The story of Tejas, the Indian Light Combat Aircraft (LCA), is the story of development and maturity of aircraft technologies in India. The historic first flight of the Technology Demonstrator-1 (TD-1) took place on 4th January 2001, four decades after the only other indigenous fighter HF-24 (Marut) flew at the very same venue HAL airport in Bangalore. In this historical context, the Tejas programme had the twin objectives of design and development of a state-of-the-art combat aircraft for Indian Air Force and alongside, bridge the technology gap of four decades in the process. Accordingly, Tejas design and development adopted a phased approach, the first one being Technology Demonstration (TD) phase. The critical fourth generation technologies identified for demonstration in this phase were quadruplex digital fly-by-wire flight control system, all glass cockpit, composite structure and microprocessor-based monitoring and controlled mechanical systems. Tejas prototype was quite unique considering the large number of new technologies packed in one prototype.

The Indian Air Force will be inducting two squadrons of LCA from the middle of 2011.
One significant concept that was effectively used in Tejas programme was the ‘National Teams’ concept for development of critical technologies. Examples are: National Control Law (CLAW) team for flight control law design and development; National Wing team for composite wing; and National Flight Test team in respect of critical development of flight test technology. National teams were formed by inducting the best available talents in the country from different organisations which have metamorphosed into centres of excellence in the respective disciplines with platform neutral technology base that can find application in future aerospace programmes of the country. Besides, the effective and efficient techno management model that was developed on the Tejas programme permitted coordination of a very large number of workcentres spread across the country The result is LCA Tejas, which is one of the world’s smallest, lightweight, multi-role, supersonic aircraft, designed to meet the stringent requirements of the Indian Air Force for frontline tactical combat aircraft for the 21st century.

The LCA integrates modern design concepts and state-of-the-art technologies such as tailless compound delta platform with relaxed static stability, fly-by-wire flight control system and advanced composite materials for structures. In addition, open architecture avionics with advanced glass cockpit, hands on throttle and stick (HOTAS), head-up display, active matrix multi-function displays and helmet-mounted display are integrated. Multi mode radar and electro-optic pod provide advanced sensor capability. The weapon capability includes conventional bombs & rockets, Laser Guided Bombs, close combat and beyond visual range missiles. The LCA has an integrated electronic warfare (EW) suite. In addition, state-of-the-art systems have been developed for hydraulics, fuel, environmental, landing gear, brake, nose wheel steering, and life support systems.

Being a nodal agency for developing indigenous combat aircraft systems for the country’s defence needs, Aeronautical Development Agency (ADA) is continuously involved in developing state-of-the-art aircraft related technologies. ADA in collaboration with Defence Research and Development Organisation (DRDO), DG-AQA, Council of Scientific and Industrial Research (CSIR), Hindustan Aeronautics Ltd. (HAL), other PSUs, private partners and academic institutions has developed many critical technologies which have been incorporated into the LCA.

This issue of Technology Focus covers the technological breakthroughs and developments made by ADA and its partners for the LCA programme.

LCA: Salient Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>13.2 m</td>
</tr>
<tr>
<td>Wing span</td>
<td>8.2 m</td>
</tr>
<tr>
<td>Height</td>
<td>4.4 m</td>
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<tr>
<td>Wing area</td>
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<td>Empty weight</td>
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<tr>
<td>Maximum take off weight</td>
<td>13300 kg</td>
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<tr>
<td>Internal fuel capacity</td>
<td>2456 kg</td>
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<tr>
<td>External fuel capacity</td>
<td>2 x 1200 Ltr Drop tank in board</td>
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<tr>
<td>Maximum speed</td>
<td>1350 kmph, CAS</td>
</tr>
<tr>
<td>Service ceiling</td>
<td>15000 m</td>
</tr>
<tr>
<td>Air-to-air missiles</td>
<td>CCM/BVR</td>
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</tbody>
</table>

Aerodynamics

ADA has developed capabilities in intricate aerodynamic design and analysis of fighter aircraft configuration. Aerodynamic analysis includes both experimental and computational methods. In experimental methods, various wind tunnel models have been designed and fabricated for testing a wide range of aerodynamic aspects. Computational methods have been extensively used for fuselage shape optimisation, wing design, aerodynamic loads estimation in complete flight envelope, pylon shaping for reduced interference drag, optimisation of leading edge devices, external stores separation, performance evaluation of intake ducts, etc., during the LCA designing. ADA is engaged in the development and refinement of computational fluid dynamics (CFD) codes, which can be used as primary tool for configuration design.

Configuration Design

The tailless compound delta-wing configuration of Tejas, optimised primarily for manoeuvrability and agility, is the culmination of intense aerodynamic design exercise. Utilising advanced CFD codes and exhaustive wind tunnel testing. The prominent geometric features of Tejas are:

From the Desk of Guest Editor

Aeronautical Development Agency (ADA) has coordinated the activities of the Tejas programme involving various organisations of the Indian Aeronautical Community and successfully designed and developed the Tejas for the Indian Air Force. The Navy version is also under development. Self-reliance in Defence implies the need to establish indigenous technologies in developing major platforms like the Tejas.

In this endeavour, we have deployed various advanced technologies into the Tejas like advanced aerodynamic configuration, carbon fibre composites, fly-by-wire digital flight control system (FCS), open architecture avionics, etc. Various enabling technologies like advanced CFD codes, structural analysis packages, system design and evaluation facility, real-time simulator, and iron bird have also been employed in development.

It is to be noted that there was a conscious effort to develop the necessary technologies indigenously by ADA, HAL, DRDO, DG-AQA, CSIR, PSUs, private partners, and academic institutions. This has created an aeronautical technology base within the country. It is important that the Indian aeronautical professional and student community be aware of the great strides made in this sector as a result of the Tejas programme. This special issue of Technology Focus on LCA and its Technologies is an attempt to create this awareness.

P.S. Subramanyam
Distinguished Scientist &
Programme Director (Combat Aircraft) &
Director, ADA

Being a nodal agency for developing indigenous combat aircraft systems for the country’s defence needs, Aeronautical Development Agency (ADA) is continuously involved in developing state-of-the-art aircraft related technologies. ADA in collaboration with Defence Research and Development Organisation (DRDO), DG-AQA, Council of Scientific and Industrial Research (CSIR), Hindustan Aeronautics Ltd. (HAL), other PSUs, private partners and academic institutions has developed many critical technologies which have been incorporated into the LCA.

This issue of Technology Focus covers the technological breakthroughs and developments made by ADA and its partners for the LCA programme.
Highly optimised wing with appropriate variation of thickness, camber and twist along the span.

- Cross-sectional area distribution along the length, adjusted for good high speed characteristics.
- Leading Edge Slats, scheduled at higher angles of attack, for favourable aerodynamic behaviour.
- Wing-shielded bifurcated air intake duct, with diveters, suitably matched with engine to avoid buzz and to minimise distortion throughout the flight envelope.

**Computational Fluid Dynamics Codes**

ADA possesses a wide range of CFD codes for design and analysis. Those used during the initial design phase include panel codes, boundary layer codes, transonic small perturbation codes, and full potential codes. For downstream design and detailed analysis, the following codes were used:

- **Cartesian Grid**
  - Cartesian grid-based solver PARSID was used for estimation of aerodynamic loads for studying effect of configuration changes and also for carrying out store separation studies.

