADE), driven by the perception within the DRDO that ADA lacked the necessary manpower and infrastructure to effectively oversee the LCA, AMCA and UCAV initiatives simultaneously. To address these challenges faced by organisations like ADA, the creation of new autonomous bodies, with increased manpower, modelled after ADA but endowed with greater flexibility, streamlined governance and enhanced collaboration with the private sector, is essential. These entities will focus on critical areas such as hypersonic, AI, digital engineering and future operational UCAVs, fostering partnerships with private firms to expedite project timelines and accelerate innovation.[58] Such bold initiatives by the Government of India are imperative for fostering growth in India's aeronautics sector.

In addition, the establishment of the IAFRL, modelled after the US AFRL, represents a transformative initiative tailored to the operational needs of the IAF. The IAFRL will serve as a dedicated research entity, integrating mission simulations, operational requirements and future warfare strategies into its R&D efforts to ensure that developed technologies align with real-world defence scenarios. By addressing both current and emerging challenges, the IAFRL will act as a bridge between conceptual innovation and operational readiness.

To ensure a strong foundation and effective implementation, the formation of the IAFRL will be mentored by established entities such as ADA, HAL, DRDO and the private sector. This mentorship model mirrors the approach used for establishing new IITs, where older IITs provide guidance and support to build capabilities in the new institutions. This collaborative mentorship will ensure that the IAFRL leverages the best practices, technical

expertise and operational insights of these seasoned organisations while fostering innovation and adaptability.

The IAFRL will play a pivotal role in advancing critical technologies, including AI, advanced propulsion systems, stealth technologies, autonomous systems and manned–unmanned teaming (MUM-T) strategies. Unlike conventional R&D organisations, the IAFRL will operate with a dynamic and mission-oriented approach, prioritising agility and rapid prototyping to address the evolving demands of modern warfare.

Furthermore, the IAFRL will collaborate closely with stakeholders across academia, private industry and the armed forces, creating a robust ecosystem for innovation. Its structure will emphasise operational feedback loops, allowing active IAF personnel to contribute real-time insights and shape R&D projects to meet tactical and strategic requirements effectively.

By aligning technological development with the specific needs of the IAF and building on the expertise of established mentors, the IAFRL will not only enhance India's defence capabilities but also establish a model for integrating military, academic and industrial ecosystems. This unique initiative is poised to be a cornerstone of India's aeronautical innovation, ensuring long-term competitiveness and self-reliance in defence technologies.[59] Together, these new entities will create a more agile and innovative R&D ecosystem, enabling India to remain competitive and develop cutting-edge combat systems ready for future deployment.[60]

Establishment of a Dedicated Aeronautical University

As part of India's efforts to build a robust R&D ecosystem, the roadmap proposed in this article recommends creation of a dedicated aeronautical university. This institution would be modelled after successful examples like the Indian Institute of Space Science and Technology (IIST) but tailored to the unique requirements of the aeronautical sector.[61] The aeronautical university will focus on developing specialised talent and conducting cutting-edge research in areas critical to the future of India's aeronautical industry, including aircraft design, avionics, propulsion systems, stealth and advanced materials. This roadmap, summarised at the end of the article, envisions a comprehensive approach to building the academic and research capabilities necessary for India's aeronautics sector to thrive. This university will collaborate closely with industry and the defence services to ensure that its research outputs are aligned with national operational needs.[62] It will serve as a hub for fostering innovation, offering specialised aeronautical programmes to equip the next generation of engineers and scientists with

the skills necessary to drive the development of advanced aeronautical platforms. Furthermore, the aeronautical university, in collaboration with the aeronautical industry, will be instrumental in developing a skilled workforce of aeronautical engineers essential for India's indigenous capability to design, test and manufacture future combat aircraft and unmanned systems and will be a source of engineers and scientists required for future programmes.

Initiating Continuous Feasibility Studies for Future Platforms

Continuous feasibility studies are essential to maintaining India's competitiveness in combat aircraft design.[63] The roadmap emphasises the importance of ongoing conceptual and feasibility studies, utilising advanced design techniques and AI-based methodologies, even for projects not yet sanctioned. These studies ensure that India remains prepared to adapt to evolving technological trends and operational requirements. Specific feasibility studies that would bolster India's aeronautical capabilities include:

1. *Conversion and Scaling Up the GHATAK UCAV to a Manned–Unmanned Deep Penetration Strike Bomber*: A platform like the US B-21 Raider' or China's H-20, designed for stealth and long-range strike capabilities, suitable for both manned and unmanned operations. This study is critical for developing a versatile strike platform capable of penetrating heavily defended airspaces.
2. *Sixth-Generation Combat Aircraft*: A highly agile, low-RCS stealth aircraft without a vertical tail, integrating fluidic thrust vectoring for advanced manoeuvrability and employing an AI pilot with active RCS control. This platform would merge the attributes of a flying-wing UCAV with the agility of modern combat aircraft, addressing future air superiority needs.
3. *Hypersonic Combat Aircraft*: A programme akin to the US SR-72 Son of Blackbird or China's WZ-8 hypersonic drone, aimed at developing platforms capable of extreme speeds for high-impact strategic missions. Such a capability is essential for time-sensitive, high-value target engagement.
4. *Electric and Non-Gas Turbine Engine Aircraft*: Feasibility studies into combat aircraft powered by electric or alternative non-gas turbine propulsion systems, aligning with future trends in energy-efficient and sustainable aviation technologies. These platforms will cater to the demand for green aviation solutions while maintaining combat readiness.
5. *Advanced Manned–Unmanned Teaming (MUM-T) Platforms*: Feasibility studies on systems where manned aircraft operate alongside a swarm

of autonomous UCAVs, leveraging AI for coordinated missions. This approach enhances mission adaptability and increases operational survivability.

Feasibility studies for these platforms are a few examples that could be conducted at five-year intervals to account for emerging technological advancements and changing strategic priorities. Additionally, circumstantial studies should be initiated in response to significant global developments in combat aviation, such as the induction of new platforms by adversaries or breakthroughs in enabling technologies like AI, materials science or propulsion.

These continuous evaluations, which are not demanding in terms of funding, will ensure India remains proactive and adaptive in the global combat aviation landscape, empowering its aeronautical sector to anticipate and address future challenges effectively. Dedicated funding and structured collaboration with ADA, HAL, DRDO, academia and private sector innovators will be crucial for sustaining this strategic effort.

