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# TECHNOLOGY TRAJECTORY FOR AN *ATMANIRBHAR* AERO ENGINE

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## INTRODUCTION

Aero engines power aircraft and use complex technologies and manufacturing processes. These technologies are closely guarded by the five countries (the UK, USA, Canada, Russia and Canada). The costs of developing and manufacturing new aircraft and aero engines are very high, and in most countries, the government bears some of the financial burden. In India, Hindustan Aeronautics Limited (HAL) is a dominant monolithic player in aero engine manufacture and the Maintenance, Repair and Overhaul (MRO) business. The Research and Development (R&D) is primarily in the Defence Research and Development Organisation (DRDO) domain. The National Aeronautics Laboratories (NAL) and Aeronautical Development Agency (ADA) also undertake some aerospace design. Due to the governmental controls, these agencies undertake R&D based on the specific needs of the defence Services as cleared by the Ministry of

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**India's lack of expertise in jet engine development will continue to be a source of concern, despite the remarkable success in rocket and missile engines.**

Defence (MoD). This is not conducive to sustained research and retention of domain expertise and design experience in the field of aero engines.

The Kaveri aero engine was developed by the Gas Turbine Research Establishment (GTRE), under the DRDO, after a 30-year developmental period. This, however, was not found suitable for the indigenous Light Combat Aircraft (LCA), as it was underpowered and overweight to meet the aircraft's performance requirements. HAL has never been seriously involved in the development of an aero engine, though it has been associated with the MRO of the engine's licence produced by it from Russia and the UK (AL-31FP, R-25, Adour 811/871 and Shakti).

India's lack of expertise in jet engine development will continue to be a source of concern, despite the remarkable success in rocket and missile engines. Although air breathing aircraft jet engines such as ramjets and scramjets are related to aviation and rocket engines, they comprise a different field altogether. Aero engines use a completely different technology, and experience cannot be transferred directly to these engines. This is primarily due to rotating components, longer life cycles and rapid thermal cycling during the aircraft's operational envelope.[1]

## THE DESIGN PROCESS FOR AERO ENGINES

The design process is initiated and constrained by the identified operational need of the aero engine. This is typically defined in the Request for Proposal (RFP) of the usage of the engine on an aircraft and the typical mission profile of that aircraft in various phases of flight. For example, for an air combat fighter the phases will be warm-up and take-off, accelerate and climb,

1. "Why is India Unable to Design a Jet Engine for Fighters?". *Indian Defence News*. http://defenceupdate.in/why-is-india-unable-to-design-a-jet-engine-for-fighters/. Accessed on December 12, 2021.

subsonic cruise climb, descend, followed by combat air patrol, supersonic penetration, ensuing combat, delivery of expendables and weapon load, escape dash, climb, subsonic cruise climb, descend, loiter, and, finally, descend and land. Detailed performance parameters are quantitatively defined for each of these phases.

The engineering design is iterative, and many valid solutions exist to achieve the performance parameters. None is unique, and the final accepted solution is based on judgement and compromises. The design teams in various domains of engine technology inevitably encounter major problems and conflicting designs. These have to be regularly shared and discussed for compromises, else the process of achieving the desired performance parameters will fail. Project management, collaboration and competition within the various teams, access to the latest tools for design and associated simulations are essential in the design process. A robust oversight mechanism by a peer group must be considered at every stage to avoid flaws and catastrophic failures in the progress. Needless to emphasise, research is necessary, and academic institutions must collaborate to facilitate the process.

The intricacies of aero engine design are not intended to be discussed in this exposition. The more inclined reader may refer to the evergreen masterpiece, *Aircraft Engine Design*.[2] The DRDO and the various engineering academic institutes like the Indian Institutes of Technology (IITs) and National Institutes of Technology (NITs) have the necessary domain knowledge at both post-graduate and research levels. Availability of academic excellence with proven research or experience in the aero engine design process is an area of concern in India, at both individual and institutional levels.