- **Structured Grid**
  - Structured multi-block grid based Navier-Stokes solver CNS3D was used for studying aircraft flow fields, especially those related to high angle of attack phenomena.

- **Unstructured Grid**
  - Unstructured grid-based Navier-Stokes solver VSP3D was used for detailed studies of flow around complex aircraft configurations. The code runs efficiently on parallel processing systems with hundreds of nodes.

**Wind Tunnel Testing of Scale Models**

Wind tunnel testing was carried out for generation of aerodynamics data for control law design, flight simulation, performance prediction, assessment and qualification of the air intake, and flow visualisation.

**Flight Testing for Validation**

Flight testing was carried out for validating/updating the aerodynamics database through system identification techniques. In addition, flight performance was evaluated towards validation/modification of performance model and creation of operating data manual.

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**Low Observability**

Low observability, also called stealth technology, deals with the study and control of signature of a weapon platform to reduce the probability of detection by an enemy. It is one of the aspects of the total approach to ensure success and survivability of a weapon platform. Radar and IR signature play a major role in detection of aircraft. The aircraft shape, external protuberances, gas, discontinuities, avionics and electro-magnetic emissions contribute to radar cross-section (RCS) of the aircraft. Similarly, engine exhaust, hot spots, and aerodynamic heating of airframe contribute to IR signature. Uncontrolled RCS and IR endanger the ability of the aircraft to survive in the modern warfare. The minimisation of the RCS and IR contribution from all these aspects to an acceptable level is one of the design challenges for the development of a fighter aircraft.

The computational capabilities for evaluation of RCS and IR signature have been developed and validated against the experimental results. The results were then analysed and used in the shape modification for reducing signature. The RCS of LCA has been brought down significantly by modifying certain shape aspects within the limitations set by aerodynamics. Appropriate coatings have been proposed for canopy and windshields to minimise the radar return from cockpit and certain hot spots on the aircraft.

A facility has been developed at Research Centre IMETR, Hyderabad, for the RCS measurements on scale models. RCS of aircraft plays a critical role in enhancing the aircraft survivability while fulfilling the mission objectives. RCS measurements of aircraft models complement prediction tools and help in identification of hot spots, thus providing diagnostics during aircraft configuration design for low observability. This facility is useful for RCS measurements of scale models in both X and W bands. It has an Ogee pylon for model mounting and a cylindrical shape jet zone with a dynamic range > 75 dB and RCS sensitivity ≤ 30 dBm. The facility provides accurate and controlled measurement environment and can be used for RCS Studies of aircraft by ISAR imaging for the identification of hot spots and gross RCS measurement in azimuth and elevation planes, both with and without stores.

The signatures of scaled models and RCS of LCA during flight conditions were evaluated in the facility. The radar absorbent materials and paints play a major role in reducing the RCS of an aircraft. Many such materials and paints have been developed by DRDO. An automated robot-controlled sputter in the facility enables coating of indium-tin oxide (ITO) on full-scale canopy and windshields of aircraft. The sputter coating facility can also be used for the application of RCS and IR coatings on aircraft transparencies. It consists of four segments viz. a seven-tank ultrasonic...
cleaning system, vacuum chamber housing 5-axes vacuum compatible robot system, 4-axes post-coating system, and a manipulator for application of silver paste housed in a CLASS 10000 Clean Room.

The facility is suitable for the application of high fidelity (HTO) coatings on complex curved canopies/windshield surfaces of thickness <300μm and of sheet resistivities <30 Ω/sq for stealth advantage and EM/Reduction.

Airframe

Tejas airframe fulfills the essential primary objectives of low structural weight and high manoeuvrability, besides a host of other critical requirements for modern combat aircraft. Advanced metallic and composite materials and ‘aero-elastic tailoring’-based optimisation techniques have been employed in the design of Tejas, leading to a highly flexible structure that satisfies the strength, buckling, and endurance requirements. The use of carbon composites not only takes advantage of the specific stiffness and strength properties of the fibres, but also the directional properties and layered construction to obtain desired deformation patterns under load in flight. The materials used in the airframe have been extensively characterised before using and significant successes have been achieved in indigenising these. Detailed analyses and ground and flight tests have been carried out to ensure that the airframe is free from aero-elastic problems such as divergence, flutter and AeroServoElastic (ASE) instabilities. The design is also dictated by FCS requirements such as minimum acceptable control power loss due to aero-elastic effects and actuator stiffness characteristics.

Materials

Composites

LCA airframe incorporates a significant level of fibre-reinforced composites with a uniquely high usage (45 per cent by structural weight and almost 90 per cent by wetted area) in the production version of Tejas. Extensive trade-off studies between construction material, airframe weight and aero-elastic losses under various flight manoeuvres conducted in the early stages of LCA programme, helped the designers to freeze on the optimal materials to be used for the airframe. Composites have led to significant weight savings compared to metals, whereas there is not much difference between the various grades of composites that were considered (see Figure). While carbon fibre composite (CFC) is the main material, other fibres such as glass and aramid have been used in a limited manner for certain functional applications such as radome. Extensive use of composites has also resulted in considerable reduction in part count, besides leading to reduced RCS. Some of the significant technologies developed are: CFC wing design, development of co-cured technology for fin and rudder, Kevlar radome, GFRP composite drop tanks and C-scan system for wing skin inspection.

Metallic Materials

Metallic materials with lightweight, high specific strength, high performance properties are used for those parts of the airframe where stringent requirements such as concentrated/impact loading, corrosion, humidity and high temperature resistance, and manufacturing complexities cannot be met by composites. Examples are landing gear, store suspension points, wing and fin leading edges, attachments points between wing, fin fuselage and so on. A major programme to indigenously develop aerospace quality materials and processes was launched for the LCA project. The number of different metals/alloys required by various components of the airframe has been reduced through a process of careful study and rationalisation, which would contribute to efficient economics of LCA production.

Design and Analysis Tools

The airframe design and analysis of LCA was done using commercially available tools. Concurrent design of trainer navy variants of LCA was carried out in PDM environment. For the dynamic and aero-elastic design and analyses, a detailed finite-element model of the entire aircraft was constructed and updated as and when test data became available. The aero-elastic analysis was based on a unique methodology of combining ‘unitary’ loads and deformations to obtain the aircraft manoeuvre, which made it possible to quickly compute results for thousands of manoeuvres at various flight conditions and aircraft/store configurations during the preliminary design stage. In order to characterise the potentially destructive interactions that occur between the flexible LCA airframe, the high authority control system and the unsteady aerodynamic loading, an AeroServoElastic (ASE) analysis package called ‘ASEPACK’ and with capability for ASE model formulation, and time and frequency domain ASE response analyses has been developed in-house and used extensively.

Tests and Test Facilities

For an efficient and effective design, the analyses and testing activities need to play complementing roles with respect to each other. The link between structural analysis and testing of LCA is shown in the figure. The sequence of ground tests carried out is also indicated.

Ground Tests

Strength tests for LCA airframe have been carried out at component and sub-assembly level. A floating rig was designed and installed for the first time in the country for the half-wing strength test. In addition, the entire airframe assembly has been successfully tested up to its ultimate load using specially designed and developed main airframe static test (MAST) facility. A permanent test rig comprising a free-free suspension system with rubber bungee cords has also been established. This rig was used to conduct ground vibration tests (GVT) to characterise structural modes, and structural coupling tests (SCT) to estimate structure control interaction levels and provide design data for notch filters to be incorporated in the feedback loop of the FCS.
The aero-elastic stability of the LCA in its operating envelope has been demonstrated by successful completion of flight flutter tests of various store configurations. State-of-the-art flight test instrumentation data monitoring and acquisition facilities have been established and used extensively for flight tests of LCA.