These studies are crucial for building advanced conceptual and feasibility design capabilities, especially in areas like AI and optimisation, ensuring that India can quickly produce innovative solutions.[64] By continuously exploring new concepts, India's aeronautical sector will be better prepared to meet future challenges and remain on par with international aircraft designers. To translate this vision into actionable outcomes, the following steps are recommended:

1. *Establish Specialised Design Teams*: Create dedicated teams within ADA, HAL, DRDO and academic institutions to focus exclusively on advanced conceptual design and feasibility studies. These teams should leverage AI-based design tools, digital engineering and multi-disciplinary optimisation techniques to develop future-ready platforms.
2. *Develop a National Design and Simulation Tools Archive*: Set up a centralised repository of high-fidelity simulation tools, optimisation algorithms and digital design frameworks accessible to all stakeholders in the aeronautical sector. This archive would standardise methodologies and reduce development timelines.
3. *Foster Collaboration Across Ecosystems*: Establish partnerships between government R&D organisations, academia and the private sector to integrate expertise and accelerate the design process. Collaborative projects can ensure that innovative concepts are aligned with real-world requirements and operational needs.

4. *Incorporate Industry and Service Feedback Loops*: Create structured mechanisms to gather continuous feedback from industry experts and active service personnel. This feedback will refine designs and ensure that emerging technologies align with operational realities. A structure like the Project Management Team (PMT) set up in ADA with the help of the IAF.
5. *Initiate Regular Feasibility Competitions*: Organise national-level design competitions at regular intervals (for example, every two years) to encourage innovation among start-ups, academic institutions and R&D labs. These competitions would focus on conceptualising next-generation platforms such as hypersonic drones or advanced UCAVs.
6. *Allocate Dedicated Funding*: Secure sustained funding for conceptual and feasibility studies, ensuring that financial resources are available for iterative development and exploratory research. Funding mechanisms could include grants for academia and incentives for private sector participation.
7. *Integrate Advanced Training Programmes*: Develop advanced training modules for design and simulation professionals, focusing on state-of-the-art techniques in AI, stealth, propulsion systems and digital engineering.

By implementing these actionable steps, India can establish a robust framework for continuous innovation in aeronautical design. This approach will not only bolster the nation's competitiveness in global aerospace but also lay the foundation for transformative advancements in combat aviation.

Engaging private sector participants, who bring agility and novel design approaches, will lead to groundbreaking innovations. Established entities like ADA and HAL will provide technical expertise, ensuring new designs are feasible and forward-thinking.

Enhancing Industry Engagement and Public–Private Partnerships

The global aeronautics industry is increasingly driven by private sector innovation, and India must nurture its private sector to create a globally competitive aerospace industry.[65] While public sector undertakings (PSUs) dominate India's aeronautics sector, private companies, start-ups, MSMEs and academic institutions have the potential to drive greater agility and innovation.[66]

The roadmap emphasises on fostering PPPs and establishing SPVs as structured platforms for collaboration between private companies and public

institutions. PPPs would enable the pooling of resources and expertise from both sectors, allowing for shared risk, expedited timelines and enhanced innovation in aeronautics projects. SPVs, specifically created for distinct projects or development goals, would streamline project management by isolating funding and responsibilities within a focused framework, reducing bureaucratic delays and promoting accountability. These collaborative models are expected to accelerate development timelines, reduce reliance on imports and strengthen India's position in the global aeronautics market.[67] To achieve this, an enabling environment must be created to support private investment, R&D and access to government contracts and funding.[68] Additionally, PSUs should optimise their role to work more closely with private companies, combining their production expertise with private-sector innovation.

Dedicated funding needs to be allocated to ensure private sector participation in continuous R&D, enabling start-ups, MSMEs and academia to contribute fresh perspectives.[69] To support this goal, funding could be channelled through existing agencies such as DST, DOE and AR&DB, or through new dedicated funding agencies. Private entities would be encouraged to submit their R&D proposals to these agencies, with selected projects receiving grants to foster innovation within the sector. A portion of the allocated annual defence budget would be reserved for initiatives that promote private sector indigenisation and growth within the aeronautical sector. This structured funding approach would empower India's private sector to play a central role in advancing national aeronautical capabilities through strategic partnerships and continuous innovation.

Promoting Indigenous Engine Development

The absence of domestically developed and certified engines remains one of India's most significant challenges to self-reliance.[70] To address this, the roadmap calls for the establishment of a dedicated, operationally certified engine development organisation tasked with designing and certifying engines for manned and unmanned platforms.[71]

India's reliance on foreign engine technology not only increases costs but also limits its strategic autonomy, particularly in situations where geopolitical factors could disrupt supply chains.[72] Developing indigenous engines will enhance India's ability to manufacture and deploy advanced combat systems and reduce its dependency on foreign technologies.[73]

A phased approach to engine development is recommended, starting with upgrading existing engines like the Kaveri before progressing to advanced

engines for future-generation aircraft.[74] To support this phased development, dedicated funding should be allocated for establishing high-altitude testing facilities and specialised aircraft testing platforms, which are essential for testing and refining engine performance under diverse conditions. Additionally, international collaborations with nations experienced in engine development, such as France's Safran and the UK's Rolls-Royce, will be vital for ensuring success in achieving world-class engine capabilities.[75] These investments and collaborations will foster a robust engine development ecosystem, integral to advancing India's aeronautics sector. International case studies demonstrate the effectiveness of such collaborations. For example, Japan's partnership with Rolls-Royce and IHI Corporation on engine technologies for the Mitsubishi F-X programme highlights the benefits of strategic alliances in engine development.

Expanding Export Capabilities

To become a global leader in aeronautics, India must actively pursue export opportunities. The roadmap highlights the need to build an export-focused industry, producing advanced aerospace products for both domestic and international markets.

Success with defence exports, such as the BrahMos missile system, shows India's potential to replicate similar initiatives in aerospace.[76] By building on its expertise, India can establish itself as a global player, exporting aircraft, UCAVs, engines and other aerospace components.

An Aeronautics Export Promotion Council should be established to facilitate international partnerships, identify export markets and streamline regulatory processes.[77] This council will help Indian manufacturers navigate global markets and increase competitiveness.

