

# Flying Testbeds Cannot Be Foreign Assets

## Building India's Flight-Science Infrastructure

***Srivatsa Ragi Venkatesh\****

*India's aero-engine development remains constrained by a systemic reliance on foreign flying testbeds, specifically Russia's IL-76LL aircraft. This study evaluates the technical and strategic risks associated with this dependency and proposes the conversion of an Indian Air Force (IAF) IL-76 into a sovereign, multi-role National Flying Laboratory. The research delineates a technical framework for this transition ranging from structural airframe reinforcement to the integration of advanced flight-test instrumentation required in the country. The article presents a phased inter-agency funding model to ensure fiscal viability. The study concludes that an indigenous flying testbed is a strategic prerequisite to de-risk development cycles for the Advanced Medium Combat Aircraft programme and safeguard proprietary performance data, and institutionalise a sustainable flight-experiment ecosystem.*

**Keywords:** *National Flight Lab; Technology Sovereignty; Testbed Conversion; Indigenous Engines; Military Aviation*

### INTRODUCTION

India's foray into indigenous jet engine development has been a story of ambition tempered by hard constraints. The Kaveri engine programme, led

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\* Mr Srivatsa Ragi Venkatesh is the founder of Reach Defence, a military media platform.

by the Defence Research Development Organisation's (DRDO) Gas Turbine Research Establishment (GTRE) lab, was sanctioned in 1989 as a clean-sheet turbofan for the Light Combat Aircraft, with a modest budget of Rs 382 crore and a projected 93-month timeline.<sup>1</sup> Over the years, Kaveri has made credible technical progress, achieving ground-based milestones and limited airborne validation aboard Russia's IL-76LL flying testbed. However, this dependency highlights a systemic structural void: the absence of a sovereign, domestically available flying laboratory. More than three decades since the programme's inception, the Kaveri experience points not to the limits of ground testing alone, but to the absence of a complete national aero-engine test ecosystem that connects design maturity, ground qualification and sovereign airborne validation.

The urgency of this requirement is underscored by the development timelines of India's next-generation aerial platforms, including the Advanced Medium Combat Aircraft (AMCA) and the Light Combat Aircraft (LCA) Mk2. Across their development blocks and future variants, India will need reliable domestic capacity to test and certify propulsion, avionics, sensors and mission systems. In the absence of such a flying laboratory, critical validation activity remains exposed to foreign schedules, priorities and access constraints.<sup>2</sup>

#### **RATIONALE: STRATEGIC NEED FOR AN INDIGENOUS FLYING TESTBED**

The Kaveri aero engine had no option but to undergo flight testing aboard a modified IL-76 LL at Russia's Gromov Flight Research Institute (GFRI) in 2010. Although these trials provided essential data that qualified the Kaveri as an airworthy flying engine, the arrangements inevitably involved costs, delays and uncertainties beyond our control.<sup>3</sup> Recent tests of the Kaveri derivative for high-altitude performance in Russia have progressed at a frustratingly slow pace, largely because Russia has prioritised its domestic programmes, such as testing the PD-8 engine for the Superjet airliner.<sup>4</sup> The cost of foreign flight testing is not limited to the price of a test slot. It also includes engine transport, integration support, specialist travel, schedule dependence, foreign-exchange exposure, telemetry and data-handling constraints, and the opportunity cost of waiting for a foreign facility to become available. Publicly available material does not establish a complete record of every delay or denial associated with Russian test access; therefore, the issue is best framed as one of structural dependence rather than as a claim of documented denial in every instance. The Kaveri programme nevertheless shows the programme-level effect of this

gap: lack of domestic infrastructure, manufacturing, and test facilities was among the reasons officially cited for delay, and the engine ultimately did not achieve the required thrust to power the LCA. A domestic flying testbed would not by itself solve design shortfalls, but it would reduce the schedule and access risks associated with validating mature engines abroad. The situation has further deteriorated due to disruptions caused by the ongoing conflict in Ukraine, complicating our efforts even more. This dependency severely limits India's autonomy in aerospace research and further stretches already tight development timelines.<sup>5</sup>

India's military and industrial infrastructure already possesses the essential organisational backbone and skilled manpower to establish a domestic flying testbed. On the Indian Air Force side, the Aircraft Systems Testing Establishment (ASTE) is ready to handle systems and engine integration, all the way up to test flying, supported by experienced test pilots familiar with transport aircraft and Airborne Warning and Control System (AWACS) platforms. Meanwhile, GTRE, as the R&D lead, along with industry partners, would oversee engine adaptation, fine-tuning and testing aboard an IL-76.

At the same time, an IL-76 conversion should also be assessed against possible Airbus-family alternatives, including A321/A330-class aircraft where applicable. The Airbus route may offer advantages in avionics modernity, global support ecosystem, fuel efficiency and long-term maintainability. It may also align with India's ongoing experience of acquiring pre-owned Airbus A-321 aircraft for AEW&C-related roles. However, for an aero-engine flying testbed, the IL-76 retains important advantages: a four-engine layout suitable for replacing or carrying an experimental engine while retaining redundancy, long Indian operating experience with the type, existing military maintenance familiarity, and direct precedent from the Russian IL-76LL model. A final platform choice should therefore compare IL-76, Airbus-family, and other candidate aircraft against pylon integration feasibility, redundancy, certification risk, lifecycle support, modification cost and expected utilisation.