To fulfil the requirement of a 110 kW gas turbine starter unit (GTSU), to provide shaft power for starting the main engine of LCA, a jet fuel starter (JFS) designed and developed and qualified by Engine and Test Bed Research and Design Centre (ETBR&DC), has successfully completed initial flight trials on LCA. JFS is configured as a free turbine engine, which comprises a gas generator, a power turbine, and accessory modules. This starter is self-sufficient and has its own lubrication and control systems. The starting cycle is accomplished fully automatically. To start JFS only fuel supply and a 28V dc electrical source are required from aircraft.

The gas generator module includes a single-stage centrifugal compressor, a single-stage axial turbine, and a reverse flow combustor. The compressor and turbine are mounted on a single shaft and supported by two ball bearings. A shaft transfer power from gas generator shaft to the accessory module, which includes a lubricating pump, a fuel pump, a fuel control valve, and start initiating dc motor. The free power turbine (FPT) module comprises a free turbine and a reduction gear system. The output shaft from the gear train is interfaced to the aircraft mounted gear box (AMAGB) through an over running clutch (ORC) fitted inside the AMAGB, thus effecting the drive connection between the FTS and the main engine. A digital electronic control unit, SECU, performs control functions and ensures safe and efficient operation of JFS.

JFS starting cycle is initiated from a single switch. This switch actuates the aircraft electrical circuitry to provide electrical power to the JFS ignition system, fuel solenoid valve, and the starter motor, which accelerates the GGTR speed. After the JFS start up sequence, the gas generator operates at a nominally constant governed speed. The aerodynamically coupled FPT begins to operate, and drives the main engine HP spool through AMAGB with ORC engaged. When the JFS output shaft reaches the desired cut-off speed (FPT speed = 9750 rpm), SECU terminates the fuel flow to the gas generator and thereby completes the JFS operation cycle.

JFS is used to start the engine both on ground and in flight. The maximum altitude of JFS operation is 5 km. As the altitude increases, the JFS operation time to achieve cut-off speed also increases. The operation time varies from 60 s at sea level to about 120 s at 5 km. However, the CRANK time is fixed at 60 s irrespective of altitude.

Integrated Flight Control System

Agility enhancement is one of the critical requirements of a fighter aircraft. Towards achieving this objective, concept of relaxed static stability was introduced in aircraft design during early 1980s. This concept of relaxed static stability led to introduction of fly-by-wire (FBW) FCS consisting of electronic equipment, electrical signalling, electro-hydraulic actuators, etc., in place of the conventional mechanical linkages. The Tejas aircraft employs concept of relaxed static stability and hence requires the FBWFCS. First time in India the required FBWFCS technology for Tejas fighter and trainer variants has been developed indigenously and successfully flight tested for more than 1500 flawless flights till date leading to initial operational clearance (IOC). With this achievement the country has joined an exclusive club of only few nations with this technology.
elite club of a very few countries possessing capability of indigenous design, development, and flight testing of state-of-the-art digital FBW FCS.

The full authority quadruplex redundant digital FBW FCS has been developed with built-in redundancy management system and mission-dependent in-flight re-configurable control laws, which ensure the required safety of flight and excellent handling qualities across the flight envelope. Distributed onboard embedded computing system hardware-based FCS line replacement units (LRUs) like digital flight control computer (DFCC), air data computer (ADC), dual pick-up control unit, primary and secondary actuators, FCS test unit, flight control panel, deicing current sensing unit (DCSU), FTI data recording unit, MILL 1553 data recording unit, modular control stick, rudder pedal assembly, etc., were indigenously developed and qualified leading to overall system certification of Tejas digital FBW FCS.

Towards achieving total self-reliance in development of digital FBW FCS a number of control law design tools, structural filter design tools, off-line handling quality analysis tools have been developed and exclusive test facilities like engineer-in-loop simulator, non-real-time simulator, real-time simulator, hardware-software integration facility (mini bird), hardware-in-loop evaluation facility (iron bird), structural coupling test facility, ground checkout system, FCS lightning test facility, etc., have been established along with adequate human resource development for safety critical onboard FCS software development, implementation, evaluation and independent verification and validation. An array of specific to test equipment like flight dynamics simulator, engineering test station, air data test system, high speed data acquisition systems, frequency response analyser (FRA), signal stimulation unit, air data system test equipment, etc., have also been indigenously developed.

ADA along with HAL, Aeronautical Development Establishment (ADE), and National Aerospace Laboratories (NAL) designed and developed the IFCS for Tejas.

**Flight Control System Architecture**

A quadruplex redundant architecture without mechanical backup has evolved to meet the fail-operate/fail-safe requirement. The Tejas digital FBW FCS uses quad redundant electrical power supply, dual redundant hydraulic power supply and meets the stringent PLOC requirement of 0.1 failures in million flights.

**FCS Sensors**

Quad redundant inertial-based rate sensor assembly (RSA) is used for the pitch, roll and yaw rate sensing. Similarly, a quad redundant inertial-based acceleration sensor assembly (ASA) is used for acceleration sensing. The ASA and RSA LRUs have the required electronics to facilitate pre-flight, pilot initiated, and continuous built-in-test (BIT). The air data sensors consist of angle-of-attack (AoA), angle-of-sideslip vanes, static pressure, total pressure, and total temperature probe. The air data sensors have built-in de-icing capability and the de-icing current is sensed using an indigenously developed DCSU.

**FCS Actuators**

The Tejas digital FBW FCS includes direct drive valve (DDV)-based primary actuators and EHSV-based secondary actuators. The primary actuators are used for elevator and rudder control surfaces and secondary actuators are used for leading edge slat (LES) and airbrake control. The primary and secondary actuators have the required electronics to facilitate pre-flight, pilot initiated, and continuous BIT.

Tejas is configured to be aerodynamically unstable in the pitch axis; the instability level depends on the flight conditions like Mach number, altitude, AoA, etc., and also on the aircraft configurations. The relaxed stability is artificially recovered using dynamic feedback of various aircraft and flight parameters. Processed pitch rate, normal acceleration, AoA, air speed information along with pilot stick/throttle inputs drive the symmetric Elevon surfaces for achieving the required pitch axis stability augmentation and response shaping. Similarly, the processed roll rate, yaw rate, lateral acceleration, angle-of-side-slip (AoSS) along with roll stick/rudder pedal input drive asymmetric Elevon and rudder surfaces for achieving the required lateral and directional response shaping, velocity vector roll, directional stability enhancement, etc. The active control technology-based control laws automatically reconfigure in-flight either for AoA demand or for normal acceleration demand based on the flight condition.