Strategic Initiatives

To achieve the desired state of India's aeronautical sector, several strategic initiatives are necessary that focus on technological development, international collaboration, industry engagement, continuous feasibility studies and the enhancement of innovative ecosystems. Collectively, they form the foundation for building a self-reliant and advanced aeronautics sector by 2047.

Technological Advancements and Digital Engineering

Developing advanced technological capabilities is central to India's aeronautical vision. Key areas of focus include AI, digital engineering,

materials science, stealth and propulsion systems for fifth and sixth-generation aircraft, Advanced AI piloted UCAVs and future combat systems.[78]

India must invest not only in acquiring advanced digital engineering tools such as high-fidelity simulations, digital twins and optimisation algorithms, but also in developing indigenous AI-based tools to streamline the design process, reduce development timelines and improve product quality.Encouraging young aeronautical graduates from institutions like IITs and IISc to innovate in areas such as AI-based Multi-Disciplinary Design Optimization (MDO) combined with Computational Fluid Dynamics (CFD) and other simulation techniques could yield powerful, homegrown design tools. Leveraging AI-driven design and manufacturing processes developed by fresh talent can significantly enhance efficiency and innovation in the aeronautics sector. Indigenous propulsion systems for both manned and unmanned platforms remain a critical challenge. An organisation with proven expertise in developing operational and certified engines is crucial for achieving genuine self-reliance in aerospace engineering and defence capabilities.[79] Additionally, advancing research into next-generation materials—including advanced composites, stealth materials and hypersonic-resistant coatings—is vital. Collaboration between academic institutions, research labs and industry will be key to integrating these technologies into India's aeronautical platforms.[80]

Strategic International Collaboration

Strategic international collaboration is crucial for accelerating India's aeronautical development trajectory. Partnerships with technologically advanced nations such as the United States, France, Israel, Sweden and the United Kingdom could potentially provide access to cutting-edge technologies in key areas like AI, propulsion systems and advanced materials.[81] While there have been instances of sanctions and withdrawal from collaborations in the past, as seen in the case of the GE-404 engines impacting India's LCA programme, the substantial market in India offers a strong incentive for foreign companies. This market appeal could be leveraged through Make-in-India initiative and private sector-led collaborations, such as the recent Airbus–TASL partnership to manufacture military transport aircraft in India (Airbus). These collaborations, structured as joint development projects, technology-sharing agreements, or research partnerships, can enable India to fast-track its technological progress while advancing towards its goal of self-reliance.[82] For example, collaborating with nations experienced in engine development can help India overcome existing gaps in indigenous propulsion

capabilities. However, unlike past collaborations that were largely West-centric, a new strategic approach could involve strengthening ties with Asian nations and countries that are potential buyers of Indian aircraft, such as the LCA and possibly the AMCA. This approach, which will be discussed in greater detail in later sections, could open new avenues for cooperation and market expansion.

These partnerships also offer India the opportunity to integrate into global aerospace supply chains, which will not only enhance its position in the international aerospace market but also support the Make-in-India initiative by fostering domestic manufacturing and innovation.[83]

Conducting Continuous Feasibility Studies of Future Aircraft Configurations

Continuous feasibility studies are crucial for developing the design capabilities required for future combat aircraft.[84] Unlike past practices where designs were initiated after government sanction, this approach emphasises ongoing design efforts using AI-based methodologies, advanced optimisation techniques and digital engineering.

Multiple teams should engage in conceptual and feasibility designs of futuristic configurations, such as unmanned stealth bombers, next-generation air superiority fighters, hypersonic manned/unmanned combat aircraft and high-altitude long-endurance (HALE) drones[85] with a competitive and innovative spirit. These studies should explore cutting-edge concepts like manned–unmanned teaming (MUM-T) systems, where manned fighters collaborate with accompanying UCAVs.[86]

By conducting feasibility studies on these futuristic configurations, India's aeronautical sector will remain agile and be prepared for future demands. This approach allows the government to have a wider selection of projects ready for sanction when required, ensuring a smoother transition into next-generation platforms.

Dedicated funding should be allocated to involve a broad range of stakeholders—including start-ups, MSMEs, academic institutions, and established players like ADA and HAL—in these feasibility studies.[87] Engaging diverse entities fosters innovation and promotes groundbreaking designs more efficiently.

Enhancing Innovation Ecosystems

To foster collaboration between the academia, industry and government, the roadmap emphasises the need for Aeronautics Technology Parks—spaces

where start-ups, MSMEs, research labs and industry can collaborate on aeronautical projects.[88] These parks will serve as hubs for rapid innovation and accelerate technological advancement.

Additionally, creating a National Design & Simulation Tools Archive dedicated to the aeronautical sector will provide engineers with access to cutting-edge design tools, simulations and optimisation algorithms, reducing development timelines and improving product quality.

The proposed IAFRL, modelled after the US AFRL but adapted to Indian requirements, will play a critical role in India's innovation ecosystem.[89] The IAFRL will focus on developing cutting-edge technologies aligned with the operational needs of the Indian armed forces, spanning mission simulations, AI-driven warfare systems, advanced propulsion and MUM-T strategies.

By bridging the gap between technological development and military operations, the IAFRL will ensure that India's research and innovation efforts are directly aligned with defence requirements. It will also provide real-time feedback from military personnel, allowing for the continuous refinement of new technologies based on operational realities.[90]

To sustain this innovation, continuous R&D funding must be allocated to a wide range of stakeholders, including start-ups, MSMEs, academic institutions and PSUs. This funding will support the exploration of new ideas and technologies, ensuring a robust pipeline of innovation.

Promoting Export Capabilities in Aeronautics

To establish itself as a global leader in aeronautics, India must actively pursue export opportunities for its advanced technologies. The roadmap emphasises the need to build an export-focused aeronautical industry capable of producing cutting-edge products for international markets.

India's success in exporting defence equipment, such as the BrahMos missile system, demonstrates its potential to achieve similar success in aeronautics.[91] By leveraging its growing expertise, India can position itself as a key player in the global market, exporting aircraft, UCAVs, engines and other components.

An Aeronautics Export Promotion Council should be created to facilitate international partnerships, identify potential markets and ensure Indian aeronautical products meet global standards.[92] The council will also work to streamline regulatory processes, making it easier for Indian manufacturers to compete globally and enhance their export potential.