Beyond programme-specific needs, the case for an indigenous flying testbed aligns directly with broader strategic capability gaps identified at the national level. The establishment of an Indian flying testbed directly addresses one of three strategic gaps highlighted by the DRDO leadership, who emphasise that the development of aero-engines requires critical domestic facilities that are currently not available to us, specifically:

1. High-Altitude Flying Test Facility
2. Flying Test Bed
3. Ground Test Engine Facility for 110-130 kN Thrust Class

Within this context, the utilisation of an existing transport platform emerges as both practical and strategically sound. The IL-76 fleet is a strategic asset to the IAF, but a considerably large one. Dedicating one airframe to testing, especially an older airframe or one due for rotation out of frontline service, would demonstrate the IAF's commitment to indigenisation. This civil–military fusion in a flying lab environment will strengthen the overall aerospace ecosystem in India.

### TECHNICAL AND STRUCTURAL REQUIREMENTS FOR IL-76 CONVERSION

Converting an IL-76 into a flying testbed (FTB) is a complex but technically viable engineering objective. The airframe's four-engine configuration, high payload capacity, and significant onboard power make it ideal for experimental flight testing. A four-engine platform allows a test article to replace a standard engine while the remaining three provide the safety redundancy required for experimental envelopes. This profile aligns with global standards, such as the Russian IL-76LL and the Boeing 747 platforms utilised by Pratt & Whitney and Rolls-Royce. One of the IL-76's outboard engine pylons can be modified to carry the test engine in place of its standard D-30 turbofan. In the Kaveri tests at Gromov Institute, one of the aircraft's four engines was replaced with the Kaveri engine, requiring an extensive airframe modification.

The mounting point must be reinforced to handle new loads, thrust variations, weight and vibration offsets, and possibly redesigned with modular adapters to support different engine sizes.

Beyond the physical mounting, systems integration is critical. The test engine must interface with the IL-76's fuel supply, electrical power and control systems. New piping and wiring will be required to route fuel to the pylon and to connect the engine's electronic control unit. GTRE has already tested and validated the Advanced FADEC (Full Authority Digital Engine Control) system, which comprises an engine-mounted Digital Electronic Control Unit (DECU) with embedded control laws, engine fuel metering units, hydraulic actuation systems, engine sensors, and more.

During the case of the GRFI-owned Russian IL-76 LL testbed, the Kaveri's mechanical, electrical and fuel systems were adapted into the host aircraft, and the engine's operation was managed from the cockpit. We could mirror this by installing a dedicated engine throttle lever or console for the test engine, along with emergency shut-off and fire suppression tied into the

IL-76's systems. In practice, the IL-76 will carry an extensive array of sensors on the test engine, measuring pressures, temperatures, vibrations, strains, fuel flows, etc.

A high-channel-count data acquisition system should be installed to record this data. Modern testbeds like General Electric's Boeing 747-400 (N747GF) have on-board systems with hundreds of channels for steady-state and dynamic measurements, plus cameras and telemetry.<sup>6</sup> The IL-76's spacious airframe allows room to install racks of data acquisition computers, telemetry transmitters, and even a dedicated station for test engineers to monitor real-time parameters in flight.

Power supply and cooling are also important considerations. A test engine may need its start-up power from the aircraft's auxiliary power unit or cross-bleed air supply, and might draw significant electrical power for its control systems, instrumentation, ignition systems, and onboard monitoring equipment. The IL-76's generator capacity must therefore be checked, with an additional generator, power-conditioning equipment, or isolated wiring added if required.

Lastly, the conversion would include setting up a flight test instrumentation (FTI) suite across the aircraft, air data booms, additional accelerometers and strain gauges on the wings and pylon (to measure the dynamic effect of the test engine), and possibly optical instruments (cameras) to observe the engine (for example, a high-speed camera trained on the engine exhaust or fan face to detect anomalies like flameouts). The Indian testbed should incorporate these best practices from day-1 for maximum mileage. All this additional hardware can be integrated without impeding the basic flying qualities of the IL-76. Overall, while the structural and system modifications are extensive, they are within the capabilities of modern Indian aerospace engineering.

### LESSONS FROM PAST INDIAN EFFORTS AND HISTORICAL CONTEXT

India, so far, has had to piggyback on foreign platforms to acquire critical flight-test capabilities. The GTRE Kaveri turbojet programme stands as both a cautionary tale and a valuable learning experience in this regard. Lacking an indigenous flying testbed, GTRE was compelled to rely on Russia's Gromov Flight Research Institute (GFRI) for in-flight testing of the engine. With over 27 flights (57 hours), the IL-76 LL testbed carried the Kaveri to altitudes up to approximately 6 km and speeds of Mach 0.6.<sup>7</sup> These trials demonstrated that the engine could be started, operated and controlled in flight. However,

the programme's known limitations in thrust, weight and maturity had already constrained its suitability for Tejas integration. The value of the flight campaign lay less in discovering these baseline shortfalls and more in generating real-flight data, operational experience, and tacit knowledge for future aero-engine development. Although the Kaveri did not ultimately meet all objectives required to power the Tejas, the flight test campaign itself was far from a failure. Notably, this achievement came despite the absence of a domestic flying testbed. However, it was enabled only through complex logistics involving the transfer of engines and personnel to Russia and tight coordination around limited test windows at GFRI, an undertaking that deserves recognition in its own right.

The Kaveri Derivative Engine (KDE), intended to power the Ghatak Unmanned Combat Aerial Vehicle (UCAV), continues to face the same structural constraints that hindered its predecessor. Although the engine has now been cleared for flight testing, it once again remains dependent on Russia's IL-76 LL flying testbed for airborne validation.