2. Jack D Mattingly, William H Heiser and David T Pratt, *Aircraft Engine Design*, Second Edition, AIAA Education Series (Reston, VA: American Institute of Aeronautics and Astronautics, Inc., 2002).

**Aerospace engineers are now using data-driven methodology to quickly improve jet engines that are more efficient in their overall performance, fuel efficiency and lower emissions. Modelling/simulation is also applied to the engine manufacturing process to reduce waste and costs.**

## MODELLING AND SIMULATION TOOLS[3]

Modelling and simulations tools are used to simulate the intricate air flows, the thermal environment within the aero engine, as well as the dynamic performance and functioning of the various rotating components. Aerospace engineers are now using data-driven methodology to quickly improve jet engines that are more efficient in their overall performance, fuel efficiency and lower emissions. Modelling/simulation is also applied to the engine manufacturing process to reduce waste and costs.

Numerous design variables must be considered while modelling. Variables that are relevant to the overall goal must be carefully iterated and frozen. For example, the shape and aerodynamic tilt of the compressor blade will affect the efficiency of the engine. There are numerous engineering parameters; approximately 300, for example, in the design of just this blade. Identifying relevant design variables is a design challenge and its solution is not unique but based on the expertise and experience of the designer. The choice results in a unique design and affects the performance of the compressor in the case so discussed.

The second issue relates to manufacturing. No manufacturing process is perfect; there will always be variations in the final product. When the design variables are finalised and components are manufactured based on the decided engineering parameters, some variations or tolerances can be accepted without deteriorating the performance and safety of the component. The simulations allows designers to quickly ascertain these

3. The Alan Turing Institute, "Streamlining Jet Engine Design and Manufacture", February 15, 2021. https://www.turing.ac.uk/research/impact-stories/streamlining-jet-engine-design-and-manufacture). Accessed on December 12, 2021.

tolerances, which are then passed on to control the manufacture process. The greater the tolerance, the cheaper the manufacturing process. Increased manufacturing tolerances for a component means discarding fewer components for failing to meet the tolerances, and, hence, less material is wasted.

Both these aspects of modelling and simulation are inherently based on the prior knowledge of the designers, which is mathematically captured through various algorithms. There are some commercially available off the shelf (COTS) tools that are used in academic research, but they are rarely the most relevant ones. Most COTS tools are highly proprietary and closely guarded by the various engine houses through strict licence agreements. In the absence of such tools, the aero engine design's rapidity, effectiveness and efficiency will always be a casualty. To fall back on aero engine components' performance testing in test rigs is not only time consuming, but cost intensive as well.

**AERO ENGINE MANUFACTURING**

Aero engine manufacturing is complex not just in terms of the process, but also due to the usage of highly specialised alloys in the manufacture. The tight tolerances in the fabrication and the quality control during various heat treatments to get the right characteristics of the component is a subject in itself. The existing capability will decide what can be done in-house and what will be outsourced by the engine designer manufacturer duo. It can be a limiting factor in the overall design capabilities of the design and manufacture of aero engines by the country. Any aero engine manufacturer must offer comprehensive and robust manufacturing capabilities for aero engine components and assemblies, with particular expertise in complex fabrications and rotating components, including shafts. These may be in-house facilities or outsourced to associates.

Besides HAL, Bharat Forge Ltd (BFL) in India has the capability and capacity to manufacture high-quality aero engine compressors, rotating parts and turbine components as per aviation manufacturing standards.

**To achieve optimal performance, whether in terms of heat management or air flow enhancements, rigorous design improvements in all areas related to aerodynamics, metallurgy and manufacture are required.**

Both companies use state-of-the-art technology and manufacturing processes, however, their capabilities are still work in progress.[4]

**AERO ENGINE TECHNOLOGY TRAJECTORY**

The improvements in aero engine have focussed mostly on the design process, rather than on new technology discoveries or concepts. To achieve optimal performance, whether in terms of heat management or air flow enhancements, rigorous design improvements in all areas related to aerodynamics, metallurgy and manufacture are required.