Industry Engagement and Private Sector Participation

India's aeronautical sector has traditionally been dominated by PSUs such as HAL and DRDO. While these institutions have been instrumental in building indigenous combat aircraft capabilities, achieving self-reliance and global competitiveness now requires a strategic shift towards increased private sector involvement.[93]

Globally, the aeronautics industry is primarily driven by private sector companies like Lockheed Martin, Boeing and Northrop Grumman, which lead in the commercialisation of advanced technologies. In contrast, India's sector remains heavily reliant on PSUs and government organisations like DRDO and ADA. Despite their significant accomplishments, these PSUs and other government organisations often face bureaucratic delays, limited flexibility and slower innovation cycles.[94] To address these challenges, India must adopt policies that actively encourage private sector participation, facilitating the development of advanced technologies and creating a more competitive ecosystem.[95]

In recent years, the Indian government has made important strides in promoting private sector participation through initiatives like the 'Make in India' programme and the Defence Production Policy.[96] These initiatives have begun to transform the aeronautical landscape, allowing private companies to play a greater role in defence production and R&D.[97] Additionally, policies facilitating FDI in defence have attracted global aeronautical companies to establish manufacturing and R&D centres in India.[98]

To further accelerate private sector engagement, the establishment of SPVs and PPPs is recommended.[99] SPVs can fast-track development projects by pooling resources from the government, private companies and international partners, while PPPs will enable collaboration between private firms and public institutions such as HAL and DRDO. These models facilitate the exchange of expertise, joint development of technologies and faster commercialisation of projects.[100]

The private sector must play a leading role in developing new technologies in key areas like AI, autonomous systems, advanced materials, stealth fabrication and digital engineering.[101] Start-ups and MSMEs can inject fresh perspectives and agility into design and development processes, while established players such as Tata, Larsen & Toubro (L&T) and Mahindra can scale up production.[102] By fostering closer collaboration between public and private entities, India can accelerate the development of next-generation combat aircraft, UCAVs and other aeronautical platforms.[103]

Private sector involvement should extend beyond domestic projects. By developing advanced capabilities and competitive products, India's aeronautical industry has the potential to become a global exporter of combat aircraft and aeronautical components.[104] To facilitate this, the government must create an enabling environment for exports and support the participation of private companies in global supply chains. Initiatives like the creation of an Aeronautics Export Promotion Council, as outlined in the previous section, will be crucial in helping Indian companies navigate international markets and establish themselves as competitive global players.[105]

Strategic International Partnerships

India's aeronautical sector has significantly benefitted from international collaborations, particularly with countries like Russia, France and Israel, which have provided crucial technologies and technical expertise.[106] These partnerships have been instrumental in enabling India to develop indigenous capabilities in aircraft design, avionics and weapons integration.[107] However, challenges have also arisen, for example, the development of the LCA initially relied on collaboration with France, but when French partners withdrew, India and ADA were left to complete the project independently. Similar hurdles, such as delays in the supply of GE-404 engines, have posed risks to timelines and project continuity. Despite these setbacks, fostering a robust and innovative private sector in aeronautics can help India become more resilient and self-sufficient, ultimately reducing dependence on foreign collaborations and achieving long-term success. As India progresses towards self-reliance in aeronautics, it remains essential to explore partnerships, particularly with economically advanced and technologically capable Asian nations. Countries like South Korea, Japan, Taiwan and Indonesia have established aeronautics sectors, are financially stable and demonstrate a culture of innovation and invention. Collaborative efforts with these nations could emulate the cooperative spirit of alliances like BRICS, which has successfully brought together countries to reduce financial dependence on the Western world and the US dollar. By establishing a collaborative aeronautics framework within Asia, India and its partners can work towards countering Western dominance in aeronautics technologies, avoiding the risks of future sanctions or sudden withdrawal from partnerships that Western nations have historically imposed. This approach would allow India and its regional allies to pool resources, share expertise and build a resilient, self-reliant aeronautics ecosystem across Asia.[108] International collaboration is particularly important

in next-generation technologies—such as AI, autonomous systems, stealth and hypersonic—where India's domestic capabilities are still evolving.[109] Collaborating with countries that have expertise in these areas will accelerate technological development and support India's ambition to remain competitive on the global stage.[110]

Beyond technological development, collaborations with countries interested in purchasing the LCA and its variants should be prioritised. Nations in Southeast Asia and Africa have shown interest in acquiring the LCA due to its cost-effectiveness and capabilities.[111] Establishing partnerships with these countries—not only to supply aircraft but also to share technology, training and maintenance expertise—will help India secure long-term export opportunities while strengthening strategic defence relationships.[112]

India must also focus on partnerships in supply chain management and manufacturing. Integrating Indian companies into global supply chains for engines, avionics and advanced composites will position India as a key player in the global aeronautical industry.[113] These efforts will boost India's export capabilities and enhance its competitiveness in international markets.[114]

To facilitate these partnerships, the Indian government should establish a dedicated mechanism to coordinate international collaborations in aeronautics.[115] This body would bring together stakeholders from government, military, industry and academia to identify potential partners, negotiate agreements and oversee the execution of joint projects. The focus should be on creating synergies with nations that align with India's strategic defence goals and share its vision for the future of aeronautics.

By engaging in these targeted partnerships, India can enhance its technological and manufacturing capabilities while expanding its presence in global defence markets. Such collaborations will accelerate technological development, strengthen India's defence preparedness, and ensure that its aeronautical sector remains at the forefront of global innovation and competitiveness.

Recommendations and Future Pathways

India's journey towards a globally competitive and self-reliant aeronautical sector necessitates a strategic framework that addresses current challenges while capitalising on emerging opportunities. The following recommendations outline a roadmap for building a sustainable and innovative aeronautical industry:

1. Accelerate Indigenous Engine Development

The development of indigenous operational aircraft engines is crucial for achieving self-reliance in combat aviation.[116] To accelerate progress, establishing a dedicated, certified engine development organisation in partnership with the private sector is essential. This new government-private entity should prioritise the refinement of existing engines, such as the Kaveri, while advancing research on next-generation propulsion systems capable of powering fifth- and sixth-generation platforms.[117]

2. Strengthening Research and Development Ecosystems

Strengthening collaboration between the academia, industry and the military is essential to foster cutting-edge developments in aeronautical systems. Currently, Indian industry often does not view academia as a key partner in research and development. In contrast, countries like the US assign professors from the academia to aircraft industries, enabling direct involvement of academia in industry projects with active research content. In the early stages of the LCA Project, faculty from IIT Bombay were deputed to ADA for foundational studies, an approach that could be revived to benefit current projects. Aircraft companies could further support the academia by establishing advanced design, simulation and research centres dedicated to classified, fundamental research within Aeronautics Technopark. These Technoparks would provide students and faculty opportunities to work on real-world industry challenges.