**Control Law**

**IFCS Test Facilities**

The following test facilities have been established at ADA and partner establishments:

**Engineer-in-Loop Simulator at NAL**

- Real-time control law design simulator with excellent real world visuals
- Rapid prototyping tool for Tejas handling qualities optimisation
- Simulator has been used to develop and integrate the six degrees of freedom (DoF's) model; all the critical sub-system models of Tejas such as primary actuator nonlinear models, complex undercarriage model, etc.
Salient Features

Provides necessary instrumentation and control for conducting the structural coupling test on the Tejas aircraft

Provides adequate data for notch filter design to avoid control structure interaction and for flight clearance towards aircraft structure

Computer controlled VXI and GPIB based automatic test equipment

Real-time, ground based test facility equipped with state-of-the-art air data test station, air data test system flight dynamics simulator, engineering test station, portable avionics test station, data acquisition, and analysis and storage systems

Developed for Tejas IFCS evaluation with air data computers

Real avionics LRU interfaces with DFCC in open-loop mode

Automated test facility for enhanced throughput with minimal human intervention

Simulator for pilot-in-loop evaluation of control law for handling quality assessment

Inner surface of the 9 m diameter dome is used as the projection screen

6-channel projection system configured using high-end graphics card

Geometrically-corrected, edge-blended, seamless projection of the imagery on dome surface

Mini Bird Test Facility at ADE

Salient Features

Real-time, hardware-in-loop and engineer-in-loop ground-based test facilities for carrying out hardware/software integration.

Provides capability to drive the DFCC OFP either through the control of engineer/pilot or through the canned inputs from the host computer.

Hydraulic rig provides interface between DFCC and actuators. Visual display provided in the cockpit.

Iron Bird I and Iron Bird II Test Facilities at ARDC, HAL

Salient Features

Real-time hardware-in-loop and engineer/pilot-in-loop ground-based test facility for Tejas IFCS evaluation.

The ironmongery is similar to Tejas fighter structure and all 13 FCS actuators are mounted and hydraulically powered.

Tejas single-pilot cockpit, simulated avionics system, under carriage and nose wheel system are also coupled in the rig.

Engineering test station to interface with DFCC and to inject failures and flight dynamics simulator to simulate the flight.

A host of data acquisition, analysis and storage computers.

Sub-system integration, system integration, performance verification of air data system and control law, pilot-in-loop normal, failure mode and fault-free tests and built-in-tests for IFCS are carried out.

Avionics and Weapon System

Architecture

Tejas avionics architecture integrates sub-systems and performs major functions such as mission and stores management, navigation and guidance, sensors management, communication, electronic warfare (EW), defensive aids, cockpit controls, onboard health monitoring, and redundancy and failure management.

Tejas avionics is based on federated avionics architecture with functionally partitioned and distributed LRUs interconnected via a Mil. Std. 1553B data buses. The avionics is centered around open architecture computer (OAC). Weapon system provides precision weapon launch platform for air-to-air, air-to-ground, and air-to-sea missions. In Tejas, avionics and weapon system development cycle follows the V process. Tejas Avionics architecture implementation is classified into the following domains:
Mission System

Open Architecture Computer

The system and mission related tasks are performed by OAC, which also performs bus controller function. The present scheme is to configure OAC as a single processing station for mission and weapon aiming computation, symbol generation, and video switching, thereby integrating three independent functions into one. The approach has minimised data latency and overall aircraft weight and volume. In the architecture, redundancy has been provided by two identical units. The main functions performed by OAC are:

- Operational/mission functions (navigation guidance, etc.)
- Cockpit man-machine dialogue management functions.
- Functions which link/manage external equipment like sensors, stores, and communication and navigation equipment.
- Avionics and weapon-aiming computations.
- Avionics and weapon system maintenance functions.
- Bus exchange management function.
- Switching sensor video from store stations to display surfaces.

Glass Cockpit and Controls

Tejas has a glass cockpit with mult-function display (MFD), head-up display (HUD), and helmet-mounted display (HMD), and two smart standby display units (SSDUs) along with active matrix liquid crystal display (AMLCD)-based multi-function upfront control panel (MF-UFCP) with keyboard for data entry. The display systems provide flight information parameters, navigational symbols, and target weapon release cues on its screen. Cockpit interface unit (CIU) provides input output interface between cockpit and OAC. It also generates voice warning. A centralised warning system provides pilot with critical warnings display with audio tone.

Sensors

Multi-mode Radar

The radar is the primary sensor on the LCA for scanning and multi-target tracking. It provides air-to-air, air-to-ground, and air-to-sea search, detection, and tracking. It also comprises high resolution synthetic aperture radar (SAR), inverse synthetic aperture radar (ISAR), and performs signature and target-avoidance functions.

Laser Designator Pod

Laser designator pod (LDP) is an electro-optic sensor for targeting and designating of ground targets (day/night), low-level flight at night, and anti-aircraft targeting. The LDP comprises a forward-looking infra-red (FLIR), dual-mode laser, closed-circuit digital (CCD) camera, laser tracker, and a laser marker. It illuminates the target and locates it with respect to current position of the aircraft. This data is used by OAC for target designation and weapon delivery computation.

Communication, Navigation, and Identification

The communication-navigation-identification (CNI) suite primarily performs communication, navigation, and identification functions.

Communication System

Communication system has a vital role of establishing the link between the aircraft and the ground stations and between aircrafts themselves. LCA is equipped with INCOM1 and RCOMO equipment. This equipment is a secure jam-resistant airborne radio communication set and provides simplex two-way communication in the VHF and UHF frequency bands, and voice and data communications with the associated sets in the airborne environment.

Navigation

Inertial Navigation System-Global Positioning System (INS-GPS): It is the primary navigation sensor and computing unit. INS-GPS performs a wide range of navigation functions such as on-ground autonomous integrable gyrocompass alignment, on-ground fast alignment on stored heading, and in-flight alignment on GPS. It computes pure inertial (GPS), and optimal navigation by hybridisation with embedded GPS receiver. It also performs steering computation.

Radio Altimeter: It gives altitude of the aircraft above the terrain just below the aircraft, and the height information for low-level flights for weapon-aiming computations on the display surfaces.

Tactical Air Navigation (TACAN): It is a line-of-sight system and provides slant range of the aircraft from the ground station using transmitter/transponder technique.

VHF Omni Range-Instrument Landing System (VOR-ILS): It is a radio-based guidance system to guide the aircraft in poor visibility conditions during approach to runway. The ILS receiver in the aircraft receives the runway approach guidance signals, and when coupled with the autopilot (AP), guides the aircraft automatically to the centreline of the runway and on the descent path defined by the instrument landing system (ILS) beams.

Smart Standby Displays (SSDUs): Two smart standby displays provide independent display information of critical parameters to pilot to serve as backup to primary displays (Get-U-Home).

Onboard Recording System: Two onboard recording systems, viz., digital video recorder for all the data buses and video information and solid-state crash data recorder (SSCDR) for all critical parameters. Based on ground these are supported by data analysis systems.

Identification

Identification of Friend or Foe A/G (IFFA/G): The IFFA/G is to identify friend or foe aircraft.

Electronic Warfare

The operational role for Tejas envisages strikes/missions in hostile air space. To enable it to accomplish this mission, it is provided with EW armour comprising radar warning receiver (RWR) and countermeasure dispensing system (CMDSS).

Radar Warning Receiver

The RWR provides early warnings to the pilot through displays and audio about radio frequency (RF) threats. Audio is generated through audio management unit (AMU). It detects and gives the information about the position of the RF sources illuminating the aircraft. This consists of PR and captive works (CW) receiver, which are pre-programmed to counter the RF threats.

Countermeasure Dispensing System

The chaff and flare is a countermeasure to engage IR and RF threats.