The overall efficiency of a jet propulsion engine is based on the thermal efficiency and propulsive efficiency. The thermodynamic cycle efficiency is achieved by improving the compressor ratio and power output by increasing the turbine inlet temperature. The latter is increasingly an area of research in metallurgy, with thermal barrier coatings and use of composites.

While designing aero engines, the designer has to make a choice on whether to improve the thrust rating, fuel efficiency or the heat management within the engine. This is dictated by the operational role and the trade-offs therein. Each of these entails taking into account a variety of design elements and parameters that yield a unique solution. However, the **adaptive cycle architecture** integrates these in one single design.[5] The General Electric (GE) XA100 fighter jet engine is a uniquely designed aero engine that maximises combustion efficiency for extended time on station

4. Bharat Forge Website. https://www.bharatforge.com/businesses/aerospace. Accessed on December 13, 2021.
5. "The Superjet: How GE's Adaptive Cycle Jet Engine Could Supercharge Military Aviation Alyssa Newcomb", October 25, 2021. https://www.ge.com/news/reports/the-superjet-how-ges-adaptive-cycle-jet-engine-could-supercharge-military-aviation. Accessed on December 13, 2021.

combat air patrols or enhances the power rating for advantage in aerial combat manoeuvres. It is not an either-or designed engine, but can operate in both modes seamlessly. It is a design marvel, but could have been manufactured only with latest manufacturing technologies like additive manufacturing and use of Ceramic Matrix Composites (CMCs), particularly the turbine blades which are not possible with traditional materials and manufacturing processes.

**The core engine is the heart of the system design that converts the thermal energy of the fuel combustion to an efficient rotary motion for the compressors and turbines. This core engine is designed with great care and becomes the main building block for the family of engines that will be developed around it.**

The open-fan concept[6] optimises combustion and thereby decreases hazardous emissions. In contrast to other aero engines, the front fan is not enclosed in a case. The 13-ft diameter fan was produced utilising the CMC technology, and a bypass ratio of 70:1 in comparison to the Leading Edge Aviation Propulsion (LEAP) engines of 11:1. The higher the bypass ratio, the greater is the thrust. This design has been a game changer in the airlines industry.

The core engine is the heart of the system design that converts the thermal energy of the fuel combustion to an efficient rotary motion for the compressors and turbines. This core engine is designed with great care and becomes the main building block for the family of engines that will be developed around it. It is this core engine technology that is closely held by the aero engine giants like GE, Rolls Royce, Honeywell, Safran, etc. For example, the RISE (Revolutionary Innovation for Sustainable Engines) team at GE is using CMCs that can withstand high turbine inlet temperatures beyond the melting

6. Tomas Kellner, "The Future of Flight: Engine-Maker Unveils New Technology Development Program to Cut CO2 Emissions By 20%", June 14, 2021. https://www.ge.com/news/reports/the-future-of-flight-engine-maker-unveils-new-technology-development-program-to-cut-co2. Accessed on December 15, 2021.

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point of advanced metallic superalloys. In a core engine this translates into a dramatic increase in the thermal efficiency.

**COMPOSITES**

Composites comprise a family of materials—Ceramic and Metal Matrix Composites (CMCs and MMCs), Fibre-Reinforced Polymers (FRPs) and Polymer Matrix Composites (PMCs)—that have revolutionised the design of aero engine components by weight reduction and improved performance, thereby outperforming traditional materials. They are now increasingly being used on high-tech carbon fibre fan blades and in hot sections because of their ability to withstand extremely high temperatures. Rolls-Royce is developing SiC CMCs that are lighter than traditional alloys and can withstand temperatures of 1,900°C. Similarly, GE9X has CMC material in the combustor and turbine. The use of CMCs has now allowed the engines to operate at much higher turbine entry temperatures and combined with weight reduction, improved their performance and efficiency.[7] A320neo and 737 MAX jets LEAP engines have composite structures, fan blades, turbine shrouds and fan case made of CMCs. The C919 aircraft of China with the LEAP engine, has the nacelle made of about 60 per cent CMCs. India's Dassault Rafale jets have the M88 engines nacelles and nozzles made of thermo-structural composites from Safran Ceramics.[8]

In India, the Gas Turbine Materials and Processes (GTMAP) has been established in the Aeronautics Research and Development Board of DRDO.