However, using the Russian platform, while helpful, comes with inherent delays and constraints, as Russia's test fleet remained busy with its own PD-8 and other engine test schedule.<sup>8</sup> Furthermore, there are cost implications each time. India effectively 'leases' the testbed time. In addition to costs, there is limited flexibility to extend or modify test plans on the fly, since the asset is not under our full control.<sup>9</sup>

It is worth noting that India has attempted to fly test-bed aircraft in the past. In the 1990s, the DRDO's Airborne Surveillance Platform (ASP) project (Project 'Airawat') fitted a Hawker HS-748 turboprop aircraft with a rotodome-mounted surveillance radar to develop an indigenous AWACS capability. Two prototype aircraft were flown for several years to validate the radar concept, essentially serving as sensor testbeds. Unfortunately, a tragic crash in 1999 of one HS-748 testbed halted things in their tracks.<sup>10</sup> Nonetheless, that experience demonstrated DRDO's ability to integrate and flight-test a complex sensor suite on a surrogate aircraft. More recently, in the post-2010 era, for the indigenous AEW&C system (Netra), DRDO conducted extensive flight trials of its radar and mission system on modified Embraer EMB-145 jets.<sup>11</sup>

These examples underscore a consistent theme: when India invests in a dedicated test platform, whether for engines or sensors, it reaps significant R&D benefits, but the lack of a permanent, owned platform makes each effort ad hoc and dependent on available resources or foreign help.

The lesson from past efforts is clear. India has the technical competence to conduct advanced flight testing, but lacks a permanently available test aircraft and supporting infrastructure. This has forced repeated reliance on ad hoc arrangements or foreign platforms, resulting in inefficiency and loss of continuity. Establishing an IL-76 flying testbed would institutionalise this capability and provide a consistent national platform for future programmes.

### KEY CHALLENGES AND CONSIDERATIONS

Implementing an IL-76 flying testbed is a complex endeavour that will encounter several challenges. Policymakers must anticipate these and plan mitigation strategies. Here are some details on the main categories of challenges, technical and regulatory, and discuss how to address them:

#### **Technical Complexity and Engineering Challenges**

Modifying a large transport aircraft such as the IL-76 for experimental flight testing is an inherently demanding engineering task that requires conservative design assumptions and phased validation. The airframe was not originally intended to host non-standard engines, experimental payloads, or modern avionics, and their integration can significantly alter structural loads, vibration behaviour, thrust symmetry, and electrical demand profiles. These changes introduce elevated risks across airframe integrity, handling qualities, and onboard systems compatibility.

The IL-76's control systems for example, lack modern fly-by-wire auto-compensation, so this relies on pilot skill and possibly minor aerodynamic tweaks.<sup>12</sup> Systems integration presents an additional layer of complexity. The testbed must accommodate engines or sensors whose electrical and control requirements may differ significantly from the host aircraft. Compatibility of electrical power (different voltages/frequencies), data protocols, etc., can be an issue. For example, if the test engine's electronics require 115 V AC at 400 Hz, they can be powered from the IL-76's main or APU generator, which supplies 200/115 V AC at 400 Hz.<sup>13</sup>

However, if the engine uses electric starting, integration becomes complex. The IL-76 relies on pneumatic starters, while the Kaveri and its future variant engines could use an electric starter-generator that draws high-current DC power. Supporting this would require a dedicated onboard system or ground power unit, along with interface adjustments for safe start-up and control. The Russian campaign is useful here as a practical precedent. The original Kaveri did not go straight from bench testing to flight. It moved

through ground runs, altitude-condition testing, integration checks, and then clearance for a defined Flying Test Bed envelope. Once integrated with the IL-76 at Gromov, it completed 27 flights and 57 hours of airborne testing, proving that the engine could be started, operated, monitored and shut down safely in flight. The same phased logic applies to the dry Kaveri derivative. Its interrupted high-altitude validation cycle has now been reported as completed, and the next step is Flying Test Bed evaluation once the required integration and flight-clearance gates are met. This is precisely why the electrical-start, power-interface and control-integration questions matter: the issue is not whether a Kaveri-class engine can be flown on an IL-76, as that precedent already exists, but whether India should continue depending on a foreign airframe, foreign integration team, and foreign test schedule for each successive engine variant.

Perhaps the most unpredictable challenge is the behaviour of the prototype engine or system itself. These are, by definition, not fully proven. An engine could suffer flameout, a turbine failure, or other malfunction while airborne. Mitigation with extensive ground testing is the first defence, only taking airborne those units that have passed rigorous bench tests.

Even then, the testbed must include safety features to handle emergencies around the test engine. While the IL-76 already has a fire suppression system for its engine bays and APU using Freon-based extinguishers, this set-up may need to be extended to cover the new test engine area. Quick shut-off valves should be added to the test engine's fuel line to stop fuel flow instantly in case of fire. The aircraft also uses a neutral gas system to reduce the risk of fuel tank explosions, which should be checked for compatibility if the test set-up alters fuel or airflow paths.

The test team should have clear contingency plans in case the test engine behaves unexpectedly, cut it off and land if telemetry shows an anomaly, terminate the test point, etc. This disciplined approach is standard in flight test programmes.

### **Regulatory and Administrative Challenges**

Even though this is a military programme, there are still regulatory hoops. Centre for Military Airworthiness & Certification (CEMILAC), as discussed, will have to certify both the modified aircraft and each test plan.<sup>14</sup> This inevitably introduces iterative review cycles that can influence configuration decisions, safety margins and test sequencing. Early institutional alignment is therefore essential to prevent downstream delays. Establishing a joint working arrangement with CEMILAC and The Directorate General of Aeronautical

Quality Assurance (DGAQA) participation from the outset would help integrate certification requirements into the design and planning phase, rather than treating them as post-hoc approvals. Where foreign technical assistance is involved, additional administrative care is required to manage export controls and protect sensitive data, necessitating clear contractual boundaries and strict compartmentalisation of responsibilities.

