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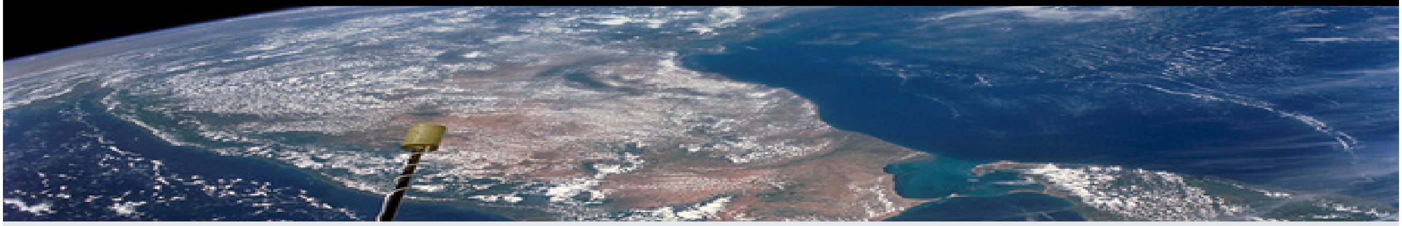

Historic Flight by Army, Air Force Chiefs in Indigenous LCA Fighter Jet

Image Courtesy: PTI

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"Our vision is to transform the Indian Air Force into a future-ready, technology-driven force that is agile, adaptive, and fully capable of safeguarding national interests in all domains"

- Air Chief Marshal AP Singh PVSM AVSM
Chief of the Air Staff, Indian Air Force

Contents

Opinions and Analysis

Air Power

Space

Aerospace Industry

Opinions and Analysis

Historic Flight by Army, Air Force Chiefs in Indigenous LCA Fighter Jet

09 February 2025

Source: ANI | https://www.aninews.in/news/national/general-news/historic-flight-by-army-air-force-chiefs-in-indigenous-lca-fighter-jet20250209202857/

General Upendra Dwivedi an Air Marshal AP Singh (Photo/ANI)

Bengaluru (Karnataka), India, February 9 (ANI): In a first, Army chief General Upendra Dwivedi and Air Force chief Air Chief Marshal AP Singh on Sunday took to the skies together in the indigenous Light Combat Aircraft (LCA) Tejas.

This first ever flight with two chiefs in the cockpit not only marks a personal milestone for the two Chiefs, who are course mates, but also underscores the growing synergy and integration between the Indian Army and the Indian Air Force (IAF).

"It was the best moment of my life. As you are aware Air Chief Marshal AP Singh is my course mate and we have been together since our NDA days. I wish he had met me earlier; I would have changed my option to the Air Force. I have told earlier also if I had gone to the Air Force, I would have been a fighter pilot. From today AP Singh is also my guru. I relished. I must admire the kind of challenge Air Force pilots take. It's a good start for Aero India 2025," Dwivedi told reporters.

The flight is a powerful demonstration of India's advancing defence capabilities, particularly in the realm of self-reliance. The Tejas, developed entirely within India, is a shining example of the nation's commitment to 'Aatmanirbharta' (self-reliance) in defence. The successful operation of this homegrown aircraft signifies the significant strides India has made in the field of indigenous defence aviation.

Today's flight also highlights the enhanced cooperation between the services, an essential pillar for modern warfare. As both Chiefs soared together in the skies, they exemplified the deepening bond and collaboration between the Army and the Air Force, vital to achieving operational excellence. The Indian Army's role in the air domain is becoming increasingly pivotal, especially in tactical battle areas where advanced technologies such as helicopters, unmanned aerial systems, and air defence systems play a crucial role.

This historic moment serves as a clear indicator of the evolving landscape of warfare, where jointness and seamless integration between the Army and the Air Force will define success in the future. The ongoing decade of transformation (2023-2032) is reshaping the future of defence operations, and the period of 2024-2025 will be crucial for integrating cutting-edge technologies across all domains.

Aero India 2025, the premier aerospace exhibition, provides an exceptional platform for defence industry leaders to engage, collaborate, and explore emerging technologies. It serves as an ideal venue for the Indian Armed Forces to forge stronger ties with the industry and acquire the best solutions to modernize and enhance their operational capabilities.

Today's flight by General Dwivedi and Air Marshal Singh is not only a remarkable event but a reflection of India's unwavering commitment to nation-building through indigenous defence production. As the country continues its journey towards self-sufficiency, the collaboration between the Army and the Air Force, backed by innovations like the Tejas, reinforces India's standing as a rising global defence power.

Earlier in the day, Defence Minister Rajnath Singh said the government has galvanised the entire defence sector, especially the aerospace sector, where it has been made possible to produce fighter jets like LCA Tejas and Prachand in India.

Speaking at the Curtain Raiser event for Aero India 2025, he said that India was not merely designing or developing major equipment in the country, but has also been able to develop a supply chain for the same. (ANI)

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Aerospace Would be Exposed in Potential Trade War

Jens Flottau | 07 February 2025

Source: Avaition Week | https://aviationweek.com/aerospace/manufacturing-supply-chain/opinion-aerospace-would-be-exposed-potential-trade-war

Jens Flottau/AW&ST

Commercial aircraft manufacturing and the airline industry have been going through one of their most operationally and financially challenging periods for several years now. After the COVID-19 pandemic had slowly dissipated, airlines—often burdened with multiple billions of dollars in debt needing to be repaid—were struggling to rebuild their fleets amid unexpected and unprecedented delays in the delivery of new aircraft or spare parts. Manufacturers have also struggled with rebuilding production capacity and are still far from the levels of six years ago.

Two themes have been present all along: a dysfunctional, disrupted supply chain and much higher than usual inflation that has temporarily slowed to more normal levels. Many small (and some big) suppliers are on the brink, and the aerostructures industry is in particular trouble.

If anyone hoped that things would finally improve in the next few years, that could quickly turn out to be a misjudgment. It looks like supply chain disruption and inflation could be themes that will accompany the global commercial aerospace industry for the next four years. The new U.S. administration under President Donald Trump has begun rolling out tariffs, first against Mexico, Canada and China, and likely soon to be followed by the European Union. China has already announced retaliatory measures; the tariffs against Mexican and Canadian imports in the meantime have been suspended for a month.

While it is impossible to predict what will happen next, the initial measures could still evolve into a broader, protracted global trade war. How severe the impact on aviation will be depends on the exact nature of measures that remain to be seen. What is clear: The industry will be hurt more by a broader trade war.

Major players are starting in different positions. Boeing builds its aircraft only in the U.S., but it receives components for them from all over the world. GE Aerospace and Pratt & Whitney engines are also made up of parts sourced from around the globe. Airbus builds commercial aircraft in France, Germany, China, Canada and the U.S.—and, of course, the parts for them come from everywhere.

Many U.S. aerospace companies have moved some work to Mexico, and there are Canadian components in Airbus A220s built in Mobile, Alabama. China is importing U.S.-made engines to power the Comac C919. Aircraft parts are coming from India and Brazil, among many other countries.

Sustained tariffs—or even worse, export sanctions—are introducing the very real danger of creating more disruption in an already highly stressed supply chain that—in spite of everything—seemed to be on the verge of stabilizing.

The administration's hope that companies could react by onshoring work again appears to be far-fetched. Such actions would include very expensive multiyear projects, and a new U.S. administration could opt for completely different trade policies in four years. Plus, the main reasons for offshoring—such as high costs—continue to persist or are getting worse.

One misunderstanding about tariffs is that they are paid by the countries upon which they are imposed. In fact, in this case, U.S. airlines and their customers—so ultimately the flying public—would have to foot the bill in the form of higher air fares. In a broader sense, inflation would return. Tariffs for aerospace goods would make Boeing aircraft more expensive—even a 737-8 delivered from Renton, Washington, to Delta Air Lines or another 787 sent to United Airlines' Chicago base from North Charleston, South Carolina. Those aircraft would become even less competitive if they were to be delivered to a foreign carrier based in a country that has put in place its own tariffs to counter the U.S. measures.

For the record, around 65% of all Boeing aircraft are delivered to non-U.S. customers and about the same share of Airbus jets goes to non-European operators, analysis from Vertical Research Partners shows.

In the immediate aftermath of the pandemic, airlines have benefited from pent-up travel demand. More recently, the solid economic trends in many countries, including the U.S., have supported travel spending. What companies and individuals do not like before making decisions on investments or leisure travel is uncertainty. An imminent trade war that would threaten investments and jobs is introducing just that.

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Pakistan Air Force to Gain "12-14 Year" Edge Over India with J-35A Fighter Acquisition

10 February 2025

Source: Defence Security Asia | https://defencesecurityasia.com/en/pakistan-air-force-to-gain-12-14-year-edge-over-india-with-j-35a-fighter-acquisition/#google_vignette

J-35A

DEFENCE SECURITY ASIA – Pakistan's bold move to secure up to 40 J-35A fifth-generation fighter jets from China is set to reshape the regional air power equation, granting its air force a formidable edge over its long-standing rival, India.

Retired Air Commodore Zia Ul Haque Shamshi, a former senior officer of the Pakistan Air Force (PAF), asserts that the acquisition of the advanced J-35A will leave the Indian Air Force (IAF) lagging behind, giving Pakistan a technological upper hand for the next 12 to 14 years.

"India is not expected to acquire fifth-generation fighter jet capabilities within that timeframe, which will provide Pakistan with a strategic edge," he stated.

Last year, the Pakistan Air Force (PAF) sent shockwaves through the region with strong indications of its intent to acquire the cutting-edge J-35A stealth fighter, a next-generation war machine developed by China's Shenyang Aircraft Corporation.

Air Chief Marshal Zaheer Ahmed Baber Sidhu further fueled anticipation, declaring that the J-35A would soon take its place in the PAF's arsenal, signaling a transformative leap in Pakistan's aerial warfare capabilities.

"Negotiations have been conducted for the acquisition of the J-35A, which will soon become part of the Pakistan Air Force," he said during an event last year.

Recently, Pakistani media reported that the PAF has already sent a group of its pilots to China for training on the J-35A fighter jet, further reinforcing the country's commitment to integrating fifth-generation fighter technology into its fleet.

The J-35A is China's second stealth fighter after the J-20 "Mighty Dragon."

While the J-20 remains exclusive to the Chinese Air Force, the J-35A has been developed with potential export customers in mind.

This latest acquisition will further expand the presence of Chinese-made fighter jets in Pakistan's air force inventory, which already includes the J-10C and the jointly developed JF-17.

Reports that Pakistani pilots have begun training on the J-35A indicate that Islamabad is on a definitive path toward fielding fifth-generation fighter aircraft.

This move has raised concerns in neighboring India, which continues to rely on 4.5-generation fighters such as the Sukhoi Su-30MKI and Rafale jets.

India now faces the prospect of dealing with not just China—whose air force already operates the J-20—but also Pakistan, which appears set to introduce its own fifth-generation fighters.

According to analysts, Pakistan's acquisition of the J-35A, as reported by its media, is likely intended to replace its aging fleet of American-made F-16s and French-built Mirage 5 aircraft.

If confirmed, this procurement could significantly alter the balance of air power in the region and pose a new strategic challenge for India.

The J-35A is expected to enhance Pakistan's tactical flexibility, allowing its air force to conduct deeper penetration missions into enemy airspace.

China has been actively promoting the J-35A for export, even establishing a dedicated office to attract potential foreign buyers.

Unlike the J-20, which Beijing has restricted from export—similar to how the U.S. limits sales of the F-22 Raptor—the J-35A is being positioned as a viable alternative for international customers.

The J-35A stands as a formidable force in modern aerial warfare—a single-seat, twin-engine, medium-sized stealth fighter engineered for dominance.

Boasting cutting-edge low-observability technology and cost-effective operational efficiency, it is poised to challenge the world's most advanced combat aircraft.

Reports indicate that China is gearing up for the J-35A's integration into carrier-based operations, positioning it as a direct rival to the U.S. Navy's F-35B and F-35C variants developed by Lockheed Martin.

Though its full technical specifications remain shrouded in secrecy, the aircraft's Maximum Take-Off Weight (MTOW) has reportedly surged from 25,000 kg to 28,000 kg, hinting at increased firepower and endurance.

Powering this stealth marvel are WS-19 engines, each delivering a staggering 12 tons of thrust—an upgrade that solidifies its place as a next-generation powerhouse in the skies.

The fighter jet is equipped with two internal weapons bays, each capable of carrying two medium-range air-to-air missiles.

Additionally, it features external hardpoints for various bombs and missiles, enhancing its multirole combat capabilities.

Pakistan's decision to procure the J-35A is poised to reshape the regional air power equation, compelling India to accelerate its own efforts to develop or acquire fifth-generation fighter jets.

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Air Power

Strategic Premises for the Future of India's Air Power

Diptendu Choudhury | 24 February 2025

Source: ORF | https://www.orfonline.org/research/strategic-premises-for-the-future-of-india-s-air-power

The exploitation of the aerial domain and the leveraging of air power—with its capacity to rapidly adapt technology tailored to conflict dynamics—is a sine qua non of modern warfare. This is reflected in recent conflicts, whether in Russia's extensive employment of air power in the standoff against Ukraine, Israel's aerial attacks in Gaza and Lebanon, Myanmar's military air strikes against anti-junta resistance, the Houthi rebels' disruption of Red Sea traffic with drone and missile attacks, the Turkish air strikes against Kurdish militants in Syria and Iraq, or the recent Pakistani air strikes against Afghanistan. Adding to such instances of direct deployment of air power is its use for coercion and political signalling in all critical and potential conflict zones. China's aggressive and escalating use of large combat aircraft formations to transgress Taiwan's airspace, which has effectively erased the sanctity of the median line in the strait separating the two nations, is a key example. Thus, control of the aerial domain, both over land and sea, has emerged as a military security imperative—one that is no longer an air-force-only requirement but a crucial joint warfighting necessity.

Key Takeaways for India

Contemporary conflicts present a number of strategic air-power takeaways for India's security context, particularly considering the threat from China and Pakistan, two nuclear-armed adversaries with formidable air forces. In India, too, all future conflicts will involve highly contested air spaces, where any degree of airspace control will have to be fought for, whether over tactical battlespaces, penetration corridors, or hostile airspaces. Unless a certain degree of control exists, offensive action by enemy air forces will have a detrimental impact on India's surface operations.

To consider that India's future wars can be fought and won without the aggressive use of offensive air power, whether over land or sea, would be a fallacy. However, India's current offensive advantage due to fighter force ratios, better weapons payload capacity, higher mission rates, larger number of airfields, dispersed launch and recovery capabilities at lower altitudes, swift turnaround between missions, and A-A refuelling and AWACS/AEWC integration[a] is rapidly diminishing.

A nation's offensive military capabilities are fundamentally tied to effective deterrence. Thus, the fusion of air defence (AD) with offensive air operations is an operational reality of all professional air forces worldwide.

The Indian Air Force (IAF) is no exception, with its integrated AD (IAD) capability that synergises AD operations with all offensive air operations. This is bolstered by an extended IAD (EIAD) system with a multi-tiered array of AD sensors and surface-air weapon systems that allow engagement of the enemy deep inside adversarial airspaces, well before they enter friendly airspace, to carry out aggressive depth offensive missions.

It is this offensive capability to take the war to the enemy by penetrating the adversary's heartland that is currently the IAF's only asymmetric advantage against China. This sole military advantage needs to be bolstered with future-generation combat platforms, combat enablers, and advanced A-A and air-ground weapons. The conceptual and doctrinal fusion of the IAF's future EIAD operations with the IAF's future offensive capabilities is an imperative for India's joint military strategy as it will create the tactical conditions necessary to penetrate Chinese anti-access/area denial defence systems in Tibet and defeat Pakistan's robust AD network.

Modern battlespaces are intensely busy, with a dense area of airspace that needs close surveillance and control to ensure every air threat can be detected, identified, and engaged with. Moreover, during hostilities, the entire volume of airspace, including the tactical battle areas of the Indian Army, needs to be closely managed to enable the free operation of all friendly air and surface missions. The detection of enemy air threats and their engagement at the farthest possible ranges, the deconfliction and maximum exploitation of airspace and fratricide, and the prevention of all future air operations are only possible through the automated and networked visibility of the entire volume of air space. This is currently possible due to the IAF's Integrated Air Command and Control System (IACCS), which creates networks and data links between all surface and airborne radars and AD weapon systems. During India's airstrike on Jabba Top and its follow-on air operations in 2019, the IACCS proved its capability in ensuring dynamic situational awareness in combat and the shortest possible sensor-shooter kill chain.

Future measures to upgrade the IACCS must focus on integrating the Indian Army's surveillance radars with the IAF's EIAD coverage as it would enable a more comprehensive and cost-effective AD for all surface operations, whether defensive or offensive. The IACCS will also need to be upgraded to an aerospace command-and-control system to incorporate the safety of aerial platforms that include space while allowing complete freedom to engage with all types of adversarial aerial and space threats.