7. "Composite Material Applications in Aerospace", https://compositesuk.co.uk/system/files/documents/INSIGHT09-COMPOSITES.pdf. Accessed on December 15, 2021.
8. Global Aero Engine Composites Market Analysis & Outlook Report, 2020-2025. Key Players are GE Aviation, Safran, CFM International, Meggitt & Hexcel Corp November 14, 2019. https://www.globenewswire.com/news-release/2019/11/14/1947338/0/en/Global-Aeroengine-Composites-Market-Analysis-Outlook-Report-2020-2025-Key-Players-are-GE-Aviation-Safran-CFM-International-Meggitt-Hexcel-Corp.html. Accessed on December 17, 2021.

The thrust areas of research and core areas and scope have been put up on their website.[9] These are in the areas of aero engine structural materials and processes, special coatings like thermal barriers, advanced manufacturing process development for components, high temperature sensors, life prediction methodologies, modelling and simulation of materials and processes. This is a welcome move for aero engine development. A focussed and project management approach is needed, with accountability to ensure synergy with the design agencies and manufacturing entities to achieve the overall aim of having an *atmanirbhar* aero engine.

## OVERCOMING KEY MANUFACTURING CHALLENGES

The Defence Metallurgical Research Laboratory (DMRL) in Hyderabad has developed a titanium and nickel-based alloy that can withstand temperatures more than 1,000°C that can be used in the manufacture of High-Pressure Compressor (HPC) discs. To manufacture these discs, it has set up a near-isothermal forging technology using its unique 2000 MT (metric tonne) isothermal forge press.[10] These alloys are difficult to work with and not many nations have the capability to undertake the manufacture of such critical aero engine components. It is one of the manufacturing challenges that the DRDO has addressed. DMRL has now transferred this knowhow to MIDHANI (Mishra Dhatu Nigam Ltd) through a licensing agreement.

The International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), has developed powders suitable for the 3D printing technique using the inert gas atomiser, by melting unused scrap material. By utilising this Directed Energy Deposition (DED) process, it can significantly reduce the repair costs and overhaul time of an aero engine. ARCI is also developing a laser-DED process for Ni-based superalloy in the repair of aero

9. "Thrust Areas of Research (Specialist Panels) of Aeronautics Research & Development Board (ARDB)". https://www.drdo.gov.in/aeronautics-research-development/thrust-areas-research-specialist-panels). Accessed on December 17, 2021.
10. Ministry of Defence, "DRDO Develops Critical Near Isothermal Forging Technology for Aeroengines", PIB Delhi, May 28, 2021. https://pib.gov.in/PressReleasePage.aspx?PRID=1722418. Accessed on December 17, 2021.

engines. ARCI successfully created the technique for refurbishing helicopter pinion housing assemblies by cutting out the damaged layer and reconstructing it using the laser cladding method, followed by final machining. Whereas laser cladding and laser-DED are comparable techniques, laser cladding is used for two-dimensional deposition (surface coating), while laser-DED is used for the manufacture of three-dimensional parts.[11] These are welcome developments in special materials which now need to permeate into the manufacture and MRO of aero engines.

## AERO ENGINES DEVELOPMENTS

### *Kaveri*

The Light Combat Aircraft (LCA), as of now, are powered by the GE-F404 engines, whereas the next Mk-2, including the Advanced Medium Combat Aircraft (AMCA), will be fitted with the GE-F414. The Government of India intimated to the Parliament on November 29, 2021, that in the future, an indigenous aero engine, in collaboration with an international engine house, will be developed for the LCA variants and AMCA.[12] However, to ensure that these aircraft are developed independently of aero engines, they will first be fitted with the GE-F414 engines. The technology and expertise acquired in the development of the Kaveri engine will be gainfully utilised in this new endeavour.