The academia could play a transformative role in advancing the education of service personnel and industry scientists, helping them stay updated with the latest technologies and even pursue advanced degrees. Currently, the involvement of academia in aeronautics is limited to theoretical research and classroom education, with little direct engagement in real-world design, prototyping and testing activities. To bridge this gap, academia should actively contribute to enhancing technology readiness by organising as one example, pilot-scale flying demonstrations of unmanned prototypes. These demonstrations would gather valuable design insights and flight control data well before the metal-cutting phase of full-scale aircraft prototypes, a step that is currently underutilised in India.

Moreover, dedicated flight test centres are not yet accessible to academic institutions. Making these facilities available would enable students and faculty to test scaled prototypes and conduct autonomous swarm drone flights, significantly elevating the technology readiness levels of academic

research. Such opportunities would expose students to practical challenges, foster innovation and provide data critical for iterative development.

These initiatives are currently underdeveloped in India's aeronautical ecosystem. By integrating academia into hands-on R&D activities, like global best practices, India can strengthen collaboration between academia, industry and the armed forces. This approach would ensure a steady flow of innovation within India's aeronautics industry, aligning academic research with operational and industrial needs.

3. Increase Private Sector Engagement

The government should actively promote collaboration in the aeronautics sector through targeted policy reforms, tax incentives and streamlined approval processes that reduce bureaucratic delays.[118] By encouraging PPPs and establishing SPVs, the government can enable private companies to work alongside public institutions, leveraging the private sector's agility and innovation to advance critical aeronautical projects. These initiatives would make it easier for private entities to participate in large-scale aeronautics programmes, providing financial support and a structured framework to accelerate research, development and production within the sector. This approach would strengthen India's capacity for rapid technological advancements and promote self-reliance in aeronautics.[119]

4. Foster International Collaborations

Leveraging international partnerships, especially with friendly advanced Western aircraft-developing nations and Asian countries, will accelerate technological progress.[120] While the US has previously demonstrated unreliability, such as in the case of the GE-404 engine supply, France too has a history of withdrawing support, notably during the development of the LCA programme. Despite these setbacks, it is important to remain open to collaboration with these nations, particularly considering renewed possibilities for improved relations and shared strategic interests. Strategic collaborations like the Artemis project, where India and the US are jointly working on lunar colonisation, highlight the potential for successful partnerships when aligned interests and mutual benefits are involved.

Additionally, India can spearhead the establishment of a regional partnership in aeronautics with Asian countries such as Japan, South Korea and Taiwan, modelled after the European Union's collaborative framework in aeronautics. These countries have demonstrated significant aeronautical expertise—Japan with its Mitsubishi X-2 Shinshin stealth fighter, South

Korea with the KF-21 Boramae programme, and Taiwan with its indigenous defence fighters. By forming a cooperative framework, these nations could pool resources, share technology and co-develop next-generation platforms, enhancing regional self-reliance and reducing dependence on Western nations. Such partnerships, based on equal leadership and mutual respect, would ensure that all participants benefit while advancing their individual technological objectives.

By establishing itself as a dependable and innovative regional partner, India can take the lead in driving technological collaborations that align with shared strategic goals. This regional framework would foster long-term partnerships not based on immediate sales but on a mutual commitment to advancing defence and aeronautics capabilities, thereby strengthening the collective position of Asia in the global aerospace arena.

5. Expand Export Capabilities

Building a competitive export industry in aeronautics is essential. Establishing an Aeronautics Export Promotion Council will assist Indian companies in navigating international markets and positioning themselves as global exporters of aircraft, UCAVs and aeronautical components.[121] Introducing export-oriented policies, including R&D subsidies and tax incentives, will encourage the growth of India's aeronautical exports.[122]

6. Developing Future Aircraft Platforms

Focusing on the development of diverse next-generation aircraft platforms—including sixth-generation fighters, unmanned stealth bombers and advanced UCAVs—is crucial to India's aeronautical growth.[123] While feasibility studies on some UCAV concepts have been conducted, further studies are required in areas such as manned–unmanned teaming, hypersonic aircraft and alternative propulsion systems. Supporting these continuous feasibility studies through dedicated government funding will ensure India remains at the forefront of aircraft design and innovation.[124] Additionally, exploring the development of civil aeronautical platforms, such as autonomous aerial transportation systems for urban environments, will expand India's presence in the civilian market and demonstrate its comprehensive aeronautical capabilities.

7. Creating an Enabling Environment for Innovation

The government must establish a robust regulatory and financial framework to drive continuous innovation in the aeronautical sector.[125] A Defence Aeronautical Technology Council, reporting directly to the Prime Minister's

Office (PMO), should be created to streamline regulatory approvals and foster collaboration among the academia, industry, and defence organisations. Practical steps include piloting a single-window clearance system for R&D projects and aligning council activities with existing initiatives to avoid redundancy.

To promote indigenous innovation, the government should introduce tax incentives tailored for start-up companies in defence aeronautics. This, along with targeted grants and a dedicated defence R&D budget, will ensure sustained financial support for high-priority projects. Establishing Innovation Hubs and Aeronautics Technology Parks within defence corridors can provide essential infrastructure for start-ups and MSMEs, enabling them to contribute effectively to cutting-edge technological advancements.