The governance model should also define how approved private-sector entities in India can access the flying testbed. As India's aerospace ecosystem expands beyond DRDO and Defence Public Sector Undertakings (DPSUs), a national flying laboratory should not become a closed single-agency asset. Access can be structured through booked test campaigns, technical-readiness gates similar or aligned to the National Technology Readiness Assessment Framework (NTRAF) assessment, CEMILAC-supervised safety reviews, data-protection agreements, export-control screening and cost-sharing rules. Private engine or sub-system developers should be allowed to use the facility only after completing prescribed ground-test, safety and documentation requirements. This would convert the aircraft from a project-specific platform into a national flight-test service while preserving airworthiness discipline and security control.

### **Public Perception and Continuity Challenges**

The viability of a flying testbed programme depends not only on technical execution but also on sustained institutional and political support. Early test campaigns will inevitably surface engine or system shortcomings, and these outcomes must be communicated as the purpose of flight testing rather than interpreted as programme failures. Managing expectations is therefore critical. Stakeholders should be prepared for engine shutdowns or aborted tests as normal elements of envelope expansion, far preferable to failures on operational aircraft. Transparent milestone-based communication can help maintain confidence. For instance, publishing that 'This flight test covered 6 km altitude and a speed of 0.6 Mach in its maiden test flight' helps to build confidence and patience.<sup>15</sup>

### **Project Management—The Silent Challenge in the Indian Defence Landscape**

The IL-76 testbed programme spans multiple stakeholders, including the IAF, DRDO, HAL, and industry partners, making governance and ownership clarity critical. Fundamental questions around aircraft ownership, pilot allocation and long-term operational responsibility must be resolved

early, as ambiguity here can stall execution. These are not procedural details but structural decisions that directly affect availability, accountability and programme continuity. The IL-76 testbed programme should not be governed through diffuse shared control. A programme of this nature requires one accountable lead entity with authority over development, configuration control, budgeting, scheduling, airworthiness coordination, safety accountability, utilisation planning and long-term operation. A useful Indian precedent is the National Flight Test Centre (NFTC), which brought flight-test discipline, programme coordination, test pilots, engineers, and certification interfaces into a defined structure for the Tejas programme.<sup>16</sup> The proposed IL-76 flying testbed could draw from this model, but with one important refinement: support roles must not dilute accountability. Under such a model, the IAF may provide the airframe, aircrew, basing and operating discipline; DRDO and GTRE may provide the technical test objectives, instrumentation, engine-interface design and data-analysis backbone; HAL and other industry partners may support modification and lifecycle sustainment; and CEMILAC and DGAQA should be integrated early for airworthiness and quality-assurance oversight. These roles may be formalised through a memorandum of understanding, but ownership of scheduling, configuration control, budget execution, safety responsibility, utilisation planning and long-term operation should remain with a single empowered flight-test authority. This same authority should also own the finance-facing business case, so that the testbed is justified through booked programme demand and measurable utilisation, rather than strategic intent alone. With disciplined systems engineering, phased funding and early coordination, the testbed can be executed as a long-term strategic capability rather than an ad hoc project.

### **Platform Under Utilisation Risk**

The case for a flying testbed is not without risks. A converted IL-76 would impose capital expenditure, annual operating cost, airframe opportunity cost, modification risk, certification burden and long-term sustainment obligations. The platform may also be underutilised if India's engine-development pipeline does not generate enough mature test articles. Further, some test objectives may be better served by upgraded ground facilities, altitude test cells, or engine test houses. These trade-offs do not negate the need for a flying testbed, but they make utilisation planning central to the proposal. The aircraft should be sanctioned only as part of a wider national

aero-engine test ecosystem, with committed users, booked test campaigns, multi-year funding and a clear governance model.

### **Ground Testing, Simulation and Airborne Validation**

A flying testbed should not be viewed as a substitute for ground infrastructure. Modern ground-test facilities, altitude test cells, component rigs, endurance runs, hardware-in-loop systems and computational modelling can replicate several critical conditions, including pressure, temperature, inlet flow, fuel-control behaviour, thermal loads and defined altitude envelopes. These facilities remain the first line of validation and must mature an engine before it is taken into flight. The limitation is that ground testing cannot fully reproduce the integrated behaviour of an engine installed on an aircraft. Real flight introduces pylon loads, vibration, inlet distortion, aircraft manoeuvre effects, relight behaviour, installation-specific thermal interactions, control-response dynamics, emergency procedures and pilot-test-team decision-making inside a live envelope. Thus, the question is not whether India should choose between ground testing and airborne testing. It requires both. Ground infrastructure matures the engine; a flying testbed validates it under controlled real-flight conditions before operational aircraft integration.