The Kaveri project was sanctioned in 1989 and generated a total outflow of Rs 2,035.56 crore through the course of the project's 30 years. Nine prototype aero engines have been developed and have accumulated about 3,200 engine hours of operation on various test-beds. The Flying Test-Bed

11. Business Line, Indian Researchers Perfect Manufacture of Additive Used in Aircraft Engine Repair", Our Bureau, New Delhi, Updated on August 24, 2021. https://www.thehindubusinessline.com/news/science/indian-researchers-perfect-manufacture-of-additive-used-in-aircraft-engine-repair/article36080063.ece. Accessed on December 13, 2021.
12. Special Correspondent, "India to Develop Jet Engines for Aircraft", *The Hindu*, New Delhi, November 30, 2021. https://www.thehindu.com/news/national/india-to-develop-jet-engines-for-aircrafts/article37762645.ece. Accessed on December 13, 2021.

(FTB) trials have also been conducted on the IL-76 aircraft in Russia. The valuable experience, domain and technology validation has now given confidence to Indian designers for the next phase. How this plays out in the future is totally dependent on the commitment of the MoD. It is in the interest of the LCA/AMCA project that the aero engine project is not linked to the timelines. What are the options for the Kaveri core engine? It is being given to understand that it may find use in smaller aerial vehicles like the Remotely Piloted Aircraft (RPA), etc., and for validating other technologies being indigenously developed in the country.

**It is in the interest of the LCA/AMCA project that the aero engine project is not linked to the timelines.**

**LEAP (LEADING EDGE AVIATION PROPULSION)[13]**

LEAP is a high-bypass turbofan manufactured by CFM International. It has been manufactured in the 1A, 1B, 1C variants. The bigger LEAP-1A and LEAP-1C have a bypass ratio of 11:1, while the smaller LEAP-1B has a bypass ratio of 9:1. A higher bypass ration ensures greater propulsion efficiency, which also results in lower fuel consumption as well as harmful emissions. The latest technologies developed in-house have been utilised in their manufacture. The fan blades have been manufactured using a patented Safran technology of 3D-woven composite material and the RTM (Resin Transfer Moulding) process, resulting in lighter, stronger and more durable fan blades. Additionally, the low-pressure turbine blades are machined from an innovative titanium-aluminide alloy that is lighter and withstands higher temperatures. The low-pressure turbine rings and blades are using CMC materials, and the fuel injectors are 3D printed.

13. "LEAP-1A, a New Generation Engine for the A320neo Family". https://www.safran-group.com/products-services/leap-1a-new-generation-engine-single-aisle-commercial-jets?gclid=EAIaIQobChMIrLS7hZv-9AIVTpVLBR00Zw9gEAAYASAAEgK-KfD_BwE. Accessed on December 13, 2021.

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**PRATT & WHITNEY GTF ENGINES[14]**

The Geared Turbo Fan (GTF) has fundamentally altered the way more practical aviation engines operate. A carefully built gear box was incorporated into the shaft linking the low-pressure turbine and the low-pressure compressor's first stage fan, allowing the turbine and fan to spin at different speeds. The fans rotate at a speed nearly three times slower than the low-pressure turbine, eliminating the sonic pressure losses and resulting in 16 per cent reduction in fuel consumption and 75 per cent reduction in the acoustic footprint. With over 1,100 aircraft and over 11 million engine flight hours of service experience, these engines have proven to be the quietest, greenest, and most efficient family of engines for single-aisle aircraft. The GTF architecture represents a turning point in jet engine design and associated technology.