By adopting a phased and collaborative approach, India can accelerate its aeronautical innovation, boost indigenous capabilities and strengthen its position as a global leader in aerospace technologies.[126]

8. Establish an Aeronautical University for Talent Development

Developing a steady pipeline of specialised aeronautical talent is essential to support the growing demands of the aeronautical sector.[127] Establishing a dedicated aeronautical university, similar to China's Beihang University and Nanjing University of Aeronautics and Astronautics of China, will be pivotal in training future engineers and scientists. This institution would differ from traditional universities by focusing exclusively on aeronautics and associated engineering disciplines, such as avionics, stealth technology, propulsion systems and advanced materials. It would include facilities like simulation labs, specialised wind tunnels and an airfield for flight testing innovative, scaled prototypes to trial technologies such as fluidic thrust vectoring. Collaborating with industry and defence organisations, the university would ensure that its research and education align closely with practical sector needs. By fostering aeronautical talent and driving innovation, this specialised institution would play a critical role in the long-term growth of India's aeronautical capabilities.[128]

Conclusion

India's aeronautical sector is at a transformative point, with a robust pathway to becoming a globally competitive and self-reliant industry by 2047. This article's strategic roadmap outlines critical steps to address current gaps, foster indigenous capabilities and position India as a leader in combat aircraft

and UCAV technologies. The proposals emphasise key priorities such as establishing a dedicated aeronautical university, fostering PPPs, and creating Aeronautics Technology Parks to catalyse industry–academia collaboration, expedite R&D timelines and nurture a steady pipeline of aeronautical talent.

Implementing the proposed structural reforms, advancing research and development, increasing private sector engagement and building strategic international partnerships are foundational steps for India to reduce foreign dependence and strengthen national security. The roadmap advocates dedicated funding to support feasibility studies for next-generation technologies, such as hypersonic combat aircraft and manned–unmanned teaming systems, which are essential to maintaining a cutting-edge combat force. Additionally, initiatives like high-altitude engine testing and the establishment of an operationally certified engine development organisation will ensure India's capabilities align with global benchmarks.

Strategic international collaborations, particularly with technologically advanced Asian nations, offer India a unique opportunity to balance reliance on Western partnerships while promoting regional self-reliance. These partnerships, coupled with market-driven incentives through the Make-in-India initiative, encourage global investment and provide India with access to essential technologies, while mitigating the risks associated with potential sanctions or export limitations.

The roadmap also stresses the significance of establishing a high-level Defence Technology Council to oversee and coordinate long-term strategic planning across the aeronautics sector, ensuring alignment with India's defence and technological goals.

In conclusion, the journey towards a self-reliant aeronautical sector requires sustained collaboration, dedicated funding and a long-term commitment from government, industry and academia. By implementing this roadmap, India will be well-positioned to not only meet its defence needs but also to become a significant contributor to the global aeronautics landscape, reinforcing its standing as an innovation hub and strategic aeronautics exporter by 2047.

Notes

1. Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', *The Times of India*, 2 May 2022, available at https://timesofindia.indiatimes.com/blogs/col-nagial/atmanirbhar-bharat-and-self-reliance-in-defense/; Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', Centre for Joint

Warfare Studies, 20 September 2023, https://cenjows.in/atmanirbhar-bharat-indigenisation-in-defense-sector/.

2. 'ADA Annual Progress Report', Aeronautical Development Agency, 2016, available at https://www.ada.gov.in/images/Annual%20Report%202015-16.pdf; Amrita Nayak Dutta, 'The AMCA Will Bring India Among a Select Group of Nations, Which Have Developed a Fifth-Generation Fighter', *Indian Express*, 8 March 2024, available at https://indianexpress.com/article/india/fifth-gen-fighter-amca-project-gets-ccs-nod-9202191/; Biju Uthup, P.M. Soundar Rajan, T.D. Joseph, Suresh Kumar, Surya S. and Akhil A. Chandran, 'Unmanned Combat Air Vehicles, International Strategy and Security Studies Programme', Classified Report, NIAS Bangalore, July 2022.
3. 'Exclusive: Inside the World of India's Most Secret Combat Aircraft Program', *Livefist*, 2 February 2018, available at https://www.livefistdefense.com/exclusive-inside-the-world-of-indias-most-secret-combat-aircraft/.
4. Akhil Kadidal, 'HAL Loyal Wingman Project to Go Airborne by 2024', *Janes*, 23 March 2022, available at https://www.janes.com/defense-news/news-detail/hal-loyal-wingman-project-to-go-airborne-by-2024; Maxwell Goldstein, 'Sixth-Generation Fighter Programs', *Grey Dynamics*, 1 February 2024, available at https://greydynamics.com/sixth-generation-fighter-programs/.
5. 'Scheme for Innovations for Defense Excellence (iDEX)', Ministry of Defence, Government of India, May 2021, available at https://www.ddpmod.gov.in/sites/default/files/iDEX%20scheme%20Final3.pdf.
6. 'Indian Institute of Space Science & Technology', 2024, available at https://www.iist.ac.in/.
7. RK Narang, *India's Quest for UAVs and Challenges*, KW Publishers, Delhi, 2020; Kris Osborn, 'Air Force Chief: 6th-Gen NGAD Stealth Fighter Will Use AI to Network Drones', *The National Interest*, 6 December 2023, available at https://nationalinterest.org/blog/buzz/air-force-chief-6th-gen-ngad-stealth-fighter-will-use-ai-network-drones-189431.
8. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', *OnlyIAS*, 17 January 2024, available at https://pwonlyias.com/current-affairs/defense-technology-roadmap-of-india/.
9. D. Peri, '5th Generation Fighter Jet Project Gets Cabinet Committee on Security Approval', *The Hindu*, 7 March 2024, available at https://www.thehindu.com/news/national/ccs-approves-development-of-amca-indias-fifth-gen-fighter/article67926162.ece.
10. Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', n. 1; Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
11. 'ADA Annual Progress Report, 2016', n. 2.
12. Amrita Nayak Dutta, 'The AMCA Will Bring India Among a Select Group of Nations, Which Have Developed a Fifth-Generation Fighter', n. 2.