For over a decade, the IAF's IACCS has ensured extensive air domain awareness (ADA). Though the move towards greater ADA is welcome, it is not enough for the future. Globally, space has become a contested domain that is increasingly being weaponised. Airspace management and control is no longer sufficient, given that near space, at the very least, will be extensively used for military applications in the future. Hypersonic weapons, such as space glide vehicles and fractional orbital bombardment systems, Ballistic Missile Early Warning System (BMEWS), and Anti-Satellite Weapon (ASAT) capabilities—including co-orbital systems, directed energy weapons, high-powered lasers, space-enabled electronic jamming, and spoofing—pose a serious threat. Moreover, apart from a military perspective, controlling space is equally important from a civilian angle, given the immense growth potential of India's civil aviation sector and civil leveraging of space as a national enterprise.

Thus, India must move towards a greater awareness of near space and space. The concept of ADA must be extended to an integrated aerospace domain awareness (IADA), which includes situational awareness of the air, near space, and outer space. Two areas crucial for India's future security in this context are the development of an IADA capability and the transition from an integrated air defence capability to an integrated aerospace defence capability (IADC). India must accelerate its research and development (R&D) to create a comprehensive IADC architecture that builds on a futuristic IADA architecture. This will need a larger national commitment, with work towards building a proactive synergy between the IAF and India's civil space and aviation industries.

In terms of expanding India's sensor coverage, building aerial surveillance sensors over island territories is also an imperative, given the strategic importance of the Indian Ocean region to India's economy, national security, and vital interests. This would make India's peacetime AD more robust and resilient. In addition, active control over India's six Air Defence Identification Zones (ADIZ), which are designated sovereign airspaces over its mainland and island territories, must be ensured to detect, identify, track, and control all aerial traffic and factored into India's future aerospace security awareness and control architecture.

A Comprehensive Approach to Civil and Military Aviation

Civil aviation is a key element of a nation's comprehensive air power, and India must realise the potential of collaboration in the defence and civil aviation industry. There are large areas of overlap between civil and military aviation in national security due to the interoperability of capabilities and capacity redundancies. The aviation sector also has the potential to contribute to economic growth, foreign policy support, diplomacy, political support and signalling, and humanitarian assistance. India needs to develop a comprehensive and visionary aerospace technology development and production (ATDP) strategy that embraces public-private partnerships and invest heavily to make the aviation industry a profitable economic venture. India's aviation industry expects investments of INR 350 billion (US$4.99 billion) over the next four years, with the government planning to invest US$1.83 billion for the development of airport infrastructure and aviation navigation services and build 220 new airports by 2025.

The country is already known for cost-competitive space research, development, and production. Expanding this model to an integrated military-civil aviation industry will be a truly strategic investment for the future, given the immense regional demand for affordable combat platforms, critical enablers, AD radars, weapon systems, aerial weapons, fixed and rotary-wing civilian passenger and transport aircraft, and unmanned platforms. This will not only fill inventory gaps but also expand regional influence by creating technology dependencies through generating extensive low-cost competitive exports.

Another critical concern is the ever-widening gap between the IAF and the Pakistan Air Force and the People's Liberation Army Air Force (PLAAF), both in terms of platform capabilities and combat inventory. India's already delayed fifth-generation Advanced Medium Combat Aircraft (AMCA) project is still a decade from being deployed, by which time China would have altered the air power balance and infrastructure in Tibet in its favour. This means that, by the time the AMCA arrives, China's sixth-generation platform would already have been deployed, not only in Tibet but also in Pakistan, leaving India lagging in technology and military capability. Of equal concern is that, in this period, the IAF's mainstay fourth-generation fleet will also be a decade older, despite its upgraded capabilities. This does not bode well as Beijing increasingly leverages its air power capabilities as an instrument of its coercive foreign policy over Taiwan and the East and South China Seas, signalling its future use against India. There is already a visible increase in PLAAF's air activity across disputed borders, with Beijing building extensive infrastructure across disputed regions, including the creation of border villages. An increase in aerial violations and coercive air activity to bolster Beijing's narrative building and support its territorial ambitions in Ladakh and Arunachal Pradesh can be expected to become the future normal.

The long hiatus since India's only unfettered use of offensive air power in the Indo-Pakistan war of 1971 has led to a strategic air blindness in the national security approach. The salience of air power in the land and sea domains has led to increasing aspirations of service-specific air power capabilities instead of work to coalesce and strengthen the military's joint capabilities in a nation with a limited defence budget. The vertical domain is the IAF's area of core competence and it is the IAF's capabilities that must be strengthened to holistically address the future security needs of the nation and the joint warfighting needs of the other services.

The extensive use of air power in current conflicts underscores its continued relevance and expanding methods of use, such as in manned and unmanned platforms, diverse long-range precision weapons, hypersonic and advanced aerial missiles, sophisticated air defence systems, and surface and space-launched weapons that operate across the aerospace continuum. Air power is the essential, integrating thread in future multi-domain operations, connecting land, sea, and space. With China remaining resolute in its pursuit of becoming a world-class military power by 2047 and asserting its role as the central global state, or Zhōngguó, it has strategically focused on advancing its air and space power capabilities, with its sixth-generation fighters already surpassing those of the US.

Conclusion

India's growing economic and great-power status places it in strategic competition with China across all domains. With two strong adversarial air forces, control of the vertical domain will be highly contested and will impact all future surface operations; therefore, they must be part of future joint military strategies. The fusion of India’s future EIAD system with its depth offensive capabilities will be a strategic warfighting imperative. Given the increasing fusion of the air and space domains and its importance to future national security and sovereignty, aerospace domain awareness and aerospace defence need to be urgently integrated, invested in, developed, and expanded. A holistic ATDP strategy, which addresses India’s vast civil aviation potential and future military air power needs, would help the country’s aviation industry become robust and productive. Till we achieve true Atmanirbharta in future generation fighter production, critical inventory gaps must be filled with foreign purchases while leveraging other areas of proven production in the indeginous aviation industry. Air power will remain a vital instrument of national power, and New Delhi must do all it can to maintain the nation’s current asymmetric advantage over Beijing by prioritising India’s comprehensive air power requirements.

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India's Fighter Jet Battle: US v Russia in the Skies

Soutik Biswas | 04 March 2025

Source: BBC | https://www.bbc.com/news/articles/cdjyyd7nw1zo

The F-35 in action at Aero India 2025, the region's biggest air show, in Bengaluru city

India faces a crucial choice in modernising its air force - but is a cutting-edge American fighter jet the answer?

During his Washington visit last month, Prime Minister Narendra Modi met US President Donald Trump, who announced they were "paving the way" for India to acquire F-35s, a jet primarily sold to close allies and partners.

The F-35 is a "fifth-generation" multi-role fighter jet with advanced sensors, AI-driven combat systems and seamless data-sharing capabilities. Built to evade radar, it's the most sophisticated jet in the skies - but at $80m a pop, also one of the most expensive. (Stealth is a key characteristic of a "fifth-generation" fighter.)

Many believe that with its fighter squadrons dwindling and China's military growing, India faces a high-stakes choice: splurge on the state-of-the-art but costly F-35 from the US or strengthen defence ties with Russia through local production of its most advanced stealth fighter jet Sukhoi Su-57.

Experts believe the reality is more nuanced, with the US-Russia "dogfight" largely a media hype – fuelled more recently by the appearance of both jets at Asia's biggest air show, Aero India, in the southern city of Bengaluru last month.

Trump's F-35 offer seems more "symbolic" than practical, driven by his push to sell US weapons, according to Ashley J Tellis, a senior fellow at the Carnegie Endowment for International Peace.

Integrating a "fifth generation" aircraft into the India air force (IAF) plans - centred on the homegrown Advanced Medium Combat Aircraft (AMCA) and more Rafales - would be challenging, especially without co-production rights. Being developed by India's Defence Research and Development Organisation (DRDO), the AMCA is India's own stealth fighter.

"It is unlikely that the F-35 will be offered for co-production to India - any acquisition will likely be a straightforward sale. This is unlikely, among other things, to sit well with Modi's emphasis on making in India and the significant end-user monitoring in the event of an F-35 sale will likely not be welcomed by India either," Mr Tellis told me.

India's challenges with the F-35 are its steep cost, heavy maintenance and operational issues - the jet's availability is around 51% for the US Air Force, according to security expert Stephen Bryen, author of a Substack column, Weapons and Strategy. "The question is whether India is willing to invest billions of rupees in the F-35, knowing it could do better buying the Russian jet."

But many dismiss the Su-57 as a real contender, noting that India exited the decade-long programme to co-produce the jet with Russia in 2018 over disputes on technology transfer, cost-sharing and specifications.

To be sure, India's air force is ageing and short on fighter jets.

It operates 31 fighter and combat squadrons - mostly Russian and Soviet-era aircraft - far below the sanctioned 42. A key challenge is finding a long-term replacement for the Sukhoi-30, the IAF's versatile workhorse from Russia.

Christopher Clary, a political scientist at the University of Albany, recently pointed to unsettling data from the ISS Military Balance for India: between 2014 and 2024, China added 435 fighter and ground attack aircraft, Pakistan gained 31, while India's fleet shrank by 151.

India's planned fighter jet expansion is largely homegrown, with plans to acquire over 500 jets, mostly light combat aircraft.

Orders for 83 Tejas Mark 1A - an agile multirole homegrown fighter - are confirmed, with another 97 expected to be ordered shortly. Meanwhile, the heavier, more advanced Mark 2 is in development. The homegrown stealth jet remains at least a decade away.

India also has plans to buy 114 multirole fighter jets under the IAF's $20bn Multi-Role

Fighter Aircraft (MRFA) programme requiring foreign jets to be built in India under a transfer of technology deal - its biggest hurdle.

Stalled since 2019, the Indian government is looking at a transparent and non-controversial procurement process after it faced criticism over the acquisition of 36 Rafales in a government-to-government deal. Five jets are in contention, with Rafale leading as it is already in service with the IAF.

Experts say India's air force modernisation faces three key hurdles: funding, delays and dependence on foreign jets.

Defence spending has shrunk in real terms. The foreign fighter jets programme risks a drawn-out fate. While India prioritises home-made, DRDO's delays force stopgap foreign purchases, creating a repeating cycle. Breaking it requires delivering a capable homegrown jet on time. Deliveries are also delayed due to a holdup in supplies of General Electric's F-404 engines for the jets.

A key challenge is the mismatch between the defence ministry's vision and the IAF's needs, says Rahul Bhatia, an analyst at Eurasia Group, a geopolitical risk consulting firm.

The Tejas Mark 1 faced early scepticism from the air force, leading to upgrades like the Mark 1A and Mark 2. "But the decades-long development cycles frustrate the armed forces, especially as their requirements keep evolving as newer technologies become available, which in turn contributes to further delays," Mr Bhatia told me.

Even the Indian Air Force chief AP Singh has made no secret of his frustration over delays.

"I can take a vow that I will not buy anything from outside or I will wait for whatever is developed in India, but it may not be possible if it does not come at that pace [on time]," Air Marshall Singh told a seminar recently.

"At the moment, we all know that we are very badly off when it comes to numbers [of fighters]. And the numbers which were promised are also coming a little slow. So, there will be a requirement to go and look for something which can quickly fill up these voids," he said, referring to the delayed Tejas Mark 1A deliveries, which were supposed to begin last February but have yet to start.

India's clear priority is a homegrown stealth fighter, with more than $1bn already committed to its development. "A foreign stealth jet would only be considered if India's immediate threat perception shifts," says Mr Bhatia. China has two so-called stealth fighters - the J-20 and J-35 - but they likely fall short of US standards.

Most experts believe India will choose neither the American nor Russian fighters. "In the short term, as seen in past conflicts, emergency buys may fill gaps. The medium-term focus is co-production, but the long game is clear - building its own," says Mr Bhatia.

For India, the future of airpower isn't just about buying jets - it's about building them, ideally with a strong Western partner. But for that vision to succeed, India must deliver its homegrown fighters on time.

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Air Force Triples Funding for Prototype Sixth-Gen Fighter Engine

Stephen Losey | 29 January 2025

Source: Defence News | https://www.defensenews.com/air/2025/01/28/air-force-triples-funding-for-prototype-sixth-gen-fighter-engine/

The Air Force has expanded funding for a cutting-edge adaptive engine that would power the Next Generation Air Dominance fighter, while the future of NGAD itself remains under consideration. (Air Force)

The Air Force on Monday greatly expanded funding for the prototype engine for the service's planned sixth-generation fighter.

General Electric of Cincinnati, Ohio, and Pratt & Whitney Engines of East Hartford, Connecticut, each received modifications to their initial Next Generation Adaptive Propulsion, or NGAP, contracts that bring the maximum amount for the prototype phase up to $3.5 billion apiece. That is more than three times higher than the $975 million ceiling on the original contracts awarded in 2022.

NGAP is expected to be the propulsion system for the planned Next Generation Air Dominance fighter. GE and Pratt are designing so-called "adaptive" engines, which shift to the most efficient thrust configuration for whatever situation a jet is in, to power NGAD.

The Pentagon seriously considered upgrading the F-35 Joint Strike Fighter with adaptive engines. But their cost and limited ability to fit all models of the F-35 led the Pentagon to instead upgrade the F-35′s current engines.

The progress made on adaptive engines is now feeding into the NGAP program. And even as the Air Force reconsiders its approach to NGAD and air dominance, the contract modification signals the service wants to keep work moving on the new engines.

The Pentagon said this contract award will help deliver "a state-of-the-art propulsion system with a flexible architecture that can be tailored for future combat aircraft operating across various mission threads, and digitally transforming the propulsion industrial base." The Pentagon expects the work to be done by July 2032.

Chris Calio, president and chief executive of Pratt's parent company, RTX, said the additional funding will help the company continue driving down the risks on its adaptive engine, dubbed "XA103."

"We've gone through rigorous testing over the last few years," Calio said in an earnings call with investors Tuesday. "We've been really pleased with the results there."

Pratt & Whitney said in February 2024 that the XA103 had finished a key design review with the Air Force and was on its way to ground testing in the late 2020s.

GE said in May 2024 that its NGAP engine, the XA102, finished a major design review in December 2023 and was moving towards a prototype engine test.

The Air Force has pushed for years to develop NGAD – envisioned as a "family of systems" including a sixth-generation crewed fighter, as well as drone wingmen known as collaborative combat aircraft and other advanced systems and weapons – to modernize its fleet and replace the F-22.

The program is suffering from major sticker shock, however, with initial cost estimates coming in at three times as much as an F-35, or between $250 million and $300 million. The Air Force balked and put NGAD on hold in summer 2024 as it reconsidered what the best and most cost-effective way to maintain air dominance might be.

After Trump was reelected, the Air Force's previous leadership decided it would be more appropriate to let the new administration decide its path forward.

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Unleashing Defense Drone Potential: Gore's Innovative Cable Technology

W. L. Gore | 03 March 2025

Source: Aviation Week | https://aviationweek.com/defense/unleashing-defense-drone-potential-gores-innovative-cable-technology

Innovative Cable Solutions: How Gore Supports Defense Drone Advancements

As modern defense operations become increasingly reliant on unmanned aerial systems (UAS), optimizing weight, durability, cost, and performance in defense drones is essential. These aircraft must carry sophisticated payloads while maintaining agility, endurance, and resilience in extreme conditions. W. L. Gore & Associates, a global leader in high-performance aerospace cables, plays a critical role in advancing the capabilities of defense drones through cutting-edge cable solutions.

Advanced Cable Technology for Enhanced Mission Readiness

One of the primary challenges in defense drone development is achieving the right balance between weight, cost, and performance. Traditional data and power cables can contribute to excess weight, cost, and complexity, limiting flight endurance and mission efficiency. Gore's qualified cables are on the shelf, leveraging materials and advanced engineering to enable ultra-lightweight, high-performance drones with increased payload capacity and longer range. Gore's cables minimize both size and weight without compromising reliable electrical performance in terms of bandwidth, EMI resilience, and latency mitigation.

By leveraging Gore's extensive expertise in aerospace cable engineering, defense drone manufacturers can reduce overall cable weight through advanced downgauging techniques. These techniques involve using smaller gauge conductors, leveraging Gore materials that offer higher operating temperature ranges and super-finished wire break strength. The resulting size and weight reduction creates additional trade space to explore less expensive cables and connectors, tighter bend radii, and smaller structures to improve operational flexibility.

Additionally, Gore's cables are engineered to withstand extreme environmental conditions, including high temperatures, electromagnetic interference, and continuous mechanical stress. This ensures that drones can operate reliably in harsh combat environments, whether in desert conditions, maritime operations, or high-altitude missions. The durability and long lifespan of Gore's cables minimize maintenance requirements, reducing downtime and improving overall mission readiness.

Power Over Data – A Game Changer for Defense Drones?

Gore cables also bring the potential to support Power over Data (PoD) solutions, which allow power and data to be transmitted through a single cable. This not only reduces the number of cables required but also simplifies drone wiring architectures, leading to further weight and space savings. With fewer cables onboard, engineers reduce costs and complexity while gaining greater flexibility in system design to optimize internal layouts and enhance overall mission readiness.

For defense drones operating in complex battlefield environments, the efficiency and reliability of onboard systems are critical. PoD technology helps streamline drone architectures, enabling faster data transmission for high-resolution sensors, cameras, and communication systems. This ensures real-time situational awareness, enhanced target tracking, and better coordination with ground control stations. The integration of PoD solutions allows drones to execute precision missions with increased responsiveness and accuracy.

These advancements enable defense drone developers to take an innovative approach to aircraft design, ensuring that every reduction in weight enhances maneuverability, endurance, and overall mission effectiveness. The combination of downgauging and Power over Data exemplifies how Gore's expertise in aerospace cable solutions is setting new industry standards for lightweight, high-performance electrical systems.