**ROLLS ROYCE ULTRA-FAN[15]**

The Ultra-Fan is a Rolls Royce design based on a three shaft geared-turbofan engine and a variable pitch fan system. The Power Gearbox Technology (PGB) of this engine is unique and very advanced. The PGB is the heart of the Ultra-Fan engine that has a planetary gear design. It enables the turbine at the engine's back to operate at high speeds, while the fan at the front operates at a lesser speed to maximise efficiency. The engine will be a new generation of Ultra-Fan engines capable of powering both narrow and wide-body airliner aircraft. Additionally, these engines will be more fuel efficient than the previous Trent engine series. Rolls Royce intends to test this engine using only 100 per cent sustainable fuel. The ALEC Sys lean

14. Pratt & Whitney, "GTF Sustainability Starts With the Gear". https://pwgtf.com/. Accessed on December 18, 2021.
15. "Rolls-Royce Reaches New Milestone as World's Largest Aero-Engine Build Starts", Press Release. https://www.rolls-royce.com/media/press-releases/2021/29-03-2021-rr-reaches-new-milestone-as-worlds-largest-aero-engine-build-starts.aspx. Accessed on December 18, 2021.

burn combustion system is central for ensuring the fuel burn efficiency and consequent low emissions.

The Ultra-Fan also incorporates the use of CMC in the fan blades, high pressure turbines, etc., and the additive manufacturing techniques in its various components. The 140-inch front fan blades are of a unique design; despite its huge size, the weight is considerably reduced to make the design viable. The Ultra-Fan is also part of Rolls-Royce's Intelligent Engine vision. The digital twin of the fan blades allows storage of real-time performance and engineering data for predictive performance and failure analysis.[16]

## HAL'S CRITICAL ROLE IN AERO ENGINES[17]

HAL began developing aero engines in the 1960s. A prototype engine, the HJE-2500 for the HJT-16, was developed and tested but this 11 kN engine was not mated with the trainer aircraft. However, a low rating turbojet engine (PTAE-7) of 4 kN thrust was developed and successfully fitted to the Pilotless Target Aircraft (PTA) used in aerial target practice. In the 1980s, HAL designed a few small gas turbines used for starting engines of various aircraft. This was the 110 kW turbo shaft engine (GTSU-110/127) for starting the LCA engine, the 60 kW starter generator engine for starting the AI-20D engine of the AN-32 aircraft, the air producer engine for starting the Adour-811, the 871 engines of the Jaguar and Hawk aircraft and the auxiliary power unit for the Fifth Generation Fighter Aircraft (FGFA) class aircraft.

HAL has assigned nearly Rs 1,000 crore from its internal funds for engine development. The Aero Engine Research and Design Centre (AERDC) is developing two engines: the HTFE-25 of 25 kN thrust that are envisaged to power trainer aircraft, Unmanned Aerial Vehicles (UAVs), twin-engine small fighter aircraft or regional jets, and the HTSE-1200 of shaft power rating

16. "Rolls-Royce begins Building Ultra Fan Aero-Engine Prototype", edited by Hannah Mason, Associate Editor, Composites World. https://www.compositesworld.com/news/rolls-royce-begins-building-ultrafan-aeroengine-prototype. Accessed on December 18, 2021.
17. Editor 2021, AEROMAG "Asia's Premier Aerospace & Defence Publication", HAL: Force Behind Indian Forces. http://www.aeromag.in/articlesingle.php?article=44. Accessed on December 18, 2021.

for the light and medium weight helicopters. Substantial progress has been reported by HAL on these engines with incorporation of some contemporary technologies in their fabrication.

HAL is also progressing on the development of special aero engine materials and associated processes. A significant development is the coating of single crystal blades using Enhanced Physical Vapour Deposition (EBPVD) established in collaboration with ARCI, Hyderabad. The HAL Agricultural Refinance and Development Corporation (ARDC) partnership has enlisted an ecosystem of approximately 70 enterprises to assist in the research and subsequent transition to production of the technologies being developed in this niche area.