Store Management System

The store management system (SMS) handles a wide range of weapons and stores. The SMS, 31760B-based architecture, is responsible for weapons and sensor pods interface, stores inventory, safety interlocks, selective and
emergency jettison, and missile control. This system consists of stores interface box (SIB) and pylon interface box (PIB) which integrates the stores through weapon busses. While SIB is a front-end weapon management computer to ensure operational readiness assessment of each weapon, PIB enables stores recognition, target acquisition and tracking, stores selection, arming, fusing, and release.

**Utility Systems Management System**

The utility systems management system (USMS) consists of environment control and fuel management (ECFM) and brake hydraulics electrical control (BHEEM) electronic units (EUs) to control and monitor the inputs/outputs of different sensors, valves, and other entities of the aircraft systems. The EUs are interfaced to OAC to display data related to systems like engine, electrical hydraulics, fuel life support, and environmental control.

**Avionics and Weapons Systems Test Facility**

The system validation facilities have been established to ensure robustness in testing and fault isolation and fault fix on ground before the system is certified and cleared for aircraft flying usage. The facilities cater to:
- Avionics and weapon delivery mission.
- Simulation of stores/weapons, use of actual or simulated LRUs/sensors.
- High-fidelity cockpit design facility toward pilot vehicle interface design.
- Integration and validation of all the aircraft hardware and software components in an integrated environment.

**Avionics and Weapons Rigs**

ADA has established the following avionics and weapons rigs for testing, and integration of various LCA’s systems/sub-systems:

- OAC Hardware Test Rig: It is used to carry out OAC hardware ATP functional test. Each hardware resource in the OAC is tested for its functionalities in the rig.
- Mission Software Test Rig: It is used to validate the system functionality in OAC. The facility caters to complete environment models/LRUs of the other aircraft sub-systems, environment for fighter/trainer/cock. The facility provides complete support environment towards white box and black box testing for its certification by IV and V team.
- MMR Test Facility: The rig has been established for radar system integration and testing. It is used for radar standalone testing, LRU and LRU sub-levels. The rig provides environment to integrate and test the SMS functionality, SMS looming similar to aircraft, evaluation of SMS hardware and software in an integrated mode, evaluation of SMS performance parameters like timing, data latency and release sequence, warning philosophy, weapon aiming, and deployment cues.
- Avionics Integration Rig: Has been designed to achieve integrated avionics and weapon system hardware and software validation, fault injection, isolation, debugging and pre-installation (PI) checks of LRUs, standalone testing and integrated functional testing of LRUs and serviceability checks for production LRUs. The integration rigs AIR WIR and MMR are interconnected to facilitate end-to-end testing with all LRUs in an integrated environment. This has helped to optimise the flight test efforts.

**System Design and Evaluation Facility**

This state-of-the-art simulator facility facilitates pilot-vehicle evaluation and finalisation of avionics and weapons system requirements. Pilot workload assessment and procedures generation are carried out in this facility. The facility has been established to cater the PV issue and to capture design requirement. Facility provides the first hand information towards aircraft systems, ergonomics to pilots and a day and night flying.

**General Systems**

**Secondary Power System**

The LCA is powered by a single, low bypass-augmented turbofan engine. In addition to the primary function of providing thrust for the flight of the aircraft, the power plants also cater to the secondary function of generation and supply of aircraft electrical power, hydraulic power, and bleed air of engine bay ventilation and environmental control system.
A drive pad on the engine gearbox provides for tapping of engine-driven power to drive an aircraft-mounted accessory gear box (AMGB) through a power take off (PTO) shaft. The AMGB has four pads and drives two hydraulic pumps of 110 lpm x 240 bar, one integrated drive generator of 30/40 kVA, and one RFS to start the engine. In addition, one 30 lpm x 260 bar hydraulic pump and a 5 kW dc generator have also been mounted on AMGB engine gear box pads exclusively for backup power.

**Hydraulic System**

The hydraulic system comprises of two completely independent systems (4000 Psig), each being supplied by a variable-delivery, pressure-compensated hydraulic pumps driven by the AMGB. Each hydraulic circuit is equipped with central filtration in the return and pressure lines. An accumulator has been provided in each system for damping of the pump pressure ripple and to deliver fluid at peak flow demands. A bootstrap reservoir is contained in each system and sized for volume changes and sufficient reserves to cover minor external leakages in the system.

Each hydraulic system is divided into a control and a utility circuit. In case of an external leakage in the utility circuit, this will be reused via the reservoir fluid level. The utility isolation valve, operated electrically, provides maximum protection for the essential flight controls.

**Fuel System**

The LCA fuel system consists of the following sub-systems to meet the various flight/mission requirements:
- Fuel feed system.
- Fuel transfer system.
- Tank pressurisation system.
- Fuel venting system.
- Aerial/ground refuelling system.
- Cooling of other system fluids.
- De-fuelling/fuel dumping system.

**Environmental Control System**

Current fighter aircraft have air cycle machine (ACM) with high pressure water separation (HPWS) for which bleed air is drawn usually from the aircraft engine. The same has been incorporated in the LCA. The environmental control system (ECS) has been designed for following services of LCA:
- Bled air control from the engine.
- Cabin air conditioning and pressurisation.
- Avionics equipment cooling.
- Radar cooling and pressurisation.

- Cabin sealing system
- Wind screen de-misting system
- Cabin ventilation system
- Cabin air distribution and noise control
- Ground cooling system for avionics and cabin
- Air supply to fuel tanks
- Primary air supply to engine bay ejectors and ECS ejectors

**Undercarriage, Brake and Nose Wheel Steering System**

The landing gear system of the LCA is of tricycle type, incorporating two main undercarriages and one nose undercarriage. LCA has an electro-hydraulic braking system with carbon discs and a digital brake management system with anti-skid control. An electro-hydraulic power steering system has been provided for nose wheel steering.

**Life Support System**

The breathing oxygen system is vital for the pilot in a high-performance aircraft. It provides the oxygen requirements and protects him (pilot) against hypoxia and toxic agents under all environmental conditions in which the aircraft may be deployed. The oxygen system also provides the necessary pressure for the anti-g system. The system comprises: Normal LOX (Liquid oxygen) system, emergency gaseous oxygen system, and anti-g system.

**Normal LOX System**

The normal supply source for the breathing oxygen is a LOX converter with a capacity of about 5 litres of liquid oxygen. Five litre LOX would be able to meet the oxygen requirements of the pilot under 100 per cent oxygen mode for all Tejas missions.

**Emergency Oxygen System**

On ejection or normal system failure, the low pressure in the supply line will automatically permit the supply of emergency oxygen from a pressurised bottle mounted on the pilot’s seat to the oxygen regulator. An NRS prevents the supply of the emergency oxygen to the anti-g valve in these conditions.

**Anti-g System**

Anti-g system is an essential part of life support system in a modern fighter aircraft, which has high on-set rate and high sustained g forces active on the pilot during certain manoeuvres. The use of an anti-g suit raises the pilot’s black out level by 1.5 g to 2 g, considerably reducing the fatigue caused by repeated manoeuvres.