13. Rajat Pandit, 'India Tests Flying-Wing Stealth UAV Towards Building Unmanned Strike Aircraft', *The Times of India*, 16 December 2023, available at https://timesofindia.indiatimes.com/india/india-tests-flying-wing-stealth-uav-towards-building-unmanned-strike-aircraft/articleshow/106031227.cms; Biju Uthup et al., 'Unmanned Combat Air Vehicles, International Strategy and Security Studies Programme', n. 2; Biju Uthup, 'Ghatak UCAV's 1st Director Raises Concerns Over Program's Path', *Livefist*, 10 January 2024, available at https://www.livefistdefense.com/ghatak-ucavs-1st-director-raises-concerns-over-programs-path/.
14. Maxwell Goldstein, 'Sixth-Generation Fighter Programs', n. 4; John D. Gresham, 'X-47B UCAS-D to UCLASS: The Road Ahead', Defence Media Network, 8 December 2013, available at https://www.defensemedianetwork.com/stories/x-47b-ucas-d-to-uclass-the-road-ahead/.
15. Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', n. 1; Biju Uthup et al., 'Unmanned Combat Air Vehicles, International Strategy and Security Studies Programme', n. 2; Biju Uthup, 'Ghatak UCAV's 1st Director Raises Concerns Over Program's Path', n. 13.
16. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
17. Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
18. Alex Joske, 'The China Defense Universities Tracker', Beihang University, 25 November 2019, available at https://unitracker.aspi.org.au/universities/beihang-university/; Amy Chang, 'Indigenous Weapons Development in China's Military Modernization', U.S.–China Economic and Security Review Commission Staff Research Report, 5 April 2012, available at https://www.uscc.gov/sites/default/files/Research/China-Indigenous-Military-Developments-Final-Draft-03-April2012.pdf.
19. 'Exclusive: Inside the World of India's Most Secret Combat Aircraft Program', n. 3; D. Peri, '5th Generation Fighter Jet Project Gets Cabinet Committee on Security Approval', n. 9.
20. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
21. Biju Uthup et al., 'Unmanned Combat Air Vehicles, International Strategy and Security Studies Programme', n. 2; Biju Uthup, 'Ghatak UCAV's 1st Director Raises Concerns Over Program's Path', n. 13; Rajat Pandit, 'India Tests Flying-Wing Stealth UAV Towards Building Unmanned Strike Aircraft', n. 13.
22. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5; 'Defense Industrial Corridors India', Make-in-India, 19 March 2020, available at https://www.makeinindia.com/defense-industrial-corridors-india.
23. Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
24. Akhil, Kadidal, 'HAL Loyal Wingman Project to Go Airborne by 2024', n. 4; Biju Uthup et al., 'Unmanned Combat Air Vehicles, International Strategy and Security Studies Programme', n. 2; Biju Uthup, 'Ghatak UCAV's 1st Director Raises Concerns Over Program's Path', n. 13.

25. Maxwell Goldstein, 'Sixth-Generation Fighter Programs', n. 4; Smith, 'Advancing Beyond 5th Generation: NGAD's Role in Future Air Superiority', *Aerospace Journal*, Vol. 45, No. 3, 2022, pp. 112–129.
26. Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', n. 1; Biju Uthup et al., 'Unmanned Combat Air Vehicles, International Strategy and Security Studies Programme', n. 2; Biju Uthup, 'Ghatak UCAV's 1st Director Raises Concerns Over Program's Path', n. 13.
27. 'Tata Advanced Systems and Airbus Inaugurate C295 Final Assembly Line in Vadodara, India', Airbus, 28 October 2024, available at https://www.airbus.com/en/newsroom/press-releases/2024-10-tata-advanced-systems-and-airbus-inaugurate-c295-final-assembly-line-vadodara-india.
28. Ibid.; Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
29. Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
30. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5.
31. 'ADA Annual Progress Report, 2016', n. 2; Amrita Nayak Dutta, 'The AMCA Will Bring India Among a Select Group of Nations, Which Have Developed a Fifth-Generation Fighter', n. 2.
32. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8; Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
33. 'Exclusive: Inside the World of India's Most Secret Combat Aircraft Program', n. 3; Biju Uthup et al., 'Unmanned Combat Air Vehicles, International Strategy and Security Studies Programme', n. 2; Biju Uthup, 'Ghatak UCAV's 1st Director Raises Concerns Over Program's Path', n. 13; 'Defense Industrial Corridors India', n. 22; 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5.
34. Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', n. 1; Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
35. Amrita Nayak Dutta, 'The AMCA Will Bring India Among a Select Group of Nations, Which Have Developed a Fifth-Generation Fighter', n. 2.
36. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
37. Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
38. Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', n. 1.
39. Amrita Nayak Dutta, 'The AMCA Will Bring India Among a Select Group of Nations, Which Have Developed a Fifth-Generation Fighter', n. 2; D. Peri, '5th Generation Fighter Jet Project Gets Cabinet Committee on Security Approval', n. 9; Maxwell Goldstein, 'Sixth-Generation Fighter Programs', n. 4; Smith, 'Advancing Beyond 5th Generation: NGAD's Role in Future Air Superiority', n. 25.
40. Maxwell Goldstein, 'Sixth-Generation Fighter Programs', n. 4.
41. 'ADA Annual Progress Report, 2016', n. 2; 'Exclusive: Inside the World of India's Most Secret Combat Aircraft Program', n. 3.

42. Rajat Pandit, 'India Tests Flying-Wing Stealth UAV Towards Building Unmanned Strike Aircraft', n. 13; Biju Uthup, 'Ghatak UCAV's 1st Director Raises Concerns Over Program's Path', n. 13.
43. Akhil Kadidal, 'HAL Loyal Wingman Project to Go Airborne by 2024', n. 4.
44. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5; Saima Parveen, 'Combat Air Teaming System (CATS): Meaning, Components and Objectives', My India, January 2023, available at https://www.mapsofindia.com/my-india/technology/combat-air-teaming-system-cats-meaning-components-and-objectives.
45. 'Indian Institute of Space Science & Technology', n. 6; Alex Joske, 'The China Defense Universities Tracker', n. 18.
46. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
47. 'Defense Industrial Corridors India', n. 22; 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5.
48. Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', n. 1; Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
49. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8; Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', n. 1.
50. Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
51. RK Narang, *India's Quest for UAVs and Challenges*, n. 7.
52. RK Narang, 'Unmanned Aerial Vehicles in China: Options for India', Monograph, No. 87, Manohar Parrikar Institute for Defence Studies and Analyses (MP-IDSA), 2019, available at https://www.idsa.in/system/files/monograph/monograpah-87.pdf.
53. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
54. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5.
55. D. Peri, '5th Generation Fighter Jet Project Gets Cabinet Committee on Security Approval', n. 9.
56. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
57. 'ADA Annual Progress Report, 2016', n. 2.
58. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5; 'Exclusive: Inside the World of India's Most Secret Combat Aircraft Program', n. 3.
59. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
60. Smith, 'Advancing Beyond 5th Generation: NGAD's Role in Future Air Superiority', n. 25.
61. 'Indian Institute of Space Science & Technology', n. 6.
62. Alex Joske, 'The China Defense Universities Tracker', n. 18.