The lack of testing facilities for the various engine components is an issue that must be addressed on priority. Limited facilities established for the Kaveri project at GTRE, research facilities at NAL and DRDO labs and the engine manufacturing facilities at HAL are being utilised. Specialist facilities like those for testing the compressors, HP turbines, etc., are sought from foreign-friendly establishments at exorbitant costs and with unfavourable restrictions. The Flying Test-Bed (FTB) and Altitude Test Benches facilities are crucial for the design and development of aero engines and the facilities in Russia are sought on a need basis. This must be a significant area of focus for becoming *atmanirbhar* in terms of aero engine R&D. The NATO Flying Training in Canada (NFTC), in collaboration with Aircraft and Systems Testing Establishment (ASTE) in Bangalore, might serve as a lead in creating the flying test-bed on any of the existing transport aircraft of the Indian Air Force (IAF). The aero testing facilities are being seriously considered for establishment as part of the projected Aero Engine Complex by the MoD as National Test Facilities.

## CO-CREATION VENTURES FOR AERO ENGINES IN INDIA

A well-known French defence business has entered into a joint venture with an Indian company to build a military aircraft engine under the Strategic Partnership (SP) model. The project is expected to be for the military helicopters that India plans to roll out in the next few years.[18] The SP model, mooted in December 2017, allows foreign companies to establish joint ventures with identified Indian firms to develop and manufacture combat platforms in the country. This is expected to boost the military manufacturing ecosystem and infuse the much-desired technology in the defence sector corporates.

**The IAF successfully blended SAF into the AI-20D aero engine of the AN-32 aircraft without compromising the performance of the aircraft in its operational envelope.**

Even Rolls Royce has shown keen interest in co-developing and manufacturing the aero engine for the AMCA in India. In an interview to *The Print*, Kishore Jayaraman, president of Rolls-Royce India and South Asia, said,[19] "(Our) Rolls-Royce keenness is on the co-creation concept. Because at the end of the day, when we co-create, we are generating IP and the IP is generated locally. When a product is designed in India, manufactured in India, you create your supply chain and you create the services concept. It creates a whole new ecosystem in the Indian aerospace sector." This is an interesting way forward for aero engine development in India.

## SUSTAINABLE AVIATION FUEL (SAF)

SAF is a biofuel made from a variety of organic wastes or bio plants that has the same molecular characteristics as fossil jet fuel. This fuel can be introduced in any quantity without requiring any modifications to an aviation engine's existing components. This blend may contain up to 50 per cent ethanol and is approved for use in all aeroplane engines. The IAF successfully blended SAF into the AI-20D aero engine of the AN-32 aircraft

18. "Leading French Firm set to Develop Engine for Military Platform in India", *Indian Express*, December 18, 2021. https://www.newindianexpress.com/nation/2021/dec/18/leading-french-firm-set-to-develop-engine-for-military-platform-in-india-2397073.html. Accessed on December 18, 2021.
19. Snehesh Alex Philip, "Rolls-Royce Ready to Co-develop, Manufacture Fighter Aircraft Engines in India", *The Print*, September 16, 2021. https://theprint.in/defence/rolls-royce-ready-to-co-develop-manufacture-fighter-aircraft-engines-in-india/734062/. Accessed on December 20, 2021.

**Even with a 10 per cent SAF blend, India benefits significantly from reduced air pollution, more effective waste disposal, and development of new jobs.**

without compromising the performance of the aircraft in its operational envelope.

Even with a 10 per cent SAF blend, India benefits significantly from reduced air pollution, more effective waste disposal, and development of new jobs. The move away from fossil fuels will not be dramatic or painless. The government's involvement in bringing all supply chain partners, suppliers, and the aviation sector together to sustain this transition is crucial.[20] For the aero engine designers, this aspect of SAF usability needs to be incorporated *ab initio* in the design process for optimisation.