**Electrical System**

LCA comprises basic hybrid power generating system (both ac and dc) and emergency battery as backup. LCA uses hybrid power supply consisting of constant frequency ac, 3 phase, 200 V/415, 400 Hz, 4-wire, and dc (24 V) power sources. The power distribution in LCA is through an conventional electromechanical device with hardwired control logic. Electrical power generating system of the LCA comprises 30/40 kVA main power source, and 5 kVA and 5 kW standby sources. Two 24 V Ni-Cd batteries act as emergency sources in case of failure of standby sources.
AC and DC Generating System

Basic power is generated by a 30/40 kVA integrated drive generator as main power source on MMAGB, and a 5 kVA hydraulic driven generator in standby mode. The dc power is derived from two TRUs of 250 A connected in parallel and a standby 5 kW dc generator with battery as buffer.

While main generator supplies power to all ac busbars, transformer rectifier units 1 and 2 connected in parallel supply power to all dc busbars with battery as buffer, and two dedicated 0.450 kVA hydraulic motor-driven generators (HMDG) supply power to FCS channels 1 and 2. In case of failure of main power source (30/40 kVA), a 5 kVA hydraulic-driven generator (HMDG) supplies ac essential busbar and 5 kW dc generator supplies power to dc essential, dc emergency and battery busbars with battery as buffer. A dedicated 0.450 kVA HMDG power supply provides power to FCS channels 1 and 2. In case of failure of 30/40 kVA, 5 kVA and 5 kW generators/engine flame out, a Ni-Cd 44 Ah battery supply battery busbar and dc emergency busbar (endurance limited).

Software Engineering

FCS Software

The flight control software has been developed using ‘Ada’ language. Ada has the following benefits: Standardisation, support for software engineering principles like object oriented design, information hiding, abstraction, etc., ability to handle large programs, separate compilation, strong data typing, and readability and very high expressive power. ‘BONOMIC’ assembly language is used for time-critical and processor initialisation modules only.

The software development has been carried out in a VAX/HP computing environment using ICC 1960 cross compilers. Software development is as per DoD-STD-2167A and RTCA DO-178B, and reviews as per MIL-STD-521B and DoD-STD-2168. Software development plan (SDP) dictates the methodology, environment, and process to be followed for software development. Design and coding standards are also part of SDP and are basically defined to ensure deterministic behaviour of the software with respect to predictability of memory utilisation, predictability of execution time, readability, maintainability, modularity and testability etc.

Software quality program plan (SQPP) describes the procedures/process that has to be followed for design, coding, and testing. The quality program plan describes the evaluation criteria for different lifecycle phases, reviews and documentation.

The phases in the lifecycle of Tejas FCS software development are system requirement analyses, software requirements analyses, preliminary and detailed design and coding, CSU/CSC testing, hardware/software integration tests, and system level testing. Documents and artefact are generated at the end of each phase, which are reviewed and accepted to become baselines for the subsequent phase in the software development.

Mission Software

The system engineering process for avionics development was completely undertaken by ADA systems house, right from capturing the requirements with user till the flight testing.

Mission software of OAC is using component-based model driven development process. ISO standard IEC-12207 was followed for development of the mission software. Since the development model is iterative incremental, positional sequence of these activities do not necessarily imply a time order. These activities may be iterated and overlapped. All the tasks in an activity need not be completed in the first or any given iteration, but should have been completed as the final iteration comes to an end. The complete run of artefacts of the software development cycle have been developed in-house and configured for later use.

Requirements are generated using use case method and stored in repository for configuration and impact analysis. Design uses UML methodology with sub-systems concept driving the design. Preliminary design and architecture of the model is used in generating automated code for the static structure. The mission critical software of avionics has been developed using ‘Ada’ language. Complete automated process is deployed for generation of documents of the software lifecycle to reduce time to deliver. Single operational flight program (OFP) application, based on open system principles and reusable components, has been used to address variants of LCA. COTS-based hardware with real-time operating system was used as middle ware to ensure application growth as well as to cater to hardware changes. A full-fledged test facility, with features built-in to conduct exhaustive testing of the mission software, has also been established.

Independent Verification and Validation

The independent verification and validation (MIV) laboratory at ADA has been set up to address the safety issues of software-intensive systems of LCA, thereby obtaining a high level of confidence in the operations of new systems prior to their use. The MBV plays a major role in the design and development of embedded software and aims at development of hazard-free and mission success-oriented software. It carries out analysis, review, and testing of artefacts generated during various stages of software development process, employing modern CASE tools, etc., modelling and simulation, rapid prototyping, tool-based analysis, and randomised non-real-time (NRT) testing.

Seven safety-critical and 23 mission-critical software systems of Tejas have been evaluated and close to 1500 successful sorties of Tejas have been completed adhering to MBV practices. The MBV process supports standards like IEEE-12207 and RTCA DO-178B, and has evolved to support concurrent software development techniques using OOAD and model-driven development (MDD) methods for LCA applications.

An in-house NRT set up has been developed at ADA for validation and verification and stress test of safety critical onboard software in NRT mode on a target board. The test cases are generated using randomised and optimisation techniques to mimic aircraft behaviour, pilot inputs, and flight environment. This platform has the capability to execute 100 tests cases on target board with automatic analyses and report generation in just 35 h.

Quality Assurance and System Effectiveness

Quality assurance and system effectiveness plays a key role in LCA programme to impart assurance technologies and to ensure the system effectiveness from the conceptual stage. Assurances technologies in the aerospace industry play a major role in steering the vision for future and are a potential resource for corporate profitability and key for the product mainstream in the market. In the LCA programme it was a formidable task, from concept to realisation, to impart assurance technologies. Some of the noteworthy aspects in LCA programme are: Customer’s focus, synergy of efforts and pooling of technological resources/Strengths, infrastructure development on assurance technologies, proactive role of assurance discipline on system design, adoption of consortium through National Team and concept for complex developments such as CFD wing, control law and flight testing. In general, the main constituents of ‘product assurance’ are: Reliability, maintainability, survivability, airworthiness, quality assurance engineering, and system safety and logistic support.

Reliability of the product is the key factor in LCA programme and was incorporated during the design itself. LCA has features like ‘damage-tolerant design’ for structure and use of ‘high reliability’ components and concepts of ‘robust design’ and ‘parts de-rating’ in design for reliability. Exhaustive iterative tasks have been carried out in the vital
Quality assurance and system effectiveness cycle

Survivability & Vulnerability

Configuration control management

Reliability Assurance

Quality Assurance

QRTR & Training & Seminars

Maintainability

Quality Engineering

areas through reliability apportionment, modeling and prediction, failure mode effects and criticality analysis (FMECA), and fault-tree analysis (FTA) as part of integrated product development.

Besides, ‘failure reporting and corrective action system’ (FRACS) also helps during development stage.

Maintainability is another constituent of assurance technologies, which has been given utmost priority in LCA programme. Visualisation of maintainability in LCA programme by close interactions with the maintenance team of Indian Air Force (IAF), right from the early stages of the programme, has paid ample dividends. Modular concepts of equipment (LRUs/SRU’s), accessibility for ease of removal/replacement and inspectability with human factors into consideration, fault-tolerant features for computing system, continuous BIT for fault logging/reporting, and ‘maintenance BIT’ for diagnostics are some of the significant features embedded in the design of LCA. The features like ‘internal condition monitoring’, adoption of ‘reliability-centred maintenance’ (RCM), HUMS and computer-based maintenance management and resources management have been slated for accomplishing the desired maintainability goals for LCA fleet maturity.