Pioneering the Future of Unmanned Aerial Systems

Through its work with defense drone manufacturers, Gore continues to push the boundaries of what is possible in modern military aviation. By providing high-performance, space-saving cable solutions, Gore empowers defense innovators to reduce cost and enhance the effectiveness and endurance of unmanned aerial systems.

As military UAS technology evolves, strategic partnerships between leading defense companies and Gore will be instrumental in shaping the future of unmanned operations. Gore's dedication to innovation ensures that its aerospace solutions remain at the forefront of performance, reliability, and efficiency, supporting the next generation of advanced defense drone capabilities.

With an increasing emphasis on autonomous operations, electronic warfare, and network-centric combat strategies, the need for cutting-edge cable solutions will only grow. Gore remains committed to delivering the most advanced, battle-ready cable solutions to keep unmanned systems fast, agile, and mission-ready. As warfare evolves, Gore is staying ahead by continuously innovating and adapting to defense needs. In a world where superiority is measured in milliseconds, Gore delivers the technology that keeps defense forces ahead of the fight—today and for the battles to come. Learn more: gore.com/thinkgore

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China's Exercises Start to Look more like Operations, USSF Pacific Leader Says

Unshin Lee Harpley | 05 March 2025

[*Source: Air & Space Forces | https://www.airandspaceforces.com/china-exercises-ussf-pacific-leader-says/*](https://www.airandspaceforces.com/china-exercises-ussf-pacific-leader-says/)

A Schriever Spacepower Series event with Brig. Gen. Anthony J. Mastalir on Oct. 22, 2024. Photo by Jud McCrehin/staff

AURORA, Colo.—The head of Space Forces Indo-Pacific warned that China's expanding military exercises, aided by an increased use of space, are blurring the line between drills and a potential invasion of Taiwan.

"It is clear in the increasing complexity with which the PLA exercises are done in a way, that it becomes very difficult, and will become very difficult, to discern an exercise from an invasion, and that's clearly by design," Brig. Gen. Anthony J. Mastalir, commander of Space Forces Indo-Pacific, told reporters at the AFA Warfare Symposium. "We have begun to see the space piece integrated into some of that, not as much early on, but more recently."

In particular, Mastalir highlighted Beijing's growing counter-space capabilities, particularly its anti-satellite (ASAT) weapons that can target satellites in low-Earth and geosynchronous orbits. China's push to develop ASAT technologies—spanning kinetic and nonkinetic methods, from missiles to electronic jammers to robotic arms designed to disrupt satellites—has been a major concern for Space Force leaders.

Over the years, China has tested different ASAT weapons, including its first destructive test in 2007, a launch into GEO in 2013, and a fractional orbital bombardment system with a hypersonic glide vehicle in 2021. Former Rep. Jim Cooper has described the efforts as "perfecting kill shots." The 2007 test, widely criticized as reckless, left debris into LEO, exacerbating the risk for all space operations. Chief of Space Operations Gen. B. Chance Saltzman has often pointed to that test as a turning point in the history of military space operations.

Mastalir warned that lately, China has been synchronizing the posturing of such weapons with its military exercises.

"For example, when you think about the counter-space weapons that China is building, including direct ascent ASATs … those are going out and being postured at the same time that the exercise is unfolding in the East China Sea," said Mastalir. "We are starting to see more and more evidence—as they build the complexity, they're bringing more of those forces in."

Military leaders have raised alarms over China's increasingly aggressive drills around Taiwan in recent years. Already in 2025, Beijing has sent multiple spy balloons and naval warships for "combat readiness patrols" around the island. Taiwan's Ministry of National Defense has also reported numerous incidents of Chinese military aircraft encircling the island. Navy Adm. Samuel Paparo, head of the U.S. Indo-Pacific Command, called these recent actions "rehearsals for the forced unification of Taiwan with the mainland," stressing that such People's Liberation Army activities are "not exercises."

These multi-domain drills have intensified as China has moved to integrate space capabilities into its military strategy. A decade ago, the Chinese only had about two dozen satellites. Now, they operate more than 1,000—most of which, according to Mastalir, are "specifically designed to track U.S. forces."

"(China) has been building a space architecture specifically designed to keep the U.S. outside the Second Island Chain," said Mastalir. Their strategic goal, he noted, is aimed at limiting U.S. and allied forces' ability to intervene in key regional conflicts, particularly in the South China Sea and around countries like Taiwan and the Philippines.

China is also pushing to compete with Starlink in the satellite internet market, with a plan to build a "mega-constellation" of more than 600 satellites by 2025, eventually reaching a total of 14,000 satellites. Mastalir warned that the next phase of Beijing's space ambitions will go beyond communication satellites toward remote sensing.

"It's not surprising that China, too, is going to build these kinds of mega constellations—they've seen firsthand how effective it is in preserving communications in contested areas," said Mastalir. "I fully expect, as we continue to see, not just communication constellations, but the proliferation of remote sensing capabilities."

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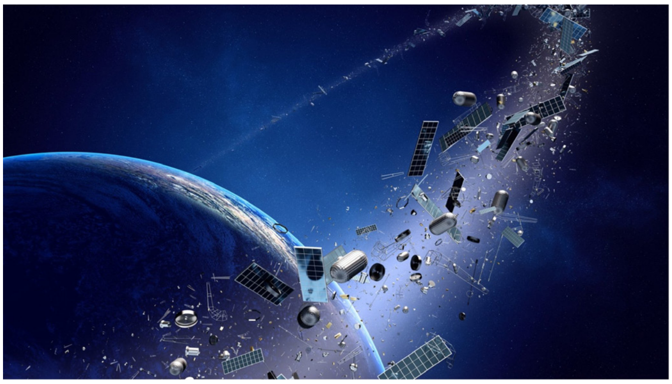
The Evolving Strategic Importance of Space in Modern Military Operations

Nicola Bonsegna | 07 December 2024

Source: IARI | https://iari.site/2024/12/07/the-evolving-strategic-importance-of-space-in-modern-military-operations/



Fonte Immagine: Howell, E. (2023). Preventing space junk collisions: NASA tests new 'space traffic rules'. Live Science.

Space has become vital to modern military operations, supporting intelligence, surveillance, communications, and navigation. The militarization and weaponization of space have led to the development of anti-satellite (ASAT) weapons and advanced defenses. Increasing cyber threats further complicate space security. The future of military space operations focuses on small satellite constellations, such as the U.S. Starshield project, reflecting space's growing role in global defense strategies. As space becomes more contested, nations must ensure its responsible use and protection.

Introduction

The importance of the space domain has grown significantly due to rapid technological advancements and increased global interconnectivity. Space now underpins critical infrastructure essential for economic activities and national security, supporting communication, navigation, and remote sensing. Space-based assets are vital for national defense, enabling missile detection, secure communications, and intelligence gathering.

Since the mid-1950s, the number of space actors has proliferated, with more countries now actively participating in space activities. This interest highlights the critical role of satellites and space technologies in both the military and commercial sectors. Nations are investing heavily in advanced space capabilities to strengthen military power and protect strategic assets, making space a contested and competitive domain.

In response to these challenges, NATO designated space as an operational domain in 2019, recognizing its importance alongside air, land, sea, and cyberspace. The European Union has also acknowledged space's strategic value, incorporating it into its security policies. Individual states, like France, have developed specialized space forces to address the growing militarization of space, further underscoring its significance in global defense strategies.

The Historical Evolution of Space in Military Strategy

From the outset, space has been closely tied to military objectives, particularly during the post-World War II ballistic missile-based nuclear arms race. Early rocket research, initially aimed at defense, extended into space, sparking the Space Race between the United States and the Soviet Union. This competition was not only about technological supremacy but also national security and ideological dominance, leading to key achievements like artificial satellites and manned space missions. Space quickly became a critical and competitive arena marked by military and technological superiority.

As space technology advanced, the military potential of satellites became evident. Nations sought to deny strategic advantages to their adversaries. Following the Soviet Union's launch of Sputnik in 1957, the United States tested its first anti-satellite (ASAT) weapon in 1959, with the Soviets developing their own ASAT system by 1973. These developments highlighted the militarization of space, though kinetic ASAT weapons were never used in conflict due to a stable deterrence posture, as attacking satellites (at the time used to support nuclear forces) would have been seen as a prelude to nuclear war.

Today, national security space systems are crucial for a wide range of military operations, extending beyond nuclear deterrence. This "militarization of space" reflects the growing use of space to support military activities on Earth. Modern militaries rely heavily on space-based systems for intelligence, surveillance, reconnaissance (ISR), communications, and positioning, navigation, and timing (PNT). For example, the U.S. military uses space technology for tasks like counterterrorism, utilizing GPS and satellite communications for precision strikes and global surveillance.

The concept of the "weaponization of space" has also gained momentum, involving the deployment of weapons in, from, or through space. Space weapons, as defined by the Center for Strategic and International Studies (CSIS), can target space-based assets or deliver destructive force from space. These weapons are categorized by their origin (Earth-to-space, space-to-space, or space-to-Earth) and their method of impact (kinetic or non-kinetic). Several categories of space weapons have already been tested or deployed, demonstrating that space has already been weaponized, fundamentally altering military strategies in this increasingly contested domain.

THE MILITARIZATION OF SPACE

Space-Based Reconnaissance and Surveillance: The Strategic Advantage

Satellites have become crucial in modern warfare, serving as the backbone for critical military operations. Their advanced capabilities in Geospatial Intelligence (GEOINT) far surpass traditional methods like aerial photography. While aerial reconnaissance during the World Wars provided tactical advantages, the advent of satellite technology during the Cold War revolutionized military intelligence. High-resolution satellite imagery now allows for detailed terrain analysis, target identification, and enhanced battlefield awareness, making them indispensable in military strategy.

One of the most important advancements in GEOINT is the ability of satellites to collect and process data in near real-time. With high-speed data links and onboard processing, satellites provide actionable intelligence quickly, improving decision-making and operational coordination in dynamic battlefield conditions.

Beyond GEOINT, satellites play a critical role in Signals Intelligence (SIGINT). Equipped with advanced sensors, SIGINT satellites intercept and analyze communications and electronic signals from adversaries. These satellites are categorized into three types:

1. Communications Intelligence (COMINT): Intercepts and analyzes voice, text, and data transmissions, both military and civilian.

2. Electronic Intelligence (ELINT): Detects non-communication signals like radar emissions, crucial for identifying enemy systems.

3. Foreign Instrumentation Signals Intelligence (FISINT): Intercepts telemetry from missiles and spacecraft, providing valuable insights into foreign capabilities.

SIGINT satellites offer vast global reach, essential for early warning systems like the U.S. Defense Support Program (DSP), which detects missile launches via infrared sensors. This real-time surveillance improves military readiness and national security, underscoring the strategic importance of space-based reconnaissance in today's defense strategies.

Space-Based Communication and Navigation: The Backbone of Modern Warfare

Space's role in the military sector extends far beyond intelligence gathering; it is the backbone of Command and Control (C2) operations globally. Space-based infrastructure supports secure, reliable communication, enabling military commanders to maintain situational awareness, make quick decisions, and coordinate operations across vast distances. These systems are vital for key C2 functions such as communication relays, navigation, and real-time data transmission, especially in dispersed or challenging environments.

The global nature of modern warfare requires seamless communication across continents. Space systems provide "over-the-horizon" communication, ensuring that real-time intelligence reaches commanders for strategic planning. This capability was showcased during Operation Desert Storm in 1991, often referred to as the first "space war." The U.S. military used the Navstar GPS satellite constellation to navigate the desert, locate enemy targets, and execute precision strikes with advanced weaponry like cruise missiles and laser-guided bombs.

Positioning, Navigation, and Timing (PNT) systems like GPS, originally developed by the U.S. Department of Defense, enable accurate targeting, navigation, and coordination on the battlefield, directly influencing the efficiency of weapon systems, including drones, guided missiles, and autonomous vehicles. Today, global navigation satellite systems like the U.S. GPS, EU's Galileo, Russia's GLONASS, and China's BeiDou are integral to military operations, making space an indispensable domain for enabling operations across all other areas of warfare.

The Weaponization of Space

The Development of Anti-Satellite (ASAT) Weapons and Space Defenses

The strategic importance of space has led nations to develop counterspace weapons aimed at disrupting or destroying space systems. These are categorized into kinetic physical, non-kinetic physical, electronic, and cyber weapons. This overview covers the first three categories.

Kinetic physical weapons are designed to strike or explode near satellites or ground stations, such as direct-ascent and co-orbital anti-satellite (ASAT) weapons. These can cause irreversible damage and create hazardous space debris, endangering other satellites. Though no kinetic attacks have occurred between nations, the U.S., Russia, China, and India have successfully tested these weapons.

Non-kinetic physical weapons damage targets without physical contact. Lasers can blind satellite sensors, while high-powered microwaves (HPMs) disrupt or destroy satellite electronics. These attacks can be launched from ground, air, or space platforms. While laser attacks are more traceable due to their precision, HPM attacks are covert and harder to attribute.

Electronic counterspace weapons target satellite communications through jamming or spoofing. Jamming interferes with signals, while spoofing tricks systems into receiving false data. These tactics are reversible and difficult to detect, making them appealing for both state and non-state actors.

The development of these various counterspace has led to the development of space defenses. The CSIS report categorizes space defenses into passive and active measures, each with its own set of strategies and mechanisms.

Passive Defenses:

1. Architectural Defenses:

- Disaggregated Constellations: Distribute missions across multiple satellites to prevent system-wide failures from a single attack.
- Distributed Constellations: Use multiple satellites for the same mission, making it harder for adversaries to disrupt the entire system.
- Proliferated Constellations: Deploy many identical satellites to increase system resilience.
- Diversified Architectures: Utilize different platforms and orbits to reduce vulnerability.

2. Technical Defenses:

- Space Domain Awareness (SDA): Advanced tracking and monitoring of space objects to detect threats.

- Electromagnetic Shielding: Protects satellites from HPMs, EMPs, and radiation.
- Filtering and Shuttering: Protect sensors from laser attacks by filtering harmful wavelengths.
- Jam-Resistant Waveforms: Spread signals across frequencies to reduce the impact of jamming.
- Antenna Nulling and Adaptive Filtering: Block signals from specific directions or frequencies to mitigate jammers.

3. Operational Defenses:

- Rapid Deployment & Reconstitution: Launch replacement satellites quickly after an attack.
- Maneuver: Satellites can evade threats through thruster-driven movements, though this reduces their lifespan.
- Stealth: Reduce satellite visibility through techniques like radar-absorbing coatings.
- Deception and Decoys: Use decoys or misleading information to obscure real satellite positions and capabilities.

Active Defenses:

1. Space-Based Defenses:

- Jamming and Spoofing: Disrupt enemy ASAT sensors and communication links.
- Laser Dazzling or Blinding: Impair the sensors of enemy satellites.
- Shoot-Back Systems: Satellites equipped with weapons to destroy incoming threats, though this risks creating more debris.
- Physical Seizure: Robotic systems on satellites can capture or disable threats.

2. Terrestrial-Based Defenses:

- Cyberattacks: Target adversary command and control (C2) systems, disabling or hijacking their space assets.
- Ground-Based Jamming and Spoofing: Disrupt the communication links of space-based threats from Earth.
- Direct-Ascent ASAT Weapons: Destroy satellites posing threats, though this creates space debris and escalates conflict.
- Kinetic Attacks on Ground Infrastructure: Target facilities supporting enemy space operations, like launch sites or command centers.
- This comprehensive range of defenses, some already in use or being developed, aims to protect space assets and maintain operational capabilities in increasingly contested space environments.

Cyber Operations and the Space Domain: A New Frontier in Warfare

The critical role of satellites in modern society and warfare has made them prime targets for adversaries. As geopolitical competition intensifies, the threat of cyberattacks aimed at espionage, disruption, or even the destruction of space assets has escalated. The interdependence of the cyber and space domains is increasingly evident. Cyber infrastructure underpins the exchange of data between satellites, ground stations, and end users, while space services rely heavily on cyber operations. This interconnectedness means that an attack on one domain can compromise the entire system.

Cyberattacks on satellites can include monitoring data traffic, intercepting information, or injecting false data into systems. Such attacks can target ground stations, end-user equipment, or the satellites themselves. These attacks often require minimal resources, making them accessible to less sophisticated actors, including private groups or individuals. A successful attack could disable critical services like GPS or allow adversaries to gain gain control of a satellite's command-and-control system, enabling them to disable communications or cause permanent damage by depleting the satellite's propellant or damaging its electronics and sensors.

The 2022 Viasat KA-SAT cyberattack, just before Russia's invasion of Ukraine, highlighted the vulnerability of space systems to cyberattacks. This attack severely disrupted Ukrainian military communications and had widespread spillover effects, affecting internet access across Europe. Similarly, China has also been implicated in cyberattacks on U.S. satellites, including incidents in 2007 and 2008 targeting the control movement of Landsat-7 satellite and NASA's Terra satellite. In 2014 Chinese hackers attacked NOAA's satellite systems, causing a temporary shutdown.

Mitigating these risks requires significant investments in secure satellites, advanced encryption, and robust data protocols. However, space technologies' limited computational power and bandwidth complicate implementing these security measures.