## STRUCTURAL REFORM FOR AN *ATMANIRBHAR* AERO ENGINE[21]

The Indian aircraft manufacturing industry can be reinforced through methods like "competitive prototyping" and coupling the design bureaus with manufacturing entities. Thomas Edison's, "I have not failed. I have successfully discovered 10,000 ways to NOT make a light bulb" is an example of how "competitive prototyping" can enable the user to quickly eliminate ineffective approaches and focus on effective ones. China has promoted several design bureaus with integral manufacturing units to increase competition, just like the USA, in the aviation industry. This should be seen favourably for the design and manufacture of aero engines in India. This will expedite, account for, and maximise, the effectiveness of the search for the *atmanirbhar* aero engine.

Structural reforms can enable the Aeronautical Development Agency (ADA) an autonomous agency with the Gas Turbine Research Establishment

20. Christoph Wolff, Lauren Uppink and Sonum Gayatri Malhotra, "How India can Become a Leader in Sustainable Aviation Fuel", June 10, 2021. https://www.weforum.org/agenda/2021/06/how-india-can-become-a-leader-in-sustainable-aviation-fuel-saf-carbon-emissions-transportation-air-quality-pollution-covid/. Accessed on December 20, 2021.
21. Pratisht Chaudhry, "Road Map to Becoming an Aerial Superpower", *Vayu Aerospace & Defence Review*, Issue VI/2021. https://www.vayuaerospace.in/Issue/202112021706142318.pdf. Accessed on December 20, 2021.

(GTRE) to compete directly with HAL along with its Aeronautical Research and Design Centre (ARDC) and Engine Research and Design Centre (ERDC) in both the military aircraft and aero engine arenas. The private companies that are now assertive in the Indian aviation canvas, along with government support, could collaborate with these structured Defence Public Sector Undertakings (DPSUs) to attain essential skills for the complete development of aircraft and aero engines. The role of the Indian Institutes of Technology (IITs) and Indian Institutes of Science (IISc) will assume greater significance in implementing "competitive prototyping".

**The role of the government in aeronautical development is critical, as is adequate funding and long-term commitment to the trajectory of aero engine development in India. This will eventually lead the pace for private players to contribute their unique skill sets and funding.**

The role of the government in aeronautical development is critical, as is adequate funding and long-term commitment to the trajectory of aero engine development in India. This will eventually lead the pace for private players to contribute their unique skill sets and funding. Governments in the majority of aerial powers have earlier played a significant role in watching developments, providing funds and mediating in conflicts between development agencies and the forces.

## CONCLUSION

During the next 20 years or so, India is expected to operate more than 1,750 passenger and freight aircraft. This is a sizeable scale of the aero engine market in operation whose MRO is waiting to be exploited in the 'Make in India' domain. This is a market that needs to be aggressively exploited for ingress of design technologies from the Original Equipment Manufacturer (OEMs) into the aero engine manufacture. The Indian armed forces have the largest helicopter procurement programmes for 1,000 plus rotary wing aircraft, including attack, utility, multi-role and lift platforms. Similarly, these also include light transport aircraft, LCA versions, and AMCA, and these entail procurement of around 3,400 to 4,000 aero engines. HAL is the only credible Indian company with domain knowledge in aircraft engine maintenance and manufacturing, despite being only a licensed manufacturer. A joint venture of Rolls Royce with HAL called the International Aerospace Manufacturing Pvt Ltd. (IAMPL) is a good example of how the ecosystem has evolved in India. IAMPL is fully endorsed by Rolls Royce for its global supply chain and manufacturing facility. It is manufacturing more than 130 different aero engine components for the technologically advanced Trent family of civil aero engines. Such alliances ensure a solid portfolio of future-ready technologies, a dedication to sustainability, major R&D investments and proven commitment. The Indian defence policy now is fully committed to indigenisation, and designed and developed 'Make in India' systems. With this new norm in procurement by the Indian MoD, many foreign OEMs and companies are seeking newer ways of cooperation, collaboration, partnership and formulating newer strategies in global chains to remain relevant in the Indian defence market. A huge potential in India is just waiting to be tapped for the design of the *atmanirbhar* aero engine. The role of the government is crucial in terms of proper finance, effective structural reforms of various developmental and design entities, and long-term commitment to the trajectory of aero engine development in India.