Survivability is one of the more important features for a combat aircraft. By design, LCA has been made less vulnerable against the hostile conditions such as lightning, bird or bullet hits. The survivability modelling of aircraft against small arms hit has been carried out and the design has taken care of the shielding requirements. Airworthiness is the demonstrated ability of aircraft fitness to fly in terms of performance, safety, integrity, and reliability. State of the art technologies of LCA multi-folded the challenges of its airworthiness. Core technologies such as CFC wing, advanced aerodynamics, fly-by-wire ECS and software-driven processor-based computing system have been incorporated for the first time on a single platform and most of the systems being highly integrated and interdependent for operations. The LRUs have been individually certified after extensive testing followed by rig level verification for individual systems. Apart from testing analysis, modelling and simulation techniques have been used as means for airworthiness certifications.

Quality function deployment (QFD) is one of the drivers in quality assurance engineering for LCA. A comprehensive ‘Quality Plan’ was evolved which in turn unified several work centres with uniform quality control norms. Reviews and audits dovetailed at various phases of the development, coupled with rapid prototyping and development testing have yielded far reaching benefits in the programme. The quality engineering function has helped in understanding all-hazard-related anomalies, better at system level for aircraft level and fix the same.

The system safety was another paramount important consideration for flight testing of LCA. Extensive analyses such as hazard analysis (HA), zonal safety analysis (ZSA), risk analysis (RA), cascading analysis (CA), and common mode analysis (CMA) were carried out. The safety testing through failure simulations and verification added advantage to predict the effects well in advance to take care of safety margin during design.

Enabling Technologies

Product Lifecycle Management

Product lifecycle management (PLM) is important for establishing a common data model and merging information from a number of sources in a unified, secure data management environment. PLM helps in managing the process of innovation, collaboration across disciplines, leverage proven process and continuous data improvement. The ultimate goal is to promote rapid, effective collaboration across multiple departments and disciplines as well as multiple organisations. Including customers, strategic partners and suppliers. In order to achieve this infrastructure that can scale to support data management across an extended enterprise, PLM systems is required. The enterprise data management needs to focus on the three strategic areas viz., data management, process management, and context management.

Enterprise wide implementation of PLM solution started with Tejas trainer/Navvy programme for better competitiveness in the design/manufacturer cycle of activities. 3-D model-based design was introduced with design in-context facilities to realise digital mockups. Minimisation of design iterations and reduction in rejection of parts was realised by defining workflows for design and manufacturing activities in PLM. The functionalities deployed in PLM during the prototype development included on-line monitoring of release of design data and work-in-progress details, legacy data handling, Web portal viewing and mark-up facilities, 3-D wire harness routing and form-board data generation, and on-line queries clearance. The build-up of production standard (PSU), release of drawings, and the dissemination of data from ‘design house’ to ‘production agency’ for single-seat Tejas series production (SP) aircraft have been realised through PLM. The scope of activities in PLM for series production is being progressively expanded to meet the requirements of design modification/manufacturing/testing/ certification/user agencies. The activities planned for SP in PLM include configuration-controlled aircraft tail number management; manufacturing execution system; service lifecycle management (SLM); PLM-ERP interface; computerised maintenance management system (CAMS); and preparation of integrated electronic technical publication for operations and maintenance. Creation of a complete integrated digital engineering environment, bringing the processes and data of all aircraft development programmes from concept/design-manufacture-test-maintenance-disposal and preserve the intellect data for next generation use is ADA’s long-term strategy for PLM.

Virtual Reality

Virtual reality centre was started with the specialists graphics and in-house developed DMU software (PRANA). It was used for 3-D visualisation; product walkthrough; collision studies; and clearance studies. This centre is getting improved as the virtual prototyping facility with the commodity graphics hardware (NVidia and ATI/ATI CLI) and both the in-house and commercial software tools. With this capability, the designer can interact with the components, refine the design, and perform integration checks.

ADA has developed a high performance visualisation software tool (VRVIEW) using open source graphics APIs exploiting the high end multi-core programming and high performance programmable graphics cards in a phased manner. Visualisation frame work with facilities of assembly loading, plug-ins for data booters, product walkthrough
The digital pilot models of the IAF pilots have been created, as per the anthropometric dimensions of the IAF population, and interfaced with the digital prototype of LCA cockpit. Delmia human software was used for creating and interfacing different percentile of IAF pilots with digital prototype of LCA cockpit located in front fuselage. Several ergonomic parameters have been studied in relation with anthropometric dimensions of the given IAF population and design variables of cockpit sub-system. The study was conducted on the ergonomic aspects such as seating accommodation, pilot vision, spatial clearance or interference, reachability, control operations (throttle, control stick, and rudder pedals) and comfort/discomfort for the 3P (shortest), 50P (average), and 98P (tallest) IAF population. The facility can be used for designing the ergonomically fit future aircraft.

**Manufacturing and Production**

**Technology Transfer to Tejas Production**

The design and development of Tejas started with two technology demonstrators and three proto-vehicles. Advanced composites, digital fly-by-wire control, advanced avionics, integrated flight control systems, are some of the technologies demonstrated in Tejas. Technologies like CAO/CAE/CAM, CNC manufacturing and automatics for components, shape memory alloys have been extensively used in Tejas. The state-of-the-art technologies in Tejas are maintained by continuous design improvements based on ground tests/flight tests results, feedback from Project Management Team of IAF, and CSIR. Realisation of reproducible aircraft with quality specifications set by the airworthiness certification agencies keeping the minimum turnaround time for operation and maintenance is a paramount requirement for series production. The proto-vehicles and production directorate of ADA has taken a
Co-cured co-bonded technology. Rudder (left) and fin.

lead role in productionisation in coordination with HAL and other Tejas workcentres. The transition from proto-
vessels to series production began with building of eight limited series production aircraft as pre-production activity.
The standard of the aircraft was raised progressively to meet the enhanced flight envelopes.

The various build standards of LCA aircraft include introduction of multi-mode radar, compliance to lightning
protection and waterproof, all weather, high-altitude flight testing, weapon integration, and delivery. Detailed
technical information regarding materials, components, engineering processes and standards, methods,
redistribution of tolerances in mating parts, weight reduction, hand tooling, standardisation of tooling holes/rigs,
interchangeability for doors/pallets, accessibility for maintenance were reviewed and introduced to the drawings
during limited series production.

Preparation of integrated electronic technical publication for operation and maintenance, finalisation of drawing
appropriability list, and equipment standard are the other activities taken as part of pre-production activity leading to
series production. With the intent of ensuring reproducible design with the quality specifications set by the
airworthiness certification agencies, production drawings are made as self-contained documents for all the
design/manufacturing/test/certification personnel. To meet the production rate, new technologies like high-
speed milling, 5-axis automated riveting and co-cured co-bonded technology for composites are being increasingly
introduced during the pre-production and absorbed in series production. Authorised Local Modification Committee
is also in place to ensure that the relevant modifications are incorporated in SP aircraft based on tail number.

Cable Testing on LCA

LCA has a complex cable network consisting of 14000 electrical wiring connections terminated on to 629 electrical
connectors utilising 40 km length of cables. Automatic cable harness tester deployed in LCA production line has improved quality, accuracy
and correctness of wiring of cable assemblies during fabrication and equipping on aircraft.

There is a drastic reduction of testing time to less than a week which otherwise was taking more than three months by manual method of
testing.