The Future of Space in Warfare: Emerging Trends and Technologies

The future of military space operations is shifting toward the use of small satellites and large constellations, reflecting modern warfare's evolving needs. Unlike traditional large, expensive satellites, small satellites deployed in vast constellations in low-Earth orbit (LEO) offer distinct advantages for military use. A key development is the U.S. Department of Defense's plan to integrate over 100 Starshield satellites, a militarized version of SpaceX's Starlink system, into its communication architecture by 2029. Starshield will feature enhanced encryption and security, ensuring military communications remain secure and under direct government control.

This trend aligns with broader defense strategies that emphasize adopting commercial technologies for military purposes. SpaceX's Starlink has already proven the viability of commercial space technologies in delivering high-speed, reliable communication services, demonstrating the potential for meeting military needs cost-effectively.

As investment in small satellite constellations grows, the strategic importance of space in warfare is also increasing. Space is becoming a potential battleground, with anti-satellite weapons and counterspace capabilities suggesting that future conflicts may extend into space. The emergence of weaponized satellites indicates a shift toward space as a domain of direct conflict, altering the nature of warfare.

Conclusion

Space has become an integral component of modern military operations, offering unparalleled advantages in reconnaissance, communication, and defense. The evolution from early satellite technology to sophisticated space-based systems like GPS and SIGINT satellites has revolutionized how nations conduct warfare, making space a critical domain for maintaining military superiority. However, the increasing militarization of space presents significant challenges.

Looking ahead, the future of space in warfare will likely be shaped by continued innovation and the strategic deployment of small satellite constellations. These advancements will enhance military capabilities but also introduce new vulnerabilities as space becomes a potential battleground. To ensure global security, it is crucial for nations to engage in responsible use of space, develop robust defense mechanisms, and foster international collaboration. As we move further into this new era, strategic planning and a commitment to peaceful space exploration will be essential to navigating the challenges and opportunities that lie ahead.

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China's Rescue of Stranded Lunar Satellites

Andrew Jones | 18 February 2025

Source: Sepctrum | https://spectrum.ieee.org/china-saves-dro-moon-mission#:~:text=China%20has%20managed%20to%20deliver,engine%20burns%2C%20and%20astrodynamic%20ingenuity

A Long March 2C rocket carrying satellites to space from China's Xichang Satellite Launch Center Imaginechina/Alamy

China has managed to deliver a pair of satellites into lunar orbit despite the spacecraft initially being stranded in low Earth orbit following a rocket failure, using a mix of complex calculations, precise engine burns, and astrodynamic ingenuity.

China launched the DRO-A and B satellites on 13 March last year on a Long March 2C rocket, aiming to send the pair into a distant retrograde orbit (DRO) around the moon. However, the rocket's Yuanzheng-1S upper stage—intended to fire the spacecraft into a transfer orbit to the moon—failed, leaving the pair marooned in low Earth orbit.

Little is known for certain about the satellites.

They must be small, given the limited payload capabilities of the rocket used for the launch, and are thought to be for testing technology and the uses of the unusual retrograde orbit. (DRO orbits could be handy for lunar communications and observation.) Critically, the spacecraft's small size means they have little propellant, making reaching lunar orbit from low Earth orbit unassisted a very tall order. However, Microsat, the institute under the Chinese Academy of Sciences (CAS) behind the mission, got to work on a rescue, despite the daunting distance.

What followed was a 167-day-long effort that first got the spacecraft out to well beyond lunar distance and then successfully inserted the satellites into their intended orbit. The operation included five orbital maneuvers, five further trajectory corrections to fine-tune the satellites course, and three gravity assists from the Earth and moon.

The first steps were small engine burns at perigee—the spacecraft's closest orbital approach to Earth—which gradually raised the apogee—the farthest point of the orbit from Earth. Once the apogee was high enough, a larger burn put the spacecraft on an atypical course for the moon.

From the Earth to the Moon

Normally, spacecraft going to the moon follow the simplest trajectory, a so-called Hohmann transfer that burns a lot of propellant to get moving and then uses another big burn to drop into orbit once the spacecraft arrives at its destination after three to four days. Instead, the Chinese took advantage of a chaotic dynamical region around the Earth-moon system to save propellant. The Japanese Hiten probe had been rescued using a similar approach in 1990, but it was sent into a conventional lunar orbit.The calculations to reach DRO—a high-altitude, long-term stable orbit moving in a retrograde direction relative to the moon—would have been arduous.

"The astrodynamics of getting to the Moon is already much more complicated than just Earth orbit missions," says Jonathan McDowell, a Harvard-Smithsonian astronomer and space activity tracker and analyst. "Involving so-called 'weak capture' and distant retrograde orbits is far more complicated still, and having to replan that in a hurry must be a nightmare, so it's a very impressive achievement."

Weak capture refers to a celestial body gravitationally capturing a spacecraft without the need for a significant propulsive maneuver. This technique, crucial for a fuel-efficient lunar orbit insertion, demands precise timing and fine trajectory adjustments, as McDowell explains.

"The way to think of these 'modern' and fancy orbit strategies is that you trade time for fuel. It takes much longer but you use less fuel. Once you get out to the apogee of the transfer trajectory—they don't say how far out that was but I am guessing over a million kilometers—you can change your final destination a lot with just a small puff of the rockets. But by the same token, a small error will make you miss your target by a long way."

Slides from an apparent Microsat presentation emerged on social media, illustrating the circuitous path taken to deliver the spacecraft to lunar orbit. The institute, however, did not respond to a request for comment on the mission.

DRO-A and B separated from each other after successfully entering their intended distant retrograde orbit. The pair have, according to U.S. Space Force space domain awareness, orbits with an apogee of around 580,000 kilometers relative to the Earth and a perigee of around 290,000 km, while the moon orbits Earth at an average distance of 385,000 km, indicating a very high orbit above the moon.

There, the spacecraft are testing out the attributes of the unique orbit and testing technologies, including communications with another satellite, DRO-L, which was launched a month before DRO-A and B into low Earth orbit. Though not a major part of China's lunar plans, the country is planning to establish lunar navigation and communications infrastructure to support lunar exploration, and the satellites could inform these plans.

DRO-A, at least, also carries a science payload in the form of an all-sky monitor to detect gamma-ray bursts, particularly those associated with gravitational wave events, such as colliding black holes, neutron star collisions, and supernovae. The instrumentation is based on China's earlier GECAM low Earth orbit gamma-ray-detecting mission, but with an unobstructed field of view in deep space and less interference.

The rescue then is a boost for China's lunar plans and space science objectives, and demonstrates Chinese prowess in astrodynamics. McDowell notes the closest approximation to this rescue is the Asiasat 3 mission, renamed HGS-1, where the satellite bound for geostationary (GEO) orbit was stuck in an elliptical transfer orbit in 1997. The satellite's apogee was raised to make a pair of lunar flybys to eventually deliver it to GEO with fuel remaining to operate for four years.

"[This] definitely shows that China is now on a par with the U.S. in its ability to manage complex astrodynamics," McDowell says.

China also pulled off a complex lunar far side sample return mission last year, requiring five separate spacecraft, and next year plans a landing at the lunar south pole to seek out volatiles including water. The successful salvaging of the DRO-A and B mission reinforces China's growing expertise in deep space navigation and complex orbital rescues. With plans to establish a permanent moon base in the 2030s, such capabilities will be crucial for maintaining and supporting long-term Moon operations.

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The Rise of Commercial Lunar Missions

Dr B.K. Das, Vipin Kumar Kaushik, Amit Sharma | 10 February 2025

Source: Business Insider | https://www.businessinsider.com/private-space-missions-flying-to-moon-2025-2

A snapshot from footage Firefly's Blue Ghost mission has captured as it orbits the moon. Firefly Aerospace

Three companies are flying missions to land on the moon right now, in the early stages of a mad dash for lunar wealth.

The moon may not be Mars-obsessed Elon Musk's favorite space destination, but many other entrepreneurs see it as an untapped economic opportunity.

That's why two Texas-based companies and one Japanese firm are flocking to the moon this month. All three missions were launched aboard SpaceX rockets.

None of them are carrying human crews, but they all lay the groundwork for more complex operations in the future as the moon opens for business.

Intuitive Machines wants to mine the moon

The Texas-based company Intuitive Machines launched its second moon-landing mission, called IM-2, on Wednesday.

The company became the first commercial enterprise to land on the moon a year ago, but the new mission is taking its ambitions further. The mission includes a rover and a hopper, which carry experimental technology for GPS on the moon and a small drill to test the technology needed to one day mine minerals and ice beneath the lunar surface.

Water ice on the moon could be broken down into hydrogen and oxygen for rocket fuel, while minerals like titanium or rare earth elements used in smartphones and computers could be sold back on Earth.

"The whole package of this mission is about prospecting," Steve Altemus, the CEO of Intuitive Machines, told Business Insider in December.

He added that eventually, he hopes to mine rare materials on the moon and bring them back to Earth.

Firefly Aerospace is testing lunar dust for NASA

For now, Intuitive Machines is the only company to ever successfully land softly (that is, without crashing) on the moon. Another Texas company, Firefly Aerospace, is gunning for second place this weekend.

Firefly's Blue Ghost mission is set to attempt its first moon landing on Sunday.

"I think a lot of us will be holding our breath, you know, lighting a candle," Ray Allensworth, the director of Firefly's spacecraft program, told BI.

If Blue Ghost succeeds, it will run experiments on the lunar surface for about two weeks, which is a full lunar day.

All in all, the spacecraft is carrying 10 payloads for NASA, mainly focusing on "what the surface of the moon looks like or feels like, trying to figure out the impacts of the regolith, how the dust interacts with materials, the temperatures under the surface, stuff like that," Allensworth said.

Japan's ispace wants people to live on the moon

Both Texas companies' moon landers are funded in part through NASA's Commercial Lunar Payload Services initiative.

The third mission en route to the moon, though, is from the Japanese company ispace.

The company's Hakuto-R spacecraft previously tried to land on the moon in 2023, but ispace reported that the lander had miscalculated its altitude when it detected an unexpected crater rim on the lunar surface, causing it to plummet and crash.

Ispace is trying again with a new mission carrying a lander and a micro-rover. The mission, called M2, launched aboard the same Falcon 9 rocket as the Firefly Blue Ghost spacecraft on January 15. M2 is taking a more leisurely route to the moon, though, with its landing set for May or June. The new lander is named RESILIENCE.

Ispace touts a future where the moon and its water resources support "construction, energy, steel procurement, communications, transportation, agriculture, medicine, and tourism."

The ispace website also advocates for permanent human residence on the moon, saying that "by 2040 the moon will support a population of 1,000, with 10,000 people visiting every year."

It's going to take a lot more moon missions to bring that vision to life. For now, for all three missions, just sticking the landing would be a huge achievement.

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Aerospace Industry

Aero India 2025: The Mahakumbh of Defence

Dr B.K. Das, Vipin Kumar Kaushik and Amit Sharma | 10 February 2025

Source: SPS Navel Forces | https://www.spsnavalforces.com/features/?id=268&h=Aero-India-2025-The-Mahakumbh-of-Defence

Reinforcing Drdo's Role as the Backbone of India's Defence Innovation: Amca 5th Gen Combat Aircraft

In the year 2025, India is witnessing two monumental events that, despite their distinct nature, embody the country's spirit of unity, resilience, and strength. The Mahakumbh Mela, the largest religious gathering on the planet, and Aero India, the nation's premier defence and aerospace exhibition, will converge in a symbolic expression of India's traditional roots and its modern ambitions. Though vastly different in scope and purpose, these events share a commonality in their representation of India's collective identity. Both events demonstrate India's stature as a spiritual and technological powerhouse, where faith and defence align in an intricate blend of progress and tradition.

The Spiritual Essence of Mahakumbh 2025: An Event Beyond Time

The Mahakumbh Mela is far more than a religious congregation—it is a timeless celebration of faith, culture, and humanity's resilience. Held at the sacred sangam (confluence) of the Ganges, Yamuna, and the mythical Saraswati in Prayagraj, this event stands as a cornerstone of Hindu spirituality. Occurring every 12 years, the Mahakumbh holds unparalleled significance, with the 2025 edition being a once-in-144-years event. This rarity elevates its importance, with the next Mahakumbh only scheduled for 2169, making the ongoing gathering a truly historic occasion.

Rooted in ancient mythology and astrological precision, the Mahakumbh's origins trace back to the legend of the Samudra Manthan, where drops of amrita (nectar of immortality) fell at Prayagraj, Haridwar, Ujjain, and Nashik. This celestial alignment, along with the belief in the sacred rivers' purifying powers, draws millions seeking spiritual merit and liberation from sins. The Kumbh Mela is timed based on specific planetary alignments, with Jupiter playing a key role. The festival occurs when Jupiter aligns with the Sun and Moon, enhancing Earth's electromagnetic fields.

Aero India 2025: A Showcase of Modern Power and Global Partnerships

At the same time that millions of pilgrims gather at the banks of the Ganges in Prayagraj, another congregation of global significance will be taking place in Bengaluru from 10th to 14th February 2025. Aero India 2025, Asia's largest airshow, is set to be a landmark event, bringing together aerospace leaders, innovators, and policymakers from across the globe. This premier platform fosters collaboration, innovation, and knowledge exchange, reinforcing India's position as a global aerospace hub.

Following the massive success of Aero India 2023, which saw participation from about 100 countries, 809 exhibitors, and a remarkable footfall of over 7 lakh visitors, the 2025 edition promises even greater engagement. Key highlights include dynamic exhibitions, cutting-edge aircraft displays, the prestigious Bandhan ceremony, finsalisation of 250+ MoUs/partnerships worth more than ₹75,000 Crores and participation of 27 Countries in the Indian Ocean Region(IOR)+ Defence Ministers' Conclave.

The event will feature expansive exhibition halls depicting various solutions, outdoor displays of large-scale systems, and business chalets designed for high-level meetings. It also provides unparalleled opportunities for B2B and B2G interactions, enabling industries to secure vital partnerships and explore market growth avenues. Additionally, Aero India offers extensive media coverage, amplifying the visibility of participants and their innovations on a global stage.

Aero India 2025 is not just an airshow—it is a stage where the future of aerospace takes flight, positioning India at the forefront of technological and strategic advancements in this critical sector.

The comparison between Aero India and the Mahakumbh may seem unusual at first glance. However, both events are, in their respective realms, symbols of India's global stature. While the Mahakumbh is a symbol of spiritual transcen-dence, Aero India represents India's ascent as a modern defence power—a nation that embraces cutting-edge technology, innovation, and international collaboration to safeguard its future.

Aero India's Strategic Importance to India's Defence Goals

Aero India has become a crucial platform for India to demonstrate its growing defence capabilities and to position itself as a key player in the global defence industry. Since its inception in 1996, the event has grown exponentially, both in terms of international participation and the technological sophistication of its exhibits. What began as a modest airshow has now become a vital stage for unveiling advanced fighter jets, drones, missile systems, and other military hardware.

Aero India acts as a catalyst for partnerships between Indian and international defence companies. The 2023 edition saw 250 B2B agreements with a combined value of ₹75,000 crore, demonstrating the potential of such collaborations to drive technology transfer and co-development initiatives.

The focus on startups and MSMEs, as seen in the exclusive iDEX Pavilion at Aero India 2023, highlights the importance of nurturing homegrown talent. The previous edition successfully pledged over ₹200 crore through the iDEX Investor Hub, emphasising India's commitment to fostering innovation in the defence sector.

Aero India 2025 plays a pivotal role in advancing India's defence objectives, aligning with the nation's vision for self-reliance and technological supremacy under the 'Make in India' initiative. In 2025, the event is expected to draw representatives from over 50 countries, including global defence contractors, aviation experts, and policymakers. By fostering joint ventures, promoting indigenous innovations, and facilitating global collaborations, the event strengthens India's defence ecosystem.

The strategic importance extends to the showcasing of India's airpower, with grand flypasts and static aircraft displays serving as a testament to the nation's growing aerospace capabilities. Aero India 2025 is poised to reinforce India's defence and aerospace goals, contributing to a robust, self-reliant, and globally competitive sector.

DRDO AT AERO INDIA 2025

The Defence Research and Development Organisation (DRDO) will present a formidable display of over 330 state-of-the-art products, systems, and technologies at Aero India 2025 in indoor pavilion, reinforcing its role as the backbone of India's defence innovation. DRDO's participation will be structured around nine key themes such as "Airborne Surveillance Solutions", "Naval Warfare", "Next-Generation Missile Systems", "Supremacy in the Skies – ADA's 5th Gen Leap", "Unmanned Aerial Systems", "RadarScape: Mapping the Invisible", "Maritime Sentinel: A New Era of Surveillance & Safety", "Sensors Suite for Fighter Aircraft" and "Raksha Kavach". All themes are being supported by various operational scenario, salient features depicted in the form of video contents using immersive technologies like anamorphic display, LED walls, Digital standees, Holographic fans etc.

Additionally, with the mandate of DRDO focussing more on technologies, 14 ad-vanced Technology Zones will highlight cutting-edge research which includes "Advanced Materials & Composites", "Surveillance & Reconnaissance Technology", "Antenna & Microwave Technology", "Soldier Support Systems", "Combat Aircraft Technology", "Corporate Directorates", "Micro Electronic Devices, Computational Systems, and Cyber Security", "Land Systems & Munitions", "Missile Technology", "Next-Gen Combat Vehicles & Tactical Mobility", "Photonics, Laser and Quantum Technology", "Electronic Warfare & Communication", "Simulation & Training Technology" and "Aero Propulsion Technology".