## **INTERNATIONAL CASE STUDIES AND BEST PRACTICES**

India would not be alone in operating a flying testbed, globally, several major aerospace players maintain dedicated test aircraft for engines and systems. These case studies provide proof of concept and valuable design philosophies that India can emulate:

### **Russian Federation (Gromov Flight Research Institute, Zhukovsky)**

Russia's Gromov Flight Research Institute (GFRI) operates one of the world's most mature flying laboratory ecosystems, with the IL-76LL (Letayuschchaya Laboratoriya) serving as the backbone of Soviet and post-Soviet engine development. The Aviadvigatel PD-14 turbofan (for the Irkut MC-21 airliner) was tested on an IL-76 LL, as is the newer PD-8 engine.<sup>17</sup> The same platform was leased by India for Kaveri flight trials, underscoring both its versatility and the institutional depth behind its operation. GFRI's experience highlights two enduring lessons. First, flight testing is treated as the final step in a long maturation chain, with extensive ground runs, taxi trials, and conservative envelope expansion underpinning safety. Second, the value of a standing flight-test institution is evident in Russia's ability to conduct parallel

engine programmes without reconstituting teams or infrastructure each time. While Russia has historically used other surrogate platforms, Russia has also historically used other platforms, e.g., a Tu-16 bomber was once used as a testbed, and a Tu-134 was fitted out to test the Soviet AWACS radar, but the IL-76 LL remains the prime example relevant to India's IL-76 plan.<sup>18</sup>

### **United States (USAF/NASA and Industry)**

The United States relies primarily on industry-led flying testbeds for propulsion development, with General Electric (GE) operating one of the most advanced examples through its Boeing 747-400 flying laboratory (N747GF). The GE test programme for the GE9X, for example, involved 72 flights and 400 hours on the 747.<sup>19</sup> GE's model underscores the value of a permanently instrumented aircraft capable of long-duration test sorties with extensive telemetry and onboard diagnostics. A full engineering team flies aboard to monitor the engine in real-time.<sup>20</sup>

Pratt & Whitney (P&W), similarly, has used a Boeing 747SP as a testbed (e.g., to test the PW1100G Geared Turbofan).<sup>21</sup> During flight trials, which can last up to eight hours, flight test engineers monitor and measure thousands of engine and aircraft parameters in real time as the aircraft flies long triangular routes at cruising altitude. Since 2001, Pratt & Whitney's testbeds have logged over 1,400 ground and flight test-cycles across more than 71 engine configurations.<sup>22</sup>

Beyond engines, the US experience also highlights the use of surrogate aircraft for avionics and sensor validation. A prominent example is the USAF-industry Cooperative Avionics Test Bed (CATBird), a heavily modified Boeing 737 used during the F-35 development programme. The CATBird was fitted out with the entire suite of F-35 sensors and mission systems inside a Boeing 737, including a nose-mounted APG-81 AESA radar, to test and validate the fighter's systems in the air without endangering a prototype during the intensive testing phases.<sup>23</sup>

### **United Kingdom (Rolls-Royce)**

Rolls-Royce has used a 747-200 for many years, but in 2019, it set out to acquire an ex-Qantas 747-400 (VH-OJU) to be converted into an even more advanced flying digital hub testbed. The plan was to invest US\$ 70 million for the acquisition and conversion of this aircraft, including high-end instrumentation upgrades.<sup>24</sup> This indicates the scale of investment considered worthwhile for a cutting-edge testbed. The project was later shelved due to the pandemic downturn, with Rolls opting to continue

with the older 747-200 testbed and Rolls-Royce opening Testbed-80, their premier engine test facility.<sup>25</sup>

This scale of investment underscores how industry values airborne testing as a core R&D enabler rather than an auxiliary capability. Although the new flying testbed did not materialise, the initiative highlighted two enduring lessons. First, modern flying laboratories are increasingly conceived as airborne data centres, capable of generating vast datasets for real-time analytics and design feedback, an approach directly relevant to an IL-76-based Indian testbed. Second, global experience shows that testbed value lies less in platform novelty than in availability, instrumentation and institutional continuity. Mature airframes, if well maintained and appropriately modified, remain effective risk-reduction tools that accelerate innovation and shorten development cycles.

#### **France (DGA Essais en vol, EPNER, and the Istres Flight Test Ecosystem)**

France offers a slightly different but highly relevant model. Rather than centring everything on a single publicly prominent engine flying testbed, it has sustained a state-industry flight-test ecosystem anchored at Istres.<sup>26</sup> DGA Essais en vol is responsible for military aircraft and aeronautical-weapon qualification and also contributes to civil certification work, while EPNER institutionalises the training pipeline for test crews within the same flight-test culture. At Istres, Safran states that its Military Engine Division supports flight-test operations by Dassault Aviation and the French defence procurement agency's Flight Test Center. The lesson for India is that sovereign airborne validation is strongest when it sits inside a wider ecosystem of flight-test governance, crew training, certification discipline and industry participation. France therefore demonstrates that the decisive national advantage is not ownership of a single modified aircraft alone, but the permanent integration of operators, certifiers, engineers and test pilots around a standing flight-test institution.

#### **China (The Chinese Flight Test Establishment and Indigenous Engine Maturation)**

China's experience is relevant because it shows how a rising aero-engine power has used flying demonstrators and airborne validation as part of a broader state-backed propulsion strategy, not as a substitute for industrial depth. Public reporting points to two useful examples. The J-10B TVC demonstrator, based on a modified Chengdu J-10B and shown publicly with

a thrust-vectoring WS-10-series engine, illustrates the use of an operational fighter platform to validate propulsion-control and manoeuvrability technologies.<sup>27</sup> Separately, reporting on the CJ-1000A indicates that China has used a Y-20 test aircraft to begin flight testing of its indigenous commercial turbofan.<sup>28</sup> The key lesson is one of sequencing. China did not wait for perfect propulsion maturity before investing in airborne validation capacity, but neither did it treat flying demonstrators as a remedy for design immaturity. Instead, airborne validation appears embedded within a larger ecosystem spanning engine institutes, flight-test organisations, production programmes and progressive platform integration. For India, the implication is clear: if a sovereign IL-76 testbed is pursued, it should be tied from the outset to a sustained engine pipeline and national test ecosystem, rather than justified as a one-off project.