63. Smith, 'Advancing Beyond 5th Generation: NGAD's Role in Future Air Superiority', n. 25.
64. John D. Gresham, 'X-47B UCAS-D to UCLASS: The Road Ahead', n. 14.
65. 'Defense Industrial Corridors India', n. 22; Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
66. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5.
67. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
68. Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
69. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5.
70. Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', n. 1; Biju Uthup et al., 'Unmanned Combat Air Vehicles, International Strategy and Security Studies Programme', n. 2; Biju Uthup, 'Ghatak UCAV's 1st Director Raises Concerns Over Program's Path', n. 13.
71. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
72. Amy Chang, 'Indigenous Weapons Development in China's Military Modernization', n. 18.
73. Biju Uthup et al., 'Unmanned Combat Air Vehicles, International Strategy and Security Studies Programme', n. 2; Biju Uthup, 'Ghatak UCAV's 1st Director Raises Concerns Over Program's Path', n. 13.
74. Rajat Pandit, 'India Tests Flying-Wing Stealth UAV Towards Building Unmanned Strike Aircraft', n. 13.
75. Maxwell Goldstein, 'Sixth-Generation Fighter Programs', n. 4.
76. Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', n. 1.
77. 'Defense Industrial Corridors India', n. 22.
78. Maxwell Goldstein, 'Sixth-Generation Fighter Programs', n. 4; Smith, 'Advancing Beyond 5th Generation: NGAD's Role in Future Air Superiority', n. 25.
79. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8; Biju Uthup et al., 'Unmanned Combat Air Vehicles, International Strategy and Security Studies Programme', n. 2; Biju Uthup, 'Ghatak UCAV's 1st Director Raises Concerns Over Program's Path', n. 13.
80. 'Indian Institute of Space Science & Technology', n. 6; Alex Joske, 'The China Defense Universities Tracker', n. 18.
81. Amy Chang, 'Indigenous Weapons Development in China's Military Modernization', n. 18; Kris Osborn, 'Air Force Chief: 6th-Gen NGAD Stealth Fighter Will Use AI to Network Drones', n. 7.
82. Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
83. 'Defense Industrial Corridors India', n. 22.
84. Smith, 'Advancing Beyond 5th Generation: NGAD's Role in Future Air Superiority', n. 25.
85. John D. Gresham, 'X-47B UCAS-D to UCLASS: The Road Ahead', n. 14; Ng Jr, 'China's Next Generation Unmanned Assassins', *Asian Military Review*, 5 June

2019, available at https://www.asianmilitaryreview.com/2019/06/chinas-next-generation-unmanned-assassins/.

86. Saima Parveen, 'Combat Air Teaming System (CATS): Meaning, Components and Objectives', n. 44.
87. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5.
88. 'Defense Industrial Corridors India', n. 22.
89. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
90. Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
91. Ibid.
92. 'Defense Industrial Corridors India', n. 22.
93. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5.
94. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
95. 'Defense Industrial Corridors India', n. 22.
96. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5.
97. Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
98. Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', n. 1.
99. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5.
100. D. Peri, '5th Generation Fighter Jet Project Gets Cabinet Committee on Security Approval', n. 9.
101. Saima Parveen, 'Combat Air Teaming System (CATS): Meaning, Components and Objectives', n. 44.
102. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5.
103. Akhil Kadidal, 'HAL Loyal Wingman Project to Go Airborne by 2024', n. 4.
104. Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
105. Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', n. 1.
106. Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1; Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', n. 1; Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
107. Amrita Nayak Dutta, 'The AMCA Will Bring India Among a Select Group of Nations, Which Have Developed a Fifth-Generation Fighter', n. 2.
108. Maxwell Goldstein, 'Sixth-Generation Fighter Programs', n. 4.
109. Smith, 'Advancing Beyond 5th Generation: NGAD's Role in Future Air Superiority', n. 25.
110. Kris Osborn, 'Air Force Chief: 6th-Gen NGAD Stealth Fighter Will Use AI to Network Drones', n. 7.
111. 'Exclusive: Inside the World of India's Most Secret Combat Aircraft Program', n. 3; Akhil, Kadidal, 'HAL Loyal Wingman Project to Go Airborne by 2024', n. 4; 'Exclusive: Inside the World of India's Most Secret Combat Aircraft Program', n. 3.
112. 'Defense Industrial Corridors India', n. 22.

113. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5.
114. Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
115. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
116. Biju Uthup et al., 'Unmanned Combat Air Vehicles, International Strategy and Security Studies Programme', n. 2; Biju Uthup, 'Ghatak UCAV's 1st Director Raises Concerns Over Program's Path', n. 13; Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
117. Balwan Singh Nagial, 'Atmanirbhar Bharat and Self-Reliance in Defense', n. 1; Rajat Pandit, 'India Tests Flying-Wing Stealth UAV Towards Building Unmanned Strike Aircraft', n. 13.
118. Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
119. Akhil, Kadidal, 'HAL Loyal Wingman Project to Go Airborne by 2024', n. 4; Saima Parveen, 'Combat Air Teaming System (CATS): Meaning, Components and Objectives', n. 44.
120. Maxwell Goldstein, 'Sixth-Generation Fighter Programs', n. 4; Kris Osborn, 'Air Force Chief: 6th-Gen NGAD Stealth Fighter Will Use AI to Network Drones', n. 7.
121. 'Defense Industrial Corridors India', n. 22.
122. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5.
123. Amrita Nayak Dutta, 'The AMCA Will Bring India Among a Select Group of Nations, Which Have Developed a Fifth-Generation Fighter', n. 2; Biju Uthup et al., 'Unmanned Combat Air Vehicles, International Strategy and Security Studies Programme', n. 2; Biju Uthup, 'Ghatak UCAV's 1st Director Raises Concerns Over Program's Path', n. 13.
124. John D. Gresham, 'X-47B UCAS-D to UCLASS: The Road Ahead', n. 14.
125. 'Scheme for Innovations for Defense Excellence (iDEX)', n. 5; Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.
126. 'Defense Industrial Corridors India', n. 22; Sharad Rastogi, 'Atmanirbhar Bharat: Indigenisation in Defense Sector', n. 1.
127. 'Indian Institute of Space Science & Technology', n. 6; Alex Joske, 'The China Defense Universities Tracker', n. 18.
128. Vijay Raghavan, 'Vijay Raghavan Panel on Restructuring and Redefining Role of DRDO', n. 8.