A major highlight of DRDO's presence will be its contribution to the prestigious India Pavilion, showcasing state of the art Defence systems. This pavilion exemplifies the combined strength of India's private industries, Defence PSUs, start-ups, and DRDO, the premier defence research organisation under the Ministry of Defence. Among the 17 DRDO products on display will be the Advanced Medium Combat Aircraft (AMCA) with all its weapons & sensors, Dornier mid life upgrade with DRDO designed systems, Advanced Lightweight Torpedo, Naval Anti-Ship Missile-Medium Range, Kaveri Derivative Aero Engine (without afterburner), Medium Range Maritime Reconnaissance (MRMR) Aircraft, Guided Pinaka, and Twin Engine Deck-Based Fighter (TEDBF).

DRDO's exhibits will be spread across indoor, outdoor, and live demonstration zones. The outdoor exhibits will feature QRSAM, AKASH NG Launcher system, Archer UAV, and VHF Radar, Advanced EW System Dharashakti etc., while the flying display will include the upgraded Dornier Aircraft with advanced mid-life modifications. Additionally, DRDO will organise a seminar titled "DRDO-Industry Synergy towards Viksit Bharat: Make in India,Make for World" to highlight its collaborative vision for self-reliance in defence technology.

With an expansive and technologically diverse exhibition, DRDO's participation at Aero India 2025 underscores India's growing strength in aerospace and defence, advancing Atmanirbhar Bharat and positioning the nation as a leader in global defence innovation.

The Common Threads and Overarching Theme

a) Unity, Strength, Faith and Global Presence

Though the Mahakumbh and Aero India differ in their focus—one being a deeply spiritual gathering and the other a high-tech defence exposition—they share underlying themes of unity, strength, faith and global presence. Both events capture India's essence as a nation that thrives on diversity and collective effort.

In the Mahakumbh, unity is seen in the convergence of millions of pilgrims, each arriving from different parts of India and the world, representing various backgrounds, languages, and customs. It is this diversity that makes the event so powerful, a visual and spiritual representation of India's motto: "Unity in Diversity." & "Atithi, Devo Bhava" The pilgrimage is a journey toward self-realisation, but it is also an expression of the collective consciousness that binds the nation together. The sight of millions standing shoulder to shoulder, immersed in devotion, reflects the strength that comes from this unity.

Similarly, Aero India is a gathering of global defence leaders, manufacturers, and innovators, each contributing to a common goal: ensuring security and stability in a rapidly changing world. Unity in this context is seen through the collaborations and partnerships that emerge from the event. India's defence sector is not an isolated entity; it thrives on global cooperation. Countries such as the United States, France, Israel, and Russia, among others, have long been key partners in India's defence acquisitions and technological advancements. Aero India 2025 will be a platform for strengthening these partnerships, fostering new collaborations, and ensuring that India remains at the forefront of defence innovation.

b) Strength Through Spirituality and Security

The strength displayed at the Mahakumbh is spiritual—a testament to the endurance of faith and the power of belief. For centuries, despite the changing tides of history, the Mahakumbh has remained a constant, a symbol of India's unbroken connection to its past. The rituals performed at the event, such as the sacred dip in the Ganges, are acts of devotion, but they also represent resilience—the strength to uphold tradition in an increasingly modern world.

At Aero India, strength takes on a different form: it is the strength of military power, technological advancement, and national security. In a world where geopolitical situations are ever changing, India's ability to defend its borders and protect its interests is of paramount importance. Aero India is not merely a show of force; it is a demonstration of India's preparedness to meet any challenge that may come its way. The advancements in indigenous defence technology, showcased at the event, underscore India's commitment to achieving self-reliance in defence manufacturing, a goal that is crucial for the country's strategic autonomy.

c) A Global Stage: India's Soft and Hard Power on Display

In 2025, the world will be watching as India takes center stage, both through the Mahakumbh and Aero India. These events highlight India's soft power and hard power—its ability to influence the world through both culture and military strength.

The Mahakumbh, with its vast global audience, showcases India's soft power in action. As a country that has long been the spiritual epicenter of the world, India's cultural and religious influence extends far beyond its borders. The event attracts pilgrims, tourists, and media from all corners of the globe, providing a glimpse into India's cultural depth and its enduring connection to the spiritual realm.

Aero India, on the other hand, represents India's hard power. It is an event that highlights the country's growing defence capabilities, its strategic partnerships, and its ambition to become a leading player in the global defence industry. The event sends a clear message to the world: India is not only a nation with a rich cultural past but also a modern power capable of protecting its interests in an increasingly volatile world and all set to become a reckoning defence force for the world.

Conclusion: The Mahakumbh of Defence

In 2025, India will stand as a beacon of extraordinary progress, seamlessly intertwining its rich cultural heritage with its bold aspirations in defence and technology. From the sacred sangam at Prayagraj to the bustling aerospace hub of Bengaluru, the Mahakumbh Mela and Aero India 2025 symbolises India's remarkable ability to unify spiritual depth with cutting-edge innovation.

Aero India 2025, hailed as the "Mahakumbh of Defence," will serve as a dynamic platform where the State, academia, investors, and international collaborators converge within a robust Defence Ecosphere to chart the future of global security and technology exchange. Anchored by the pivotal role of DRDO, the event is showcasing India's steadfast commitment to Atmanirbharta in defence by unveiling groundbreaking indigenous technologies and fostering innovation across sectors. DRDO's extensive participation will highlight India's achievements in self-reliance, while enabling foreign collaborations that accelerate co-development, technology transfers, and mutual growth in defence capabilities.

This grand congregation also aligns with India's vision of Viksit Bharat 2047, where the nation aspires to achieve holistic development through technological leadership, economic self-reliance and strategic global partnerships. The ideals of Vasudhaiva Kutumbakam—the world is one family—resonate deeply with Aero India's mission to unite diverse stakeholders in the pursuit of shared security and global progress. By integrating stakeholders across the Defence Ecosphere and emphasising the importance of indigenous innovation, Aero India 2025 will exemplify India's role as a leader in shaping a secure and prosperous world order.

As the world witnesses this extraordinary synthesis of tradition and modernity, Aero India 2025 reaffirms India's stature as a global powerhouse, embodying the spirit of unity, resilience, and innovation while paving the way for a secure and inclusive future for all.

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Global Aerospace Firms Turn to India Amid Western Supply Chain Crisis

Nivedita Bhattacharjee | 18 February 2025

Source: Reuters | https://www.reuters.com/business/aerospace-defense/global-aerospace-firms-turn-india-amid-western-supply-chain-crisis-2025-02-17/

An Airbus A330neo aircraft takes off from the Airbus delivery center in Colomiers near Toulouse, France, March 20, 2019. REUTERS/Regis Duvignau/File Photo

BENGALURU, Feb 17 (Reuters) - Airbus (AIR.PA), Collins Aerospace, Pratt & Whitney, and Rolls-Royce (RR.L), are expanding parts sourcing from India, driving growth in the country's emerging aerospace sector and pushing local firms to elevate their games, industry insiders say.

Bengaluru-based Hical Technologies and JJG Aero are among those riding the wave. Hical, a supplier to Raytheon Technology and Boeing among others, aims to double revenue to 5 billion rupees ($57.57 million) from its aerospace division in three years, said Yashas Jaiveer Shashikiran, joint managing director.

JJG Aero, also in Bengaluru’s industrial hub, took 12 years to hit $2 million in revenue but soared to $20 million in the last six, said

CEO Anuj Jhunjhunwala.

The growth is part of an Asia-Pacific aerospace surge, with 2024 revenue projected to be 54% above 2019 levels, while North America and Europe remain 3% and 4% lower, according to Accenture Research.

“Earlier, we were chasing customers. Now, they are equally interested in evaluating Indian machine shops,” Jhunjhunwala said, adding that contracts were being signed more quickly and onboarding processes being done much faster than ever before.

The companies produce parts for landing gear, wings, fuselage, electrical switches and motion control systems essential for flight safety and performance.

Leading Western plane and engine manufacturers, whose output has been constrained by strikes, production caps, and parts and labour shortages since the pandemic, say they want to source more from India to meet rising demand for air travel.

"India is the best solution to supply chain challenges,” Huw Morgan, senior vice president for aerospace procurement at Rolls-Royce, said last week at an industry event.

"Our engine volumes are growing at around 20% and the traditional supply chains are just not able to support it," Morgan said. "India is ... the best cost market."

The British company plans to double sourcing from India within five years.

The country is among the biggest aircraft buyers in the world, yet accounts for only 1% of the global supply chain market, according to the recently formed Aerospace India Association.

"Post-Covid, the global aerospace industry has reached an inflection point. While this shift began in 2020, aerospace is a slow-moving industry — it takes time for changes to materialise," said Aravind Melligeri of supplier Aequs.

MORE PLANES, MORE PARTS

India, the world's third-largest domestic aviation market by seats, is also among the fastest-growing, driving demand for maintenance services and parts.

Massive aircraft orders from IndiGo (INGL.NS), and Air India are fuelling growth across the aviation ecosystem, Air India CEO Campbell Wilson told Reuters.

Although Indian firms have long supplied the $180 billion global aerospace industry, they are now moving beyond basic manufacturing to higher-value work such as design, engineering, and system integration.

Airbus in 2024 awarded its second aircraft door contract within a year to Indian suppliers.

"India is contributing more than 1 billion euros currently in the overall Airbus supply chain and we expect to double that. Every commercial aircraft of Airbus today has some part or component that is made in India," said Michel Narchi, head Of international operations at Airbus said.

INDUSTRY EFFORTS

India's civil aviation ministry held a meeting last week with industry leaders about boosting component manufacturing, said AIA Director General Srinivasan Dwarakanath. The association represents both Indian and global firms.

He said a key step towards real value addition would be the local sourcing of raw materials such as aluminium, steel, and titanium, eventually leading to certification of designs made by Indian suppliers.

The AIA estimates that India's aerospace industry will capture 10% of the global supply chain market within a decade, with the global market projected to reach $250 billion annually by 2033.

"India also had the initial challenges of being physically farther away from the main markets of the U.S. and Europe. Engineering approvals, qualification timings, raw material sourcing - it took some time to build the ecosystem, but now India is all set," said Hical's Yashas Jaiveer.

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Aero India 2025: Challenges Continue In India's Indigenisation Process Of Defence Items

Sharath S. Srivatsa | 11 February 2025

Source: The Hindu | https://www.thehindu.com/news/national/karnataka/aero-india-2025-challenges-continue-in-indias-indigenisation-process-of-defence-items/article69206681.ece

Some of the critical components for defence items that India is looking to indigenise includes for new acquisitions such as Rafale fighter aircraft (seen in image) and Apache helicopters. | Photo Credit: PTI

As the Indian armed forces look to indigenise critical components for defence items, hundreds of products identified to be locally produced are being showcased to the private sector at the Aero India 2025 currently underway in Bengaluru. While a large number of those are for the decades-old hardware that need replacement, some of the components that India is looking at includes for new acquisitions such as Rafale fighter aircraft and Apache helicopters.

While more than 13,400 parts/components have been indigenised, more than 37,900 defence items have been listed in the positive indigenisation list by the government last year. These are to be manufactured locally involving the private sector, especially the MSMEs.

A large number of these components are for equipment, vehicles, aircrafts and helicopters among others sourced from Russia, France and Israel, sources said. "The component can be a small bolt to a big spare. For example, the production of side gear box for T-90 was successfully indigenised recently."

The Indian Air Force is looking at avionics, electronics and mechanical parts besides others for MI 17, Sukhoi MK30, MIG 29, Rafale, Mirage 2000, AN 32 and IL 76. "There are about 130 critical items identified for indigenisation and displayed at Aero India. This is a miniscule number compared to what we require," sources said.

Challenges

The indigenisation process started years ago to save foreign exchange and limit the delay in procurement but it still faces acute challenges, acknowledged an official in the Directorate of Indigenisation.

"Since the component required is part of scheduled maintenance, getting them manufactured here is a challenge as bulk orders cannot be placed. Even the orders cannot be sustained regularly. It may be difficult for MSMEs to invest on manufacturing small quantum," an official said, adding that at times the components are not available in the market or are available at a very high cost. "Procurement process itself can be delayed or the government may end up paying 10 to 20 times more."

Production of components

Another official said that though transfer of technology would have taken place, specifics for production of components are not explained. "India's strength in metallurgy is not strong. The original equipment manufacturers (OEM) do not share specific details about heat treatment, making it tough for us to produce. In this situation, India is looking at alternative components. Some may pass the stress test and some may not."

In a few components, there are times when indigenous manufacturing of parts has failed, sources said. Even among those components for which design and drawings are made available by the OEM as part of transfer of technology, it becomes difficult to manufacture in India, sources said.

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Sustainable Aviation Fuels: A Meta-Review of Surveys and Key Challenges

Sebastian Wandelt, Yahua Zhang and Xiaoqian Sun

Source: Science Direct | https://www.sciencedirect.com/science/article/pii/S2941198X24000678

The air transportation industry is under pressure to reduce emissions due to its growing contribution to global greenhouse gas emissions, which conflicts with international climate targets like the Paris Agreement (Bergero et al., 2023, Brazzola et al., 2022, Delbecq et al., 2023, Gössling and Lyle, 2021). Moreover, public awareness of aviation's environmental impact has increased, leading to heightened demand for sustainable travel options and regulatory scrutiny from governments and environmental organizations (Chiambaretto et al., 2021, Crouse et al., 2024, Filimonau et al., 2018, Rosario et al., 2024); leading to a challenging period for air transportation stakeholders (Wandelt, Antoniou et al., 2024, Wandelt, Blom et al., 2024). Fig. 1 provides a comprehensive visualization of trends in global air transportation in the last three decades, based on data from Bergero et al. (2023), highlighting the sector's sustainability challenge. Fig. 1(a) shows the growth in passenger demand measured in billion passenger-kilometers from 1990 to 2020. The COVID-19 pandemic caused a sharp decline in 2020, but has rebounded by the year 2024 (data not fully available). Driven by globalization, economic development, and consumer demand for air travel, future increases in demand are expected. Fig. 1(b) illustrates the declining CO_2 intensity of air travel, measured in grams of CO_2 per passenger-kilometer, due to improvements in aircraft fuel efficiency, advancements in technology, and air traffic management. Fig. 1(c) presents the grams of CO_2 equivalent per megajoule of energy, remaining relatively flat over the period, suggesting limited improvements in the carbon intensity of the energy sources used by aviation. Fig. 1(d) visualizes the total CO_2 emissions in billion tonnes, combining the trends from passenger demand and CO_2 intensity. The steady increase in emissions reflects the dominance of passenger demand growth over efficiency gains. Overall, Fig. 1 demonstrates that while the aviation sector has made efforts in efficiency increases, yet, the growth in demand has led to a net increase in emissions. Accordingly, achieving meaningful reductions in aviation's climate impact requires not only efficiency improvements but a more comprehensive set of strategies (Fabiana Peixoto de and Rosario, 2024, Heyes et al., 2023, Hu et al., 2022, Jaffary and Wiedemann, 2025, Quante et al., 2025, Rau et al., 2024). The International Air Transport Association (IATA) estimates that achieving net zero CO_2 emissions by 2050 will require a combination of actions, covering the development/employment of Sustainable Aviation Fuel (65%), novel technologies (13%), and offsets/carbon capture.1

The dominating role of SAFs in decarbonizing the aviation industry resulted in a rapidly growing body of primary studies in years, mainly driven by the urgency to meet international climate goals. Researchers have explored a wide range of SAF feedstocks, conversion technologies, and lifecycle impacts, resulting in a diverse and expansive literature base. As the number of primary studies has grown, however, the need to synthesize this vast knowledge as well, leading to an equally prolific "explosion of reviews"; see Fig. 2 for the yearly number of new review/overview papers on SAF, based on our search in Web of Science, Scopus, and Google Scholar. These reviews aim to consolidate findings from various subdomains in a highly fragmented research landscape. While reviews are essential for understanding the state of the art, their sheer number and scattered focus can create challenges of their own. This fragmentation mirrors the issues caused by the proliferation of primary research, with overlapping scopes, inconsistencies in methodology, and occasional redundancy. As review papers multiply, it becomes increasingly difficult for researchers to identify which reviews are most relevant, comprehensive, or authoritative. These observations underscore the need for a meta-review to orchestrate the wealth of information into a coherent framework for future progress.

In this study, we provide a meta review of surveys/overview papers on SAF. To identify relevant reviews on SAFs, a systematic search was conducted using two widely recognized academic databases, Scopus and Web of Science. The search employed carefully selected keywords such as “sustainable aviation fuel”, “biofuel aviation” “alternative jet fuel”, combined with “review” and “survey”. Boolean operators and filters were applied to refine the results, ensuring that only review papers were included, excluding primary research articles. A post-filtering process was conducted to ensure the relevance of the reviews, based on screening titles and abstracts, leading to 65 relevant review papers. This rigorous search and filtering methodology not only ensured the relevance of the selected literature but also provided a foundation for understanding recurring themes. In addition to providing a chartered map for SAF research, we have also extracted the top-10 mentioned challenges from the 65 review papers surveyed in our study. We hope that our meta-review can contribute to restoring clarity and purpose to the growing body of SAF (review) literature, ensuring that it serves as a guide to advancing knowledge in the field.