### COMPARATIVE VIEW: MAJOR ENGINE MANUFACTURE ECOSYSTEM

A comparative view of major aero-engine ecosystems shows that airborne testbeds are normally embedded within a larger engine-development chain. The United States, Russia, the United Kingdom, France and China have all used flying laboratories or surrogate aircraft to support propulsion or mission-system maturation, but none treats airborne testing as a substitute for ground-test cells, altitude facilities, endurance testing, component rigs, or certification discipline. The common pattern is that flight testbeds become valuable when they connect mature ground-tested engines to real installation effects, envelope expansion and operational clearance.

**Table I** International Flying Testbed Ecosystems and Operating Models

| Ecosystem      | Lead institution                                               | Host Platforms                          | Operating model                                                                   |
|----------------|----------------------------------------------------------------|-----------------------------------------|-----------------------------------------------------------------------------------|
| Russia         | Gromov Flight Research Institute / state flight-test ecosystem | IL-76LL, Tu-154 BM, Su-30, IL-103, Mi-8 | State-run standing test institution used across multiple propulsion programmes    |
| United States  | Industry-led, supported by NASA / USAF test institutions       | Boeing 747                              | Clear owner-operator model with strong instrumentation and programme-linked use   |
| United Kingdom | Rolls-Royce-led industrial model                               | Boeing 747                              | Company-owned testbed supporting proprietary engine development and certification |

|        |                                                                 |                                                     |                                                                                                               |
|--------|-----------------------------------------------------------------|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| France | DGA Essais en vol, EPNER, Safran / Dassault ecosystem at Istres | Fokker 100 ABE-NG, Mirage-2000, Rafale, nEUROn UCAV | State-industry model combining flight-test governance, test crew training, certification and industry support |
| China  | CFTE / AVIC / state-backed engine institutes                    | J-10B, Y-20, CJ-1000A                               | State-backed propulsion maturation through flying demonstrators and platform-specific trials                  |

Source: Author's compilation from public and annotated sources.

**Table 2** Comparative Lessons for India's Flying Testbed Proposal

| Ecosystem      | Role of airborne testing                                                                       | Relationship to ground infrastructure                                                  | Main lesson for India                                                                          |
|----------------|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| Russia         | Mature engine flight validation, including PD-14 and PD-8-class programmes                     | Airborne testing follows bench, altitude and systems testing                           | A standing institute preserves expertise, continuity and scheduling discipline                 |
| United States  | Engine certification support, propulsion risk reduction and selected mission-system trials     | Strong simulation and ground infrastructure remain foundational                        | Ownership clarity and instrumentation matter more than platform novelty                        |
| United Kingdom | Airborne validation after extensive ground testing                                             | Flight testing adds operational data to mature ground-test chains                      | Sovereign industrial testbeds protect data and accelerate design feedback                      |
| France         | Flight-test governance, certification discipline, trained crews and industry-supported trials  | Permanent flight-test culture connects operators, certifiers and manufacturers         | The national asset is the institution, not only the modified aircraft                          |
| China          | Propulsion-control demonstration and engine flight validation within a wider catch-up strategy | Airborne validation follows ground development and is tied to platform-specific trials | A flying testbed works best when backed by sustained state support and long-term engine demand |

Source: Author's compilation from publicly available sources.

## IMAGINING THE FUTURE: SCENARIOS AND BENEFITS

This section outlines realistic scenarios and the expected benefits in each case, illustrating the transformative impact such a platform could have on India's aerospace development timeline.

### **Scenario 1: Accelerating a Kaveri 2.0 Fighter Engine Development Program**

- a. In a later development phase, once a suitable 110 kN-class turbofan demonstrator has matured through ground testing, an IL-76 flying testbed could allow India to begin controlled airborne evaluation before committing the engine to a prototype combat aircraft. With an IL-76 testbed available, the engine can be mounted and flown at incremental power settings while AMCA prototypes are still on the ground. The testbed conducts a series of flights expanding the engine's envelope, starting with low-altitude, low-speed runs and progressing to transonic speeds at altitudes of around 40,000 feet.
- b. Engineers gather performance data (thrust, fuel consumption, compressor stability margins) in actual flight conditions, which feeds back into design tweaks. They could also deliberately induce stress tests, throttle slams, windmill restarts, and even shut the engine off in mid-air to test relight capability. All the while, the IL-76's other three engines keep the flight safe in case the new engine hiccups.
- c. Over a phased campaign of multiple flights, the engine's behaviour can be studied across progressively harder test points rather than being exposed to the full combat-aircraft envelope at once. Issues such as compressor surge tendency at a particular altitude, unstable fuel-control behaviour, thermal stress during high-power climbs, relight difficulty, vibration response, or installation-related airflow effects can be identified before integration with the AMCA prototype. These findings may then feed into control-law changes, hardware refinements, operating-limit definitions, or further ground-test cycles before the engine is cleared for the next phase.
- d. In this sense, the flying testbed allows a future Kaveri Aero 2.0 or AMCA-class high-thrust fighter-engine effort to proceed alongside aircraft development, rather than waiting for the combat-aircraft prototype stage to absorb propulsion risk. Its purpose is not to declare an engine fully proven merely because it has flown on a testbed, but to retire a meaningful

portion of integration, control, relight, thermal, vibration and envelope-expansion risk before installation on a prototype fighter. This can shorten learning cycles, reduce the likelihood of discovering major propulsion behaviour issues late in the aircraft programme, preserve Indian control over obtained flight-test data, and ultimately reduce dependency on foreign flying-testbed availability at critical validation stages.

### **Scenario 2: Validation of a Kaveri Derivative for UCAVs**

- a. For a future unmanned combat aerial vehicle or related medium-thrust unmanned platform, a Kaveri derivative would eventually need to move from ground and high-altitude validation to controlled airborne testing. At that stage, the IL-76 testbed could be fitted with the engine and used to expand the test envelope under conservative flight conditions. Because the test engine's thrust class and operating envelope may differ from the IL-76's standard engines, the flight profile would need to be planned conservatively, with the experimental engine brought through defined test points only after safe altitude, configuration and redundancy margins are established. The testbed might take off using its three standard engines plus partial thrust from the new engine, then the new engine is throttled up to test points once at altitude.
- b. The campaign might include long-endurance runs (to test reliability, e.g., a 3-hour continuous operation at cruise), high-power climbs (to see how the engine handles thermal stresses), and engine air-starts (shutting down and re-starting at high altitude to simulate a UAV engine flameout recovery).
- c. Over multiple flights, the new engine's fuel control is fine-tuned based on real atmospheric behaviour, and its lubrication system can be observed under representative flight attitudes, acceleration changes and manoeuvre conditions that ground testing may not fully reproduce. By the end of such trials, the engine would not be rendered fail-proof, but it would have a better-characterised operating envelope, clearer failure-mode data, and a stronger basis for certification and integration decisions. Also, any minor redesigns (say, a better oil pump needed for high-altitude lubrication) can be implemented before going into production. The overall timeline to field this engine is tightened, and the risk of costly failures in deployed UAVs is reduced. For the IAF, this means indigenous UAVs can be powered by indigenous engines sooner, enhancing self-reliance in propulsion for drones as well.

### **Scenario 3: Testing a New Radar or Sensor Suite**

- a. Traditionally, this role has been carried out by the Indian test aircraft 'Virupaksha', but for the scenario-led analysis, we will lay this out clearly. For radar and sensor systems, the role of a surrogate flying laboratory must be more limited than in aero-engine testing. A modified transport platform can support early mission-system integration, algorithm validation, data-link trials, and operator-console development, but it cannot substitute for qualification on the intended operational aircraft. Final radar and sensor performance must be assessed on the actual platform because installation geometry, electromagnetic environment, vibration, cooling, and field-of-view constraints are platform-specific. For example, a prototype AWACS radar array (which might be a rotodome or a fixed array) could be installed on the fuselage of the IL-76.
- b. The testbed, fitted out with the radar's signal processors and mission system consoles in the cabin, then flies representative operational patterns, orbiting over a test range to detect fighter aircraft or track vehicles on the ground. During these flights, sensor performance is evaluated: detection range, tracking stability, multi-target capacity, and resilience to jamming (perhaps another IAF aircraft acts as a 'red-team' jammer).
- c. Such trials would be useful only for early integration and data-generation purposes. Accurate final assessment of sensor performance, field of regard, vibration effects, cooling behaviour, electromagnetic compatibility, and operator employment must occur on the relevant operational platform.
- d. The sensor developers get early feedback under real flight conditions, e.g., how the radar's beam behaves with platform vibrations, or how the IR sensor's image quality is affected by the aircraft's heat and altitude.

### **Scenario 4: Ongoing Refinements and Upgrades**

- a. The utility of a flying testbed doesn't end with testing brand-new systems, it can be used to continuously improve existing ones. Suppose the indigenous AMCA engine is in service by 2035, but an upgrade is envisioned with better fuel efficiency or higher thrust. Rather than pulling operational fighters out of service for experimental engines, the upgrade can be tested on the IL-76 first. The same goes for iterative improvements in radars (new software modes, for instance) or integration of new weapons/sensors (like a new kind of air-launched drone interface that needs an airborne trial).
- b. The FTB became a standing 'flying laboratory' for the IAF and DRDO. It can take on projects like testing an advanced electronic warfare suite by

installing it in the testbed and simulating combat scenarios, or running trials with a high-speed data link by linking the testbed with ground stations and fighters during flight. This continuous use will help *future-proof* India's aerospace development. We will always have a means to test in the air any critical technology that comes along.

Across all these scenarios, certain common benefits emerge.

- *Risk Reduction:* By the time an engine or sensor reaches an operational platform, a meaningful portion of integration and operating-envelope risk can be retired earlier on the testbed. This increases safety (no unproven engine on a single-engine fighter, for example) and avoids costly retrofits after induction.
- *Time Savings:* Parallel development and testing can take years off programme schedules, as highlighted. This is crucial given the rapid advancements and the IAF's needs, delays of years can mean obsolescence or capability gaps.
- *Cost Savings in the Long Run:* While building a testbed is expensive, each day of testing on it can prevent failures that might cost far more (in accident losses or in having to redesign something post-deployment). Also, using one testbed for multiple projects is more economical than each project arranging its own separate flight trials infrastructure.
- *Human Resource Development:* Operating the testbed will train a cadre of Indian test pilots, flight test engineers, and scientists in the niche art of flight experimentation. These people become force multipliers, bringing know-how into other projects (including purely domestic fighter test programmes, etc.). It's building intellectual infrastructure, not just physical.
- *Indigenous Momentum:* Success breeds success. When the IAF and DRDO start clocking victories, such as an indigenous engine meeting defined performance targets, it boosts confidence to take on even more challenging projects, such as a future 6th-generation adaptive cycle engine down the line. It also signals to the world that India has come of age in aerospace R&D, which can have spin-off benefits like attracting talent and even offering testbed services to friendly nations in the future.

In short, the IL-76 testbed would be a constantly utilised asset, earning its keep through diverse deployments. The payoff is not just the individual tests, but the cumulative uplift of India's ability to design, test, and induct cutting-edge technology on its terms.