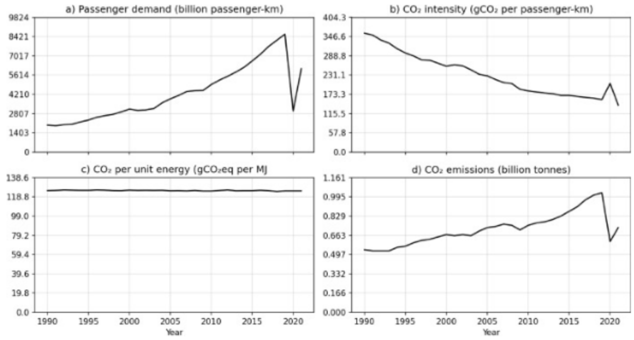

Fig. 1. Evolution of passenger demand (a), energy efficiency (b), carbon intensity (c), and total CO_2 emissions (d). A quadrupled passenger demand together with a doubled energy efficiency lead to doubled emissions, comparing the year 1990 with the year 2019. (Data source: Original data from Bergero et al. (2023), processed by Our World in Data available at https://ourworldindata.org/global-aviation-emissions).

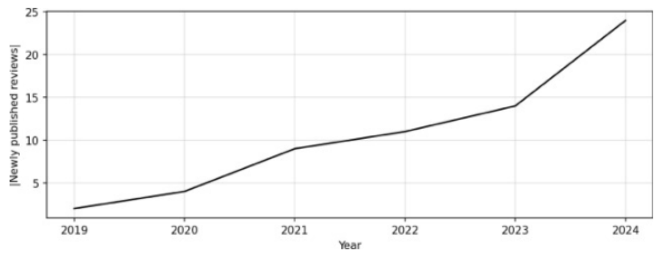

Fig. 2. Yearly evolution of newly published review papers between the years 2019 and 2024.

The remainder of this study is structures as follows. Section 2 provides an overview on SAF pathways and their potential for emissions reductions. Section 3 presents the results of our meta review over the extant literature regarding SAF as well as a set of highly important challenges to address by the community. Section 4 concludes this study.

2. Sustainable aviation fuels

SAFs are a class of fuels designed to provide a cleaner alternative to conventional petroleum-based jet fuel (Bauen et al., 2020, Doliente et al., 2020, Wei et al., 2019). Derived from renewable or waste-based feedstocks, SAFs can achieve significant reductions in greenhouse gas emissions over their lifecycle (Hu et al., 2022, Kurzawska-

Pietrowicz, 2023, Michaga et al., 2021). Unlike alternative propulsion systems, e.g., electric or hydrogen, SAFs are so-called "drop-in" fuels, meaning they can seamlessly integrate into existing aircraft and fueling infrastructure without modifications, ensuring immediate compatibility (Smith et al., 2017, Wang et al., 2024). This makes SAFs an viable option for decarbonizing aviation while more transformative technologies mature.

The American Society for Testing and Materials (ASTM) has certified several pathways, under compatibility with existing infrastructure and, particularly, engines; see Table 1 for an overview. In total, nine pathways are currently certified, with differences in feedstocks, technological maturity, and scalability. FT-SPK and FT-SPK/A integrate gasification and Fischer–Tropsch synthesis to convert biomass and municipal solid waste into hydrocarbons, with FT-SPK/A including aromatics to enhance compatibility. HEFA-SPK derive fuel from lipid-based feedstocks such as used cooking oil and algae via hydrotreatment, making it a commercially rather interesting option. ATJ-SPK uses alcohol intermediates, which are converted through dehydration and oligomerization. CHJ-SPK relies on hydrothermal liquefaction of lipid feedstocks, producing SAF through catalytic conversion. HFS-SIP focuses on sugar fermentation to hydrocarbons but has limited blend potential. HHC-SPK use genetically engineered feedstocks for tailored hydrocarbon production. Finally, PtL or e-Fuels synthesize hydrocarbons from captured CO_2 and renewable electricity, offering a pathway with significant long-term sustainability potential.

Table 1. Overview on ASTM-certified biofuel production pathways.

Abbreviation	Full name	Feedstocks	Key process
FT-SPK	Fischer–Tropsch Synthetic Paraffinic Kerosene	Biomass, Municipal Solid Waste	Gasification → Fischer–Tropsch synthesis → Hydroprocessing
FT-SPK/A	Fischer–Tropsch Synthetic Paraffinic Kerosene with Aromatics	Biomass, Municipal Solid Waste	Gasification → Fischer–Tropsch synthesis → Hydroprocessing + Aromatics
HEFA-SPK	Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene	Used Cooking Oil, Animal Fats, Algae	Lipid Hydrotreatment → Hydrocracking → Hydroprocessing
ATJ-SPK	Alcohol-to-Jet Synthetic Paraffinic Kerosene	Ethanol, Isobutanol	Fermentation → Dehydration → Oligomerization → Hydrogenation
CHJ-SPK	Catalytic Hydrothermolysis Synthetic Paraffinic Kerosene	Lipid-based Feedstocks	Hydrothermal Liquefaction → Catalytic Conversion → Hydroprocessing
HFS-SIP	Hydroprocessed Fermented Sugars Synthetic Iso-Paraffin	Sugars from Biomass (e.g., Sugarcane)	Fermentation → Hydroprocessing
Co-processing	Co-processing in Refineries	Biomass-derived Oils, Fats	Co-processed with crude oil in conventional refinery operations
HHC-SPK	Hydroprocessed Hydrocarbons, Esters, and Acids	Genetically Engineered Feedstocks	Hydroprocessing of engineered hydrocarbons or esters
PtL or e-Fuels	Power-to-Liquid/Electrofuels	CO_2 (Captured) + Renewable Electricity	Electrolysis → Syngas Synthesis → Fischer–Tropsch Synthesis → Hydroprocessing

Lifecycle emissions provide a comprehensive perspective, spanning feedstock acquisition, processing, transport, and combustion, provide an important aspect regarding the environmental impact of aviation fuels; see Fig. 3 for an overview of estimated lifecycle emissions. Conventional jet fuel exhibits the highest lifecycle emissions, predominantly arising from combustion. In contrast, all SAFs achieve significant emission reductions across their lifecycle. Among the nine SAF pathways, FT-SPK and FT-SPK/A utilize biomass or municipal solid waste feedstocks, with slightly elevated processing emissions in FT-SPK/A due to the synthesis of aromatic compounds. HEFA-SPK emerges as one of the most efficient pathways, leveraging lipid-based feedstocks such as used cooking oil and algae, achieving minimal feedstock and processing emissions. ATJ-SPK and CHJ-SPK have a complex conversion processes, leading to slightly higher processing emissions. HFS-

SIP demonstrates fewer process efficiencies. Co-processing integrates biomass-derived oils with crude oil in conventional refineries, offering moderate emission reductions. HHC-SPK relies on genetically engineered feedstocks, achieving emissions reductions similar to HEFA-SPK. Lastly, PtL/e-Fuels have near-zero feedstock emissions but higher processing emissions due to energy-intensive electrolysis and synthesis.

There exist various international and national initiatives to accelerate the adoption of SAFs. One notable global effort is the Carbon Offsetting and Reduction Scheme for International Aviation2 (CORSIA), established by the International Civil Aviation Organization (ICAO) in the year 2016. CORSIA aims to cap net CO_2 emissions from international flights through a three-way strategy: promoting the use of SAFs, improving operational efficiency, and implementing carbon offsetting mechanisms. SAFs play a central role inside CORSIA. To meet CORSIA's goals, countries and airlines are incentivized to adopt SAFs, supported by carbon credit systems that account for their lower emissions. Fig. 4 visualizes the aspirated changes in the percentage contribution of different fuel and emission reduction strategies in aviation from 2025 to 2050, based on the long-term global aspirational goal established during the 41st assembly of the ICAO. Each layer in the stacked line chart represents a specific category's normalized share, adding up to a total of 100% at any given year. The largest section at the bottom corresponds to conventional fuels, dominating the contribution in 2025 but declining steadily over time, accounting for less than 20% of the total by 2050. Biomass SAFs rise sharply in contribution after 2030, reflecting advancements in SAF production and adoption. Similarly, the share of technology improvements – such as fuel-efficient engines and next-generation aircraft designs – increases consistently, becoming one of the major contributors by 2050. Gaseous waste SAFs show moderate growth, indicating their emerging but slower adoption rate compared to biomass-based alternatives. The contribution of optimized flight operations and ground operations, grows moderately throughout the period. Other measures, including atmospheric CO_2 SAF, gain a more prominent role after 2040.

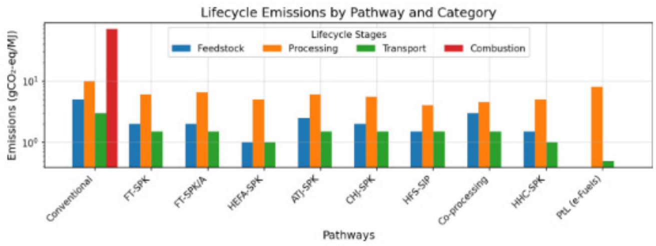

Fig. 3. Estimations of life-cycle emissions for different SAF pathways (note that the-axis is log-scaled).

At the national level, several governments/ institutions have implemented policies to promote SAF research, production, and deployment. In the United States, the Sustainable Aviation Fuel Grand Challenge3 aims to produce three billion gallons of SAF annually by 2030 and achieve net-zero emissions by 2050. Similarly, the European Union's ReFuelEU4 Aviation Initiative mandates a minimum SAF blending percentage, gradually increasing over time, to drive SAF production and integration into the aviation fuel supply chain. China5 and India6 have also taken steps by investing in SAF research and pilot projects focused on feedstocks like municipal waste and biomass. These international and national policies not only create an enabling environment for SAF adoption but also encourage cross-border collaboration in scaling SAF technologies, fostering innovation, and reducing costs.

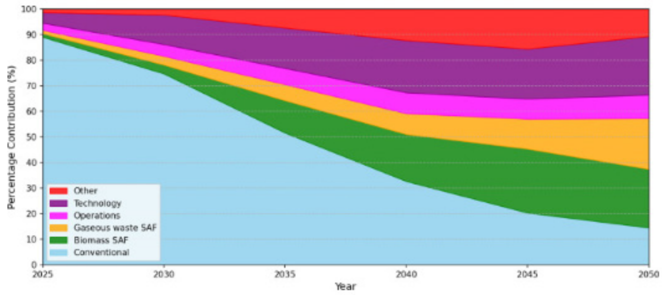

Fig. 4. Long-term global aspirational goal by ICAO for 2050 (based on data from ICAO: https://www.icao.int/environmental-protection/pages/SAF.aspx.

3. Meta review

Our meta-review helps synthesizing the extensive body of extant SAF research. We have identified and examined 65 survey/overview papers that contribute to understanding SAF development. Table 2 reports the top-20 highly cited reviews. Given the diverse, yet potentially overlapping nature of these and other reviews regarding SAF introduction, our meta-review is important in consolidating insights from the extant literature, bridging fragmented perspectives and facilitating cross-disciplinary understanding. Below, we provide an aggregated summary of the focus and major contributions of all 65 survey/overview papers in our meta review and derive a set of ten important challenges for a successful SAF implementation.

Scaling SAF production has been widely examined in the extant review literature (Chiaramonti et al., 2021, Lau et al., 2024, Marszałek and Lis, 2022). A range of overview papers, including (Braun et al., 2024, Grim et al., 2022, Peters et al., 2023), focus on the potential of PtL technologies, which could enable significant reductions in greenhouse gas emissions through feedstock diversification. Duarte et al., 2024, Zhang et al., 2023 provide novel insights into synthesis pathways, with Duarte et al. (2024) advocating for steam reforming over dry reforming due to the latter's catalyst deactivation challenges. Zhang et al. (2023), on the other hand, introduces synthetic biology and biomanufacturing techniques to convert methane and CO_2 into SAF, achieving significant greenhouse gas reductions. These studies are complemented by Hirunsit et al., 2024, Song et al., 2024, which focus on specific technical routes such as the methanol route and SAF combustion performance, calling for further studies on ASTM-approved and emerging SAFs to ensure their viability at scale. Shehab, Moshammer, Franke, and Zondervan (2023) highlights that while the EU has sufficient sustainable feedstocks for short- to medium-term SAF targets, long-term demand will require technological diversification. Kurzawska-Pietrowicz, 2023, Qasem et al., 2024, Zahid et al., 2024 explore advancements in SAF production processes, focusing on HEFA as a leading SAF production technique, as well as algae and waste residues as promising feedstocks due to their low indirect land-use change values. Additionally, Singh et al., 2024, Zhang et al., 2024 focus on technologies like zeolites for deoxygenation processes and strategies to reduce production costs while lowering carbon intensity. Kurzawska-Pietrowicz and Jasiński (2024) emphasize the need for coprehensive fuel certification to meet climate goals.

Table 2. Top-20 highly cited SAF-focused reviews in our meta-review.

Reference	Title	Citations
Wei et al. (2019)	Renewable bio-jet fuel production for aviation: A review	355
Doliente et al. (2020)	Bio-aviation fuel: a comprehensive review and analysis of the supply chain components	215
Ng, Farooq, and Yang (2021)	Global biorenewable development strategies for sustainable aviation fuel production	214
Bauen et al. (2020)	Sustainable Aviation Fuels: Status, challenges and prospects of drop-in liquid fuels, hydrogen and electrification in aviation	167
Chiaramonti (2019)	Sustainable aviation fuels: the challenge of decarbonization	159
Abrantes, Ferreira, Silva, and Costa (2021)	Sustainable aviation fuels and imminent technologies-CO_2 emissions evolution towards 2050	145
Cabrera and de Sousa (2022)	Use of sustainable fuels in aviation—a review	133
Holladay, Abdullah, and Heyne (2020)	Sustainable aviation fuel: Review of technical pathways	125
Shahriar and Khanal (2022)	The current techno-economic, environmental, policy status and perspectives of sustainable aviation fuel (SAF)	122
Heyne, Rauch, Le Clercq, and Colket (2021)	Sustainable aviation fuel prescreening tools and procedures	116
Afonso et al. (2023)	Strategies towards a more sustainable aviation: A systematic review	97
Zhang, Butler, and Yang (2020)	Recent trends, opportunities and challenges of sustainable aviation fuel	84
Capaz, Guida, Seabra, Osseweijer, and Posada (2021)	Mitigating carbon emissions through sustainable aviation fuels: costs and potential	70
Emmanouilidou, Mitkidou, Agapiou, and Kokkinos (2023)	Solid waste biomass as a potential feedstock for producing sustainable aviation fuel: a systematic review	68
Martinez-Valencia, Garcia-Perez, and Wolcott (2021)	Supply chain configuration of sustainable aviation fuel: Review, challenges, and pathways for including environmental and social benefits	65
Ansell (2023)	Review of sustainable energy carriers for aviation: Benefits, challenges, and future viability	52
Vardon, Sherbacow, Guan, Heyne, and Abdullah (2022)	Realizing "net-zero-carbon" sustainable aviation fuel	52
Teoh et al. (2022)	Targeted use of sustainable aviation fuel to maximize climate benefits	50
Kramer et al. (2022)	Perspectives on fully synthesized sustainable aviation fuels: direction and opportunities	46
Hu et al. (2022)	Strategies to mitigate carbon emissions for sustainable aviation: A critical review from a life-cycle perspective	43

Circular economy principles and the utilization of waste are highlighted in various surveys (Khalifa et al., 2024, Madugu and Lea-Langton, 2024, Xu et al., 2025). These studies advocate for coordinated policies to ensure the successful scaling of SAF production. Xu et al. (2025) adds that global efforts in policy coordination and supply chain management are critical to achieve aviation decarbonization. Similarly, Anderson et al., 2022, Raman et al., 2024 advocate for incorporating social science approaches into SAF research to comprehensively address the economic, regulatory, and societal challenges. Michaga et al. (2021) emphasizes the need for techno-economic analysis and life-cycle assessment to evaluate SAF production processes. Furthermore, Dinçer et al., 2024, Meinert, 2024, Sharno and Mahmud, 2024, Yakovlieva and Boichenko, 2022 discuss the importance of global cross-industry collaborations and the establishment of infrastructure compatibility to overcome commercialization challenges, while (Khujamberdiev and Cho, 2024, Calderon et al., 2024) stress the need for harmonizing policies and fostering collaboration among stakeholders to meet SAF production targets by 2050.

The socio-economic and regulatory dimensions of SAF development are also extensively covered in the literature. Amhamed et al., 2024, Delbecq et al., 2023, Kurzawska, 2021, Watson et al., 2024 advocate for integrating broader environmental, ethical, and economic considerations into SAF strategies, emphasizing the importance of aligning SAF development with global climate goals, such as those set in the Paris Agreement. Additionally, Detsios et al., 2023, IEA Bioenergy, 2021, Watson et al., 2024 underline the urgency of policy interventions and the role of techno-economic analyses. The potential of alternative feedstocks is explored in Phippen et al., 2022, Rony et al., 2023, both stressing the need for feedstocks that do not compete with food crops, while also being economically viable. Grimme (2023) outlines the economic challenges of SAF adoption, noting the importance of government mandates. Finally, Hooda and Yadav (2023) stresses sustainable finance's role.

De Oliveira et al., 2024, Wang et al., 2024 focus on the integration of advanced technologies like machine learning and graph theory into SAF research, highlighting the potential of data-driven approaches to optimize fuel compositions and accelerate innovation. Bibliometric analyses, such as those by Aygün et al., 2023, Dinçer et al., 2024, Duarte et al., 2023, capture the rapid growth in SAF research since 2020, focusing on themes like energy efficiency, emission reductions, and nanotechnology applications for improving combustion.

Based on the survey/overview papers covered in our meta review, we have performed an analysis of the most important challenges raised in each of the papers. Fig. 5 summarizes the top-ranked challenges in decreasing order of being frequency. We discuss these most frequently raised challenges in detail below.

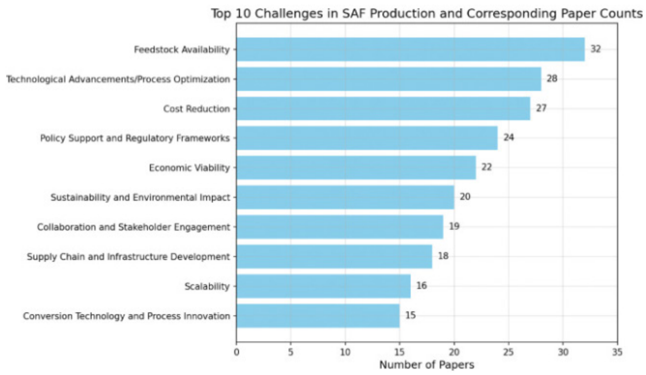

Fig. 5. Top-10 of most-frequently listed challenges for SAF implementation.

3.1. Challenge 1: Feedstock availability

Feedstock availability is the frequently cited SAF-related challenge. The availability of these feedstocks is limited by various factors, including land competition, seasonal variability, and logistical constraints. Several papers highlight that feedstock supply is often subject to market fluctuations, regulatory policies, and competing demands from other industries. For instance, used cooking oil is a promising feedstock for SAF production but is limited in quantity and suffers from inconsistent quality, making it unsuitable for large-scale applications (Zahid et al., 2024). Similarly, agricultural waste, while abundant, often faces logistical challenges in collection, processing, and storage (Calderon et al., 2024). Furthermore, as demand for SAF will increase further, competition for these feedstocks from other biofuel sectors or food production could drive up prices and reduce availability. To address these issues, there is a need for better feedstock forecasting and diversified sourcing. Additionally, innovation in feedstock alternatives like algae or lignocellulosic biomass could help mitigate the pressure on conventional sources and ensure the long-term sustainability of SAF production (Cabrera and de Sousa, 2022, Wei et al., 2019).

3.2. Challenge 2: Technological advancements/process optimization

The major purpose of technological advancements is to make SAF production more cost-effective and efficient. Current technologies face significant challenges related to energy efficiency, catalyst development, and process optimization (Grim et al., 2022, Shahriar and Khanal, 2022). Their commercial viability is hindered by high production costs and energy-intensive processes. Moreover, existing production methods require continuous optimization to reduce costs and improve performance. Particularly, the development of robust catalysts for alternative feedstocks such as lignocellulosic biomass or algae remains a critical challenge (Detsios et al., 2023, Rony et al., 2023). In addition, achieving consistent fuel quality and compliance with American Society for Testing and Materials (ASTM) standards is another hurdle for SAF technology advancements (Holladay et al., 2020). Process optimization, alongside improvements in renewable electricity access and the use of emerging technologies such as machine learning for process control, could offer significant improvements (Hooda and Yadav, 2023, Watson et al., 2024).

3.3. Challenge 3: Cost reduction

Compared to conventional jet fuels, SAF production costs are relatively high, mainly due to the expensive feedstocks and energy-intensive processes involved in production (Grimme, 2023, Shahriar and Khanal, 2022). Feedstock prices, especially for bio-based SAF derived from feedstocks like used cooking oil or algae, contribute to production costs (Phippen et al., 2022, Zahid et al., 2024). Innovations in feedstock availability, process efficiency, and alternative production pathways are essential for cost reduction. Most technologies are still in early stages and require further research to reduce costs (Grim et al., 2022, Grimme, 2023). Moreover, achieving economies of scale is crucial in driving down costs, allowing for more efficient operations and lower per-unit costs (Teoh et al., 2022). Subsidies and mandates, play a key role in lowering costs by supporting early-stage projects and encouraging investment (Sharno & Mahmud, 2024).

3.4. Challenge 4: Policy support and regulatory frameworks

Insufficient or inconsistent global policies potentially induce uncertainty for investors and stakeholders (Khujamberdiev and Cho, 2024, Kurzawska-Pietrowicz, 2023). Clear and stable policies are essential for incentivizing SAF production and use (Grimme, 2023, Sharno and Mahmud, 2024). Especially the aviation sector requires strong international collaboration to establish standardized frameworks that address feedstock sustainability, lifecycle emissions, and certification processes (Cabrera and de Sousa, 2022, Zhang et al., 2024). Policy tools such as subsidies, tax credits, and blending mandates can play an important role in reducing the economic burden on producers and encouraging investment (Teoh et al., 2022, Zahid et al., 2024). Additionally, regulatory frameworks must integrate socio-economic and environmental dimensions, ensuring that SAF production does not adversely impact food security, biodiversity, or water resources (Delbecq et al., 2023, Hu et al., 2022). A long-term vision that combines stringent emissions reduction targets with mechanisms to monitor/enforce compliance is required (Braun et al., 2024, Watson et al., 2024).

3.5. Challenge 5: Economic viability

Economic viability remains another significant barrier to the global adoption (Holladay et al., 2020, Shahriar and Khanal, 2022), exacerbated by limited feedstock availability (Grim et al., 2022, Zhang et al., 2024). Achieving cost parity with fossil-based fuels requires substantial investment in research, development, and infrastructure

(Kurzawska, 2021, Sharno and Mahmud, 2024). Additionally, one needs to escape a potential "chicken-and-egg" scenario, where low demand limits production volume, but low production volume keeps costs high (Kramer et al., 2022, Shehab et al., 2023). This can mainly be solved through policy-driven financial mechanisms (Hooda and Yadav, 2023, Raman et al., 2024) and collaborative funding models (Aygün et al., 2023, Madugu and Lea-Langton, 2024). Long-term values include co-benefits like reduced greenhouse gas emissions, enhanced energy security, and job creation in emerging biofuel industries (Bauen et al., 2020, Doliente et al., 2020).

3.6. Challenge 6: Sustainability and environmental impact

While SAF offers the clear potential to significantly reduce greenhouse gas emissions, concerns remain regarding the environmental trade-offs across its life cycle (Capaz et al., 2021, Chiaramonti, 2019, Marszałek and Lis, 2022, Zhang et al., 2024). Furthermore, the production/processing of SAF can result in emissions and environmental impacts that offset some of the potential climate benefits (Emmanouilidou et al., 2023, Hirunsit et al., 2024). Lifecycle assessments and techno-economic analyses are essential to quantify and minimize SAF's environmental footprint, ensuring that its benefits are not undermined by hidden costs (Michaga et al., 2021, Raman et al., 2024). Innovations in feedstock diversification, waste valorization, and cleaner production technologies can help mitigating these concerns early (Duarte et al., 2024, Calderon et al., 2024). Achieving sustainability also requires harmonized international standards and certifications that align environmental goals with SAF production and usage (Delbecq et al., 2023, Kurzawska-Pietrowicz, 2023).

3.7. Challenge 7: Collaboration and stakeholder engagement

Complex SAF production and deployment requires coordinated efforts among governments, industry players, researchers, and local communities (Kramer et al., 2022, Yakovlieva and Boichenko, 2022). Effective engagement ensures that diverse interests, including environmental concerns, economic viability, and energy security, are harmonized within SAF development strategies (Martinez-Valencia et al., 2021, Wang et al., 2024). This is particularly important in balancing policy frameworks with industry goals to meet ambitious decarbonization targets (Khujamberdiev and Cho, 2024, Raman et al., 2024). The aviation sector should seek cross-industry collaboration, including partnerships with agriculture, waste management, and energy sectors (Kurzawska-Pietrowicz and Jasiński, 2024, Calderon et al., 2024). Meanwhile, fostering international partnerships is critical to harmonizing regulatory frameworks and sharing best practices (Holladay et al., 2020, Zhang et al., 2020). A lack of strong stakeholder collaboration can hinder SAF's adoption by creating disjointed policies and fragmented supply chains.

3.8. Challenge 8: Supply chain and infrastructure development

SAF often rely region-specific feedstocks, requiring specialized collection, transportation, and processing facilities, posing logistical and economic challenges (Martinez-Valencia et al., 2021, Calderon et al., 2024). Accordingly, the integration of SAF into existing aviation supply chains demands significant infrastructure modifications. Nevertheless, SAF compatibility with current fuel storage, blending, and distribution systems is essential to avoid costly overhauls (Marszałek and Lis, 2022, Rony et al., 2023). Airports must invest in infrastructure for SAF storage and blending while ensuring compliance with safety and environmental standards (Kurzawska-Pietrowicz, 2023, Lau et al., 2024). Efficient and transparent supply chain coordination is also important to address regional feedstock disparities and ensure steady SAF availability (de Oliveira et al., 2024, Xu et al., 2025). Additionally, scaling SAF production requires the establishment of localized production hubs to minimize transportation emissions and costs (Khujamberdiev and Cho, 2024, Peters et al., 2023).

3.9. Challenge 9: Scalability

Current SAF production volumes fall far short of meeting the growing demand for aviation fuel (Capaz et al., 2021, Chiaramonti et al., 2021). Technological advancements are essential to increase the yield of SAF from available feedstocks and overcome technical bottlenecks, accompanied by substantial investment to achieve commercial viability at scale (Emmanouilidou et al., 2023, Grim et al., 2022). The lack of integrated production systems exacerbates the scalability issue (Peters et al., 2023). Additionally, scaling SAF production involves addressing infrastructure challenges, such as establishing upgrading blending facilities at airports and global cooperation/coordination (Kramer et al., 2022, Rony et al., 2023). Achieving scalability in SAF production requires a multifaceted approach that integrates feedstock diversification, technological innovation, infrastructure development, and strong policy support to meet the aviation industry's decarbonization goals.

3.10. Challenge 10: Conversion technology and process innovation

Current processes are energy-intensive, involve complex chemical reactions, and yield limited quantities of SAF, reducing their efficiency (Hirunsit et al., 2024, Shahriar and Khanal, 2022). Innovations in catalyst design and process engineering are vital to improving conversion efficiencies (Dinçer et al., 2024, Holladay et al., 2020). Similarly, emerging technologies like PtL offer a promising avenue by leveraging renewable electricity and captured carbon dioxide to produce synthetic SAF (Grim et al., 2022). The lack of comprehensive databases on fuel properties and standardized testing protocols poses additional barriers to process innovation. Here, non-destructive measurement techniques and computational modeling tools can play a crucial role in accelerating the development of optimized SAF pathways (Heyne et al., 2021).

4. Conclusions

Our review of more than 60 surveys regarding SAF highlights significant advancements and ongoing challenges for achieving widespread adoption. Feedstock availability requiring further optimization to meet long-term demands sustainably. Efforts in technological advancements and process optimization have yielded promising breakthroughs; however, scalability and cost reduction remain major barriers. The role of policy support and regulatory frameworks is pivotal and economic viability remains closely tied to policy mechanisms and market dynamics, while sustainability and environmental impacts underscore the importance of rigorous lifecycle analyses to ensure genuine climate benefits. We hope that our meta-review assists the community be synthesizing the literature and clarifying the most important challenges. Collectively, these findings underscore the need for a orchestrated efforts to overcome barriers and realize the enormous potential of SAF for sustainable aviation. However, it should be noted that the existing SAF literature has not fully covered all the potential challenges. For example, the world is experiencing rising geopolitical tensions, which can restrict international collaboration on SAF research and development, disrupt the global supply chain of SAF, and dampen the effort on reducing SAF cost, thereby posing a significant challenge to SAF production and adoption. Future works are still needed to address all the existing and emerging challenges associated with the supply of and demand for SAF in aviation decarbonization.

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Recent Developments in Aerodynamics

Arash Shams Taleghani and Farschad Torabi | *15 January 2025*

Source: Frontiersin | https://www.frontiersin.org/journals/mechanical-engineering/articles/10.3389/fmech.2024.1537383/full

This editorial paper examines the cutting-edge advancements in aerodynamics, a critical field within fluid mechanics, with wide-ranging applications in aviation, automotive engineering, wind energy, and beyond. As aerodynamics evolves, it influences the design of aircraft, turbines, vehicles, and energy systems, necessitating specialized tools and methods for in-depth research and application. Recent advancements in experimental techniques, computational methods, material science, and flow control technologies are driving significant changes in aerodynamic design and performance. Figure 1 presents a detailed chart illustrating the recent advancements in aerodynamic tools, methodologies, technologies, and applications.

Figure 1

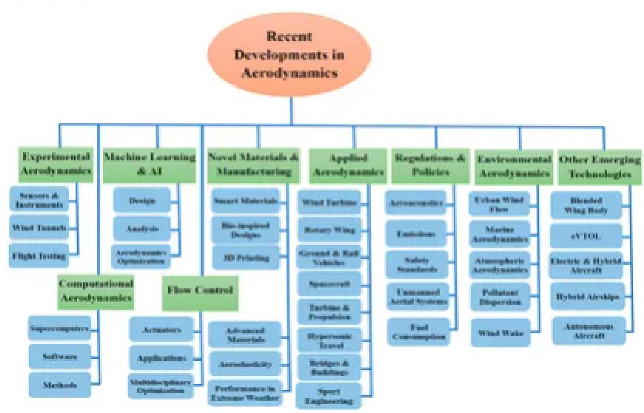

Figure 1. Chart of the key research domains in recent developments in aerodynamics

Experimental aerodynamics, particularly through sub-scale and full-scale testing and flight experiments, will make significant strides with the development of advanced sensors, instruments, and measurement systems. For example, the future of time-resolved PIV is expected to be shaped by technological advancements in imaging, data processing, and integration with emerging techniques. Future developments could allow researchers to observe flows over multiple scales simultaneously, helping to link small-scale turbulent dynamics with large-scale flow structures and improve our understanding of turbulence at all scales. The combination of higher resolution, real-time analysis, multi-dimensional measurements, and the use of machine learning will make PIV an even more powerful tool for studying aerodynamics. Wind tunnel testing will remain a crucial method for assessing aircraft performance, particularly in different flight phases (Taleghani et al., 2020; Zhang et al., 2024; Arthur, 2024). Simultaneously, computational tools, such as CFD, will progress. More accurate simulations of airflow around complex geometries are now possible, with techniques like LES (Tonicello et al., 2022) and DNS (Chiarini and Quadrio, 2021) offering higher resolution but at the increased computational cost. Machine learning and artificial intelligence are also gaining importance in aerodynamics, enabling the optimization of designs, improving CFD accuracy, and developing new turbulence models (Sabater et al., 2022). CFD is anticipated to undergo a paradigm shift with the integration of artificial intelligence and machine learning, enabling faster, more accurate simulations of complex flows, including turbulent and hypersonic regimes.

Flow control technologies, which optimize aerodynamic performance by manipulating natural airflow around structures, have evolved considerably. Advances in actuators, including modulated pulse jets (Abdolahipour et al., 2022a; Abdolahipour et al., 2022b), plasma actuators (Taleghani et al., 2018), model-free closed-loop systems (Ren et al., 2024), and hybrid methods (Azadi et al., 2024), aim to enhance control, reduce energy consumption, and improve robustness. These technologies will become particularly useful in applications where efficient aerodynamic performance is critical under varying conditions. These innovations are expected to enhance both the performance and sustainability of next-generation aircraft. Material science will continue to play a pivotal role in improving aerodynamic performance. Lightweight composites, shape-memory alloys, and advanced materials like polymeric gyroid structures (Overbeck et al., 2024) are being developed to reduce weight, enhance structural integrity, and lower drag. Finally, smart materials with adaptive surface properties will enable real-time optimization of drag and lift, ushering in a new era of dynamic, responsive aerodynamic systems. These advancements, underpinned by computational, material, and environmental innovations, will redefine the role of aerodynamics in addressing global challenges and driving technological progress. Additionally, the rise of 3D printing technology has revolutionized the production of complex aerodynamic components, enabling the creation of intricate shapes previously difficult to manufacture. This capability will open new avenues for optimizing designs in aerospace and automotive applications.