## COST ESTIMATE AND FUNDING STRATEGY

Cost and funding such an initiative remains a pivotal boundary area for decision-makers. While precise figures depend on scope and execution model, insights from similar global initiatives allow us to define a credible range.

The conversion will require the following:

1. Structural reinforcement and pylon adaptation for engine integration.
2. Systems integration for fuel lines, FADEC, power and control links.
3. Advanced instrumentation suites like telemetry, sensors and data acquisition systems.
4. Ground-based telemetry stations and mission control capability.
5. A multi-year engineering effort involving HAL, NAL, GTRE, and possibly Ilyushin.

Factoring all this in, a one-time establishment cost in the range of Rs 500–700 crores over a 3–5 year implementation period is realistic. This aligns with the Rolls-Royce benchmark from their 2021 plan to convert a Boeing 747 into a dedicated flying testbed at a cost of approximately US\$ 70 million.<sup>29</sup> Post conversion, the testbed would incur annual operating expenses for crew, fuel, maintenance and upgrades. While operating a large four-engine jet like the IL-76 is not cheap, the annual recurring cost is modest compared to the value it provides. These running expenses would scale based on flight tempo and usage.

In planning funding, a phased approach is prudent, the phasing helps spread out the cost over multiple financial years, making it more palatable. Also, some costs might be shared with specific programmes. For example, if the AMCA engine project is sanctioned, a portion of its budget could be earmarked to utilise the testbed. In such a scenario, one could argue the testbed ‘pays for itself’ by serving multiple projects which would have individually spent funds on alternative testing solutions.

The proposal should therefore be presented not as a one-off aircraft conversion, but as a utilisation-backed national test facility. Each major propulsion programme that expects to use the flying testbed should reserve test hours and instrumentation support in its baseline project budget. The business case can then be evaluated against measurable outputs: number of booked campaigns, flight hours, test points completed, foreign test slots avoided, schedule risk reduced, proprietary data retained in India, and flight-test manpower created. Sanctioning can also be phased through design study, airframe selection, conversion, instrumentation, certification and operational

use, with funding gates tied to utilisation commitments from GTRE, ADA, HAL, and future propulsion programmes. This gives Defence Finance a clearer basis to assess both return on investment and strategic necessity.

One must also consider the cost of not doing it, continuing to rely on foreign test facilities means continuously paying them (draining foreign exchange), and possibly suffering delays (which have their own cost, delayed induction of critical technology can have national security costs that aren't easily quantified in rupees). In the worst case, if geopolitical situations shift, access to foreign testbeds could be denied entirely, which would leave indigenous engine projects stranded mid-way.<sup>30</sup> That risk avoidance itself justifies the investment.

In conclusion, while investments are significant, they should be viewed as a strategic investment spread over decades of use. The funding strategy should tap into R&D allocations, such as the DRDO/GTRE budget for engine development, which is already being increased for the 110 kN engine project. It could also draw from the capital procurement budget for the modification aspects, since modifying an aircraft could be considered capital asset creation. Additionally, creative use of offsets could help. For example, if India is buying engines or aircraft from abroad, we could require the OEM to assist in our testbed development as part of offset commitments. Imagine Safran or GE providing some instrumentation or technical assistance as part of offsets for engine deals. Such ideas could alleviate direct costs.

Ultimately, the cost must be weighed against the strategic imperative, and in that light, it appears justified and even overdue. One major past mistake was under-investing in test infrastructure. Funding an IL-76 testbed project corrects that course.

## CONCLUSION AND RECOMMENDATIONS

Converting an IL-76 airframe into a state-of-the-art flying testbed for aero-engines is an ambitious endeavour, but one that promises to dramatically strengthen India's defence technological base. It is a project that embodies foresight, an investment now that will yield self-reliance dividends for decades, enabling indigenous fighters, UAVs, and surveillance platforms to be powered and equipped with home-grown systems that are tested, certified and progressively matured in India. It has highlighted that while challenges exist, they are manageable with prudent planning and collaboration.

The proposal should therefore be treated as a national test-infrastructure project, not merely as an aircraft modification project. Its value will depend

on disciplined execution: a suitable airframe must be selected, the structural and instrumentation changes must be certified, the aircraft must be operated under a clear safety regime, and its utilisation must be linked to actual propulsion programmes. The flying testbed will justify itself only if it is used across multiple development cycles, including Kaveri follow-on efforts, AMCA-class propulsion work, unmanned-platform engines, control-system validation and future upgrades.

The recommendations are therefore fivefold. First, the Ministry of Defence should commission a formal platform-selection study comparing IL-76 and other candidate airframes against redundancy, modification feasibility, cost, lifecycle support and test utility. Second, one accountable lead entity should be designated to own development, operation, scheduling, airworthiness coordination and budget responsibility. Third, DRDO, GTRE, HAL, CEMILAC, DGAQA, the IAF, and approved industry users should be integrated through clearly defined roles, not diffuse shared control. Fourth, funding should be phased and tied to booked utilisation from current and future engine programmes, so that the testbed is evaluated as a national facility with measurable output. Fifth, the project should be developed alongside expanded ground-test and high-altitude facilities, so that airborne validation becomes the final stage of a complete aero-engine test ecosystem.

India has already paid the price for under-investing in test infrastructure. Each year of delay keeps indigenous propulsion programmes exposed to foreign schedules, foreign priorities and foreign access constraints. A sovereign flying testbed will not by itself make India an aero-engine power, but without such infrastructure, India's path to becoming one remains incomplete. With careful planning, accountable ownership and sustained utilisation, the IL-76 flying testbed can become a practical national capability that strengthens India's transition from technology importer to technology creator.

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