Nature has long been a source of inspiration for aerodynamic design. Bio-inspired aerodynamics (De Manabendra et al., 2024), which studies natural flight patterns and fluid dynamics in animals, is expected to become an even more prominent field in engineering solutions. For example, the study of owl wings (Harbi Monfared et al., 2022) has led to the development of quieter flight mechanisms, which are particularly beneficial for urban air mobility applications. By mimicking the aerodynamic features of birds and fish, engineers are developing more efficient designs for both aircraft and wind energy systems. Biomimetic approaches inspired by natural systems, such as bird flight and marine locomotion, are expected to revolutionize aerodynamic design, enhancing energy efficiency and adaptability. Applied aerodynamics bridges theoretical fluid dynamics with practical engineering challenges. Researchers are increasingly focusing their efforts on the design of vehicles (including aircraft, spacecraft, drones, and cars) to withstand extreme weather conditions such as turbulence, crosswinds, and heavy rain. For aircraft, this involves developing systems to predict and manage weather-related disturbances. In automotive design, the focus is on optimizing aerodynamics for all-weather conditions, improving both safety and efficiency. Hypersonic vehicles, which face extreme aerodynamic and thermal stresses, will benefit from new materials and models designed to maintain stability at high speeds. Hypersonic aerodynamics will see significant breakthroughs in thermal management and flow control, facilitating safer, more stable designs for high-speed vehicles. Recent innovations in wind energy, such as optimized blade aerodynamics and turbine layout, have made wind power generation more efficient and sustainable (Torabi, 2022). Renewable energy systems, particularly wind turbines, will benefit from refined blade aerodynamics to maximize energy capture while minimizing environmental impacts. These advancements will reduce the number of turbines needed, minimizing the environmental footprint of wind farms while increasing power output. Aerodynamics will also play a pivotal role in the optimization of fuel efficiency and stability for both ground vehicles and rail systems. Effective aerodynamic design is essential for minimizing air resistance, improving handling, and maximizing energy efficiency in vehicles such as trucks, buses, and electric cars.

Regulations and policies significantly influence aerodynamic design. Safety standards established by agencies like the FAA and EASA will drive innovations in structural integrity and aerodynamic efficiency. As concerns regarding climate change intensify, policies designed to reduce emissions and fuel consumption, such as the ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), are likely to encourage the development of aircraft with enhanced aerodynamic efficiency (Taleghani et al., 2024). Regulations targeting noise pollution at urban airports will also lead to quieter aircraft designs, fostering advancements in technology and methodology. Additionally, policies supporting sustainable aviation technologies, including electric and hybrid propulsion systems, will encourage the development of novel aerodynamic solutions tailored to these emerging systems. In aviation, sustainable technologies will lead to ultra-efficient airframes optimized for electric and hydrogen propulsion, complemented by noise-reduction techniques critical for urban air mobility. Aerodynamics is also essential for understanding environmental phenomena such as air pollution, weather patterns, and climate change. By studying airflow and atmospheric dynamics, researchers can better predict and mitigate the impact of human activities on the environment (Christia et al., 2022). For example, urban airflow studies can inform city planning and improve pollution control strategies. The interdisciplinary field of environmental aerodynamics combines fluid dynamics, meteorology, and environmental science to address real-world challenges and enhance sustainability.

Innovative designs such as the blended wing-body concept (Gray and Zingg, 2024), which integrates the wings and fuselage into a single structure, will continue to improve aerodynamic efficiency by reducing drag and minimizing turbulence at the junction of wings and fuselage. This design is expected to allow for better lift-to-drag ratios, leading to reduced fuel consumption and increased efficiency. The exploration of electric and hybrid propulsion systems will drive further aerodynamic advancements. As electric aircraft become more viable, optimizing their aerodynamic performance will be essential for maximizing range and efficiency. Researchers will focus on designs that take into account the unique characteristics of electric motors and batteries, allowing for more efficient electric aircraft. Looking forward, several key areas are poised to shape the future of aerodynamics. One such area is the development of autonomous aircraft, which require innovative aerodynamic designs to ensure stability and control in real-time (Deniz et al., 2024). Advanced control surfaces and wing configurations are being studied to adapt to changing flight conditions autonomously. Another promising direction is the integration of renewable energy sources, such as solar-powered aircraft, which would require specialized aerodynamic designs to maximize energy efficiency and reduce reliance on fossil fuels. The growth of urban air mobility solutions, such as eVTOL aircraft (Simmons and Busan, 2024), presents unique aerodynamic challenges. The design of these vehicles must prioritize efficiency in urban environments, where concerns regarding noise and safety are particularly salient. Aerodynamic innovations will play a key role in ensuring the success of these emerging transportation solutions.

In conclusion, the field of aerodynamics continues to advance, driven by innovations in experimental methods, computational techniques, materials, and regulatory frameworks. As new challenges emerge in the design of autonomous, electric, and sustainable aircraft, aerodynamic research will remain central to addressing these issues and shaping the future of transportation and energy systems. The future evolution of aerodynamics is poised to be shaped by interdisciplinary innovation and sustainability imperatives, driving advancements across aviation, automotive, renewable energy, and space exploration. This Research Topic encompasses the latest developments in flow control, simulation methods, applied aerodynamics, and propulsion design, reflecting the multi-disciplinary nature of modern aerodynamic research.

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India "Bets On" Indigenous Combat Choppers Over LCA Tejas for Exports; Aims to Boost Revenues to 25%

Ritu Sharma | 19 February 2025

Source: Eurasian Times | https://www.eurasiantimes.com/indian-aircraft-maker-awaits-breakthrough-defense-deal/#:~:text=Home%20South%20

LCA Tejas

Aiming to increase its export revenues from the current 1 percent of total revenue to 25 percent, Indian aircraft maker Hindustan Aeronautics Limited (HAL) has done a reality check. Instead of exporting homegrown fighter jets and Light Combat Aircraft, it will focus more on exporting Dorniers and helicopters to African, Middle Eastern, and South East Asian countries.

The Narendra Modi government had set a target for all PSUs to get 25 percent of their revenues from exports. But at the moment, the HAL has zero export orders, and exports constitute just one percent of its total revenues.

Despite this, HAL's order book is expected to touch Rs 2,50,000 crore ($3B). As of December 2024, HAL had orders worth over Rs 1,30,000 crore. The next 12 months' order accretion is estimated at Rs 1,65,000 crore.

HAL is actively pursuing two major contracts in India – 97 LCA (Light Combat Aircraft) MK 1A and 156 LCH (Light Combat Helicopter) orders. These two orders will add Rs 1,30,000 crore to its order book.

Along with this, the orders for the Su-30 Upgrade, Indian Multi-Role Helicopter design and development (IMRH D&D) sanction, and regular Repair and Overhaul (ROH) orders will take the total order book to Rs 2,50,000 crore by 2025-26.

During the nine months of the current financial year (2024-25), HAL received fresh orders worth Rs 55,800 crore, comprising Rs 39,000 crore in manufacturing orders, including 240 AL 31 FP engines valued at Rs 25,350 crore and 12 Su-30MKI aircraft worth Rs 12,573 crore, and Rs 16,500 crore in ROH, spares, and D&D orders.

Contrary to this, it received export orders worth Rs 300 crores in the nine months of the financial year.

The Indian government has made the indigenous Light Combat Aircraft (LCA) 'Tejas' the flagship product on its defense exports list. Not a single month passes without news of a new country's interest in the fighter jet.

New Delhi has been aggressively pushing to sell the LCA to foreign air forces. Indian diplomats and HAL officials have been meeting foreign officials, throwing diplomatic weight behind the aircraft.

However, the HAL has realized that buying fighter jets is a big-ticket item, and not many countries can easily make that decision.

“Export of LCA is a billion dollars plus deal because it requires spares and weapons. There are not many countries that can afford it. It is one of the difficult parts of selling LCA. The countries need to have that kind of financial muscle,” HAL Chief DR. DK Sunil said. He hoped the Indian government could help the countries by extending a Line of Credit.

Many countries have shown interest in the LCA, and HAL is trying to demonstrate its capabilities through test flights in these countries. LCA Mk1A opened Aero India 2025. Moreover, HAL has established offices in Malaysia, the UK and Egypt. It is considering establishing offices in two more countries, the names of which are yet to be finalized.

When asked if the HAL has the wherewithal to meet the export demands for LCA in case the deal comes through, Dr. Sunil said that the HAL can rope in private players like Larsen and Toubro (L&T) and Tata Aerospace.

“We have a private sector partnership, where we can get up to 10 fuselages from companies like L&T and Tata, which can build aerostructures. We think we can ramp it (the manufacturing) up, but our focus with the countries is to establish MRO and repair facilities rather than manufacturing lines because the investment is high.”

However, the HAL has a backlog of 6-7 years to meet the Indian Air Force’s (IAF) requirements. Considering this, the HAL has started investing in ramping up manufacturing facilities for helicopters and exporting Dornier 228.

Dornier 228 And Helicopters

HAL made a breakthrough when it exported Dornier 228 aircraft to Guayana in 2024. Since then, HAL has fielded Dornier in a tender in Malaysia and is confident it will win the contract to supply eight aircraft to Malaysia.

Learning from its fiasco in Ecuador with its ALH Helicopters, HAL is putting more “boots on the ground.” After a series of accidents, Ecuador has grounded its ALH fleet.

“In Guayana, we have our people supporting the product. We are talking to local companies to develop the repair facility,” Dr. Sunil informed.

The HAL intends to expand manufacturing lines for Light Utility Helicopters (LUH), Light Combat Helicopters (LCH), and Advanced Light Helicopters (ALH) to meet export demands, and the public sector aircraft maker is actively promoting helicopter platforms.

The HAL’s capacity is 30 helicopters per annum. When demand is at its peak, the HAL will try to scale it up to 60 helicopters, and plans are being made to ramp up production to 90 helicopters annually.

ALH-DHRUV

An Advanced Light Helicopter carries an ATV in an underslung configuration to enhance operational and logistic stamina in forward areas.

LCH, along with LCA, is one of the flagship products designated for exports from the HAL. Argentina and Nigeria have shown interest in rotary-wing aircraft. Argentina signed a letter of intent to purchase 20 'Prachand' (Fierce) helicopters.

During the 2023 visit of Argentinian defense minister Jorge Taiana, the two countries signed a letter of intent to purchase 20 LCH.

"Regarding the MoU with Argentina, it took some time due to their internal approval. Again, funding issues are still there for getting agreements. We discussed with Morocco, Rwanda, and Congo," the HAL Chief said. The HAL Team even visited Congo to understand their requirements.

The Philippines has also expressed interest in buying seven ALH MKIII helicopters for its coast guard. In 2023, the Chief of the Filipino Coast Guard visited India. However, the deal is yet to materialize.

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Cyber Resilience Ii Aerospace and Space: Lessons from Incident Response Failures and AI-Driven Solutions

Dan Sorensen | 04 March 2025

Source: Forbes | https://www.forbes.com/councils/forbestechcouncil/2025/03/04/cyber-resilience-in-aerospace-and-space-lessons-from-incident-response-failures-and-ai-driven-solutions/

The space and aerospace industry has increasingly become a target for sophisticated cyber threats. Analyzing past incident response failures can help provide some valuable insights into enhancing cyber resilience and improving upon incident response (IR) and incident management (IM) procedures. Some of these can help us understand how integrating artificial intelligence (AI) and advanced security frameworks could mitigate such vulnerabilities.

Notable Cybersecurity Incidents In Aerospace

1. British Airways Data Breach (2018): According to the BBC, British Airways suffered a significant data breach in which attackers injected malicious code into the airline's website, compromising the personal and financial information of more than 400,000 customers. The breach was attributed to vulnerabilities in web application security, a lack of multifactor authentication (MFA) and inadequate monitoring systems.

2. SITA Supply Chain Attack (2021): TechCrunch reports that SITA, a significant IT provider for the aviation industry, experienced a breach in 2021 that affected multiple airlines globally, leading to unauthorized access to passenger data. This incident highlighted the risks associated with third-party vendors and the need for comprehensive supply chain security assessments.

3. Delta Air Lines IT Outage (2024): In 2024, Delta Air Lines faced a major technology outage due to a faulty update from a cybersecurity firm, resulting in the cancellation of thousands of flights and significant operational disruptions. This shows the importance of rigorous testing of "vendor technology" security updates and the risks of over-reliance on single security providers.

Notable Cybersecurity Incidents In The Space Industry

1. NASA's Jet Propulsion Laboratory (JPL) Breach: In 2018, NASA's JPL experienced a significant security breach when an unauthorized Raspberry Pi device connected to its network. Lessons from the 2011 and 2016 NASA breaches still did not prevent this third critical breach, as noted by Bitdefender.

Attackers exploited this vulnerability to access mission-critical systems, including the Deep Space Network. The breach was attributed to inadequate network segmentation and insufficient device management protocols. Similarly, in 2019, the GDPR register shows that user error caused another breach where a system administrator misinterpreted "all users" when assigning permissions to a web app dashboard.

2. Satellite Interference And Signal Hijacking: There have been instances where malicious actors interfered with satellite communications, leading to data interception and service disruptions. As Deloitte's August 2024 article explains, although not a new issue, these incidents highlight vulnerabilities in signal encryption and access control mechanisms within satellite systems.

Common Challenges And Failures

These incidents reveal recurring deficiencies not only in the space and aerospace sector's incident response strategies but also agnostic of the industry. Some typical aspects include failure to properly segment networks that allow attackers to move laterally across systems, accessing sensitive data and critical operations.

Unmanaged or unauthorized devices connected to networks create entry points for attackers, as seen in the JPL breach. Insufficient encryption of satellite communications makes it easier for adversaries to intercept or hijack signals. Lack of real-time monitoring and slow incident response times enable attackers to exploit vulnerabilities extensively before detection.

Breaches often go undetected for extended periods due to inadequate monitoring tools and processes. Weak access management and the lack of multifactor authentication leave systems vulnerable to unauthorized access. Failing to assess the security practices of third-party vendors can result in indirect breaches. Additionally, implementing updates without thorough testing increases the risk of system outages and new vulnerabilities.

Leveraging AI And Advanced Security Frameworks

In addressing some of these challenges, we can integrate tools such as AI and advanced security frameworks, which can help play a pivotal role in reducing human error and streamlining processes.

Enhanced Threat Detection And Anomaly Detection

Traditional security systems nowadays struggle to process vast network data in real time, which leads to delayed threat identification and mean time to respond (MTTR). AI-powered threat detection now leverages algorithms to analyze network traffic patterns better, detect network-specific anomalies and identify potential threats before they escalate.

Next-generation AI-driven SIEM (security information and event management) solutions can enhance security operations by helping filter false positives better and prioritizing critical threats, ensuring security teams focus on high-risk incidents.

Automated Incident Response And Mitigation

Incident response in the past has relied on more manual processes, which can be time-consuming and prone to human error. AI-driven security orchestration, automation and response (SOAR) platforms can improve upon existing SIEM/SOAR platforms, streamline the filtering out of false positives and even automatically respond to threats if instructed.

AI can isolate compromised endpoints, block malicious IP addresses and trigger predefined response actions, significantly reducing response times. AI-powered systems can also correlate threat intelligence across multiple sources, ensuring a more coordinated and context-aware response to cyberattacks.

Predictive Analytics For Proactive Cyber Defense

Much of IR relies on analyzing historical attack data and identifying emerging threat patterns. AI-driven predictive analytics can help organizations anticipate vulnerabilities before they are exploited. Machine learning models can analyze past cyber incidents, industry threat trends and adversary tactics, enabling organizations to proactively patch vulnerabilities and strengthen their security posture. Additionally, we can use AI to simulate attack scenarios, helping cybersecurity teams refine defense mechanisms and develop more resilient security strategies.

Improved Supply Chain Security And Risk Assessment

The aerospace and space industries rely heavily on third-party vendors, which introduces potential vulnerabilities. AI-powered risk assessment platforms can continuously monitor third-party security postures, identifying weaknesses before they become exploitable.

AI can also analyze supply chain behaviors and detect signs of suspicious activity, such as unauthorized access to supplier networks or inconsistencies in software integrity. Additionally, AI-powered cybersecurity audits and automated compliance checks can ensure that vendors adhere to strict security protocols, especially during mergers, acquisitions and system integrations.

The aerospace and space industry's growing reliance on digital technologies and interconnected systems necessitates a proactive approach to cybersecurity. Learning from past incident response failures is crucial to building a resilient infrastructure that safeguards critical operations.

These sectors can enhance threat detection, automate responses and fortify defenses against future attacks by integrating AI and advanced security frameworks. Addressing common vulnerabilities and leveraging technological advancements will ensure both aerospace and space industries remain secure, resilient and capable of sustaining safe and successful missions.

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Further Reading

1. Cratering Effects: Chinese Missile Threats to US Air Bases in the Indo-Pacific - https://www.stimson.org/2024/cratering-effects-chinese-missile-threats-to-us-air-bases-in-the-indo-pacific/
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4. Evolution of Multi-Domain Operations and Prospects for Application of Aerospace Power - https://www.idsa.in/wp-content/uploads/2024/05/18-1_Tejinder-Singh.pdf
5. Private aviation is making a growing contribution to climate change - https://www.nature.com/articles/s43247-024-01775-z
6. Comprehensive Review: Aero India 2025 and Its Impact on Global Defence - https://timesofindia.indiatimes.com/india/aero-india-2025-review

"The term 'Aerospace' was introduced in 1958 by the USAF Chief of Staff, General Thomas D White, as a new construct that depicted air and space as a seamless continuum stretching from the Earth's surface to infinity."

The Centre for Air Power Studies (CAPS) is an independent, non-profit think tank that undertakes and promotes policy-related research, study and discussion on defence and military issues, trends and developments in air power and space for civil and military purposes, as also related issues of national security. The Centre is headed by Air Vice Marshal Anil Golani (Retd).

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