Flight Testing

All flight tests related activities of LCA are planned, coordinated, and carried out by the National Flight Test
Centre (NFTC). The team has test pilots and flight test engineers from IAF and Indian Navy (IN) along with
scientists/engineers from ADA and HAL. Tejas flight tests are thoroughly planned and highly disciplined, coupled with
an efficient system in the disciplines of flight test operations, engineering and instrumentation.

Flight Test Infrastructure

The test crew realised early on that critical flight test instrumentation (FTB) system would be required to support
the flight test efforts. This was done in association with the scientists of ADA and engineers of HAL. Highlights of the
infrastructure and flight test support systems indigenously developed at NFTC are:

- Design and development of a state-of-the-art fixed telemeter station with intuitive and user-friendly displays.
- Design and development of a mobile telemeter system to support Tejas outstation trials.
- Design and development of prototype position tracking system (PTT) to improve situational awareness to
  enhance flight test safety.
- Fibre optic/safe BITE linking of the remote testing location with base station.
- Flight trajectory reconstruction from CDR data.
- Design and development of GPS-based Radio sonde to generate precise upper air data.
- Integration of airborne video system for stores separation.
- Integration of smoke-winder on test aircraft—ongoing project.
- Design and development of flight test optimisation and automation system—ongoing project.

LCA testing (clockwise from top): Cold-weather trials at Leh; Bomb release trials; and Missile launch trials.
Flight Test Process

NFTC was required to set up the flight test process from scratch, which they did by defining processes, specifications for instrumentation infrastructure and creating programme management tools. Highlights of the flight test process that is put in place are:

- Effective test crew training and grading system, which help match their skill levels with the complexity and criticality of flight tests tasked assigned to them.
- Active participation in rig-level testing of critical systems (e.g., pilot-in-the-loop testing of integrated flight control system). This process has ensured quicker debugging of the system while providing an opportunity for the test crew to fully familiarize with the system under development.
- Well-organized test point database to plan, conduct, and track flight test progress. This is an effective tool to optimize flight test effort.
- Well-structured briefing/de-briefing for each flight. The briefing/de-briefing covered tend monitoring of system parameters, which helped focus on developing faults before they reach critical levels.
- Conduct of flight test by the test director supported by safety pilot and system specialists monitoring these respectively system parameters against normal caution and warning levels.
- Reporting and tracking of issues arising out of flight test through a well-organized request for action (RFA) tracking tool. Time-based action on these RFAs is the most effective way to ensure the development problem in the system concerned is taken care of towards maturity and certification of the system.

Effectiveness and efficiency of NFTC are borne out by the fact that it has safely and successfully completed over 1500 test flights across 11 prototypes towards certification for induction of Tejas into the IAF. After validating the functionalities of onboard systems, the flight test continued towards flight envelope expansion, performance verification, sensors and weapon testing, stores separation, and so on. Outstation trials were planned and conducted on a number of occasions primarily for environmental coverage and weapon releases over designated ranges in different parts of the country.

Hot weather trials at Air Force Station (AFS) at Nagoa and Jamnagar; sea level trials at INS Rajali, Arakonam and Goa; close-combat missile (CCM) firing at INS Hansa, Goa; cold weather trials at AFS, Leh; bomb trials at Kolar, Chitrardua and Jamnagar; and drop tank jet trials at Chitrardua are some of the significant achievements of ADA with the support of various organizations.

LCA Navy Programme

The LCA Navy programme is the first indigenous effort to build a complete air element for the Navy. As per the Indian Naval doctrine, the Navy in the future would grow substantially and graduate into a formidable blue water force through acquisition of conventional aircraft carriers and a series production of Indian Aircraft Carrier (IAAC). The main aim for the IN today is to find a suitable replacement for its aging fleet of Sea Harriers, to operate from the future carriers with considerable technology and punch for years to come. This was the initiator for today’s LCA Navy Programme.

The Naval project has been divided into two phases. The first phase of development includes design and fabrication of one trainer (NP1) and one fighter (NP2), along with a ground test facility, termed shore-based test facility (SBTF), at Goa and other related test facilities. The two prototypes under build in the first phase will serve as ‘Technology Demonstrators’ to prove Aircraft Carrier Compatibility.

The second phase of the programme would have two aircraft (NP3, NP4), in the Mk2 configuration with a new engine and a structural test specimen for validation. LCA Navy is the only carrier-borne aircraft in world in the light category. This aircraft could be optimised for air defence role and will supplement heavier aircraft that would be optimised for strike role.

Challenges

The main requirements the Naval Tejas, expected to satisfy are:

- Compatible to operate from indigenous Aircraft Carrier.
- Take-off from 14° ski-jump with ~200 m deck run.
- Landing in 90 m using aircraft arrestor hook engaging ship’s arresting gear.
- Longitudinal deceleration of 4.5 ‘g’.
- Landing gear designed for high rate of descent (7.3 m/s).
- Fuel dump capability.

Technologies

LEVCON

To achieve low landing speed (approx. 130 knots), ADA and HAL have designed a special control surface, called the leading edge vortex controller (LEVCON), which is close to the forward root of the wing in the apex region. This control surface can be deflected 200° down and 300° up and when deployed for landing brings down the speed of the aircraft to acceptable levels. This control surface during flight testing will be studied for optimised position for take-off also, for performance enhancement.

Arrestor Hook

The LCA Navy aircraft would be recovered on the ship using aircraft arrestor hook, engaging ships arresting gear with 90 m wire pull out. All the equipment fitted onboard have to be qualified for the arrestor shocks induced during landing through longitudinal deceleration of nearly 4.5 ‘g’. The complete arrestor hook system has been designed in-house. The nose landing gear has also been specially designed for higher loads experienced due to large pitch down moment during engagement.

Landing Gear

High landing load is expected during landing due to 7.1 m/s sink rate arising out of a fixed glide slope and bareless landing on a carrier deck. The main and nose landing gears for the Naval LCA required complete redesign. With the help of MIDHANI, Hyderabad, a new high-strength material, called maraging steel, has been developed for the same.
Fuel Dump System

In the event of an aircraft emergency immediately after launch from the carrier, reduction in the weight of the aircraft was necessitated to enable recovery onboard. In addition to dumping external stores, fuel dump system is being used to jettison fuel to bring the aircraft within recovery limits.

Shore-based Test Facility

For certification flying of Naval LCA to simulate aircraft carrier launch on a ski-jump and arrested recovery, a shore-based test facility is being constructed at INS Hansa, Goa. This facility replicates the ski-jump launch and arrestor hook recovery for the Naval LCA, when it operates from the indigenised aircraft carrier. This facility can also be used for training pilots and maintainers in the future.

LCA Two-Seat Trainer

The two-seat tandem configuration Air Force trainer is derived from the fighter version. It has been endeavoured to maintain maximum commonality amongst all the variants of Tejas, namely, Air Force Fighter, Air Force Trainer, Navy Trainer, and Navy Fighter.

Front fuselage of trainer has been modified to accommodate the second cockpit. Both front and rear cockpits of trainer have been configured to replicate the pilot vehicle interface (PVI) as in the fighter version. The trainer version has drooped nose for better cockpit vision and larger canopy to accommodate rear cockpit with 5° additional vision for rear pilot. It has mechanically interconnected control stick, rudder pedal, and throttle. Rigorous tests have been carried out at various rigs and simulators towards the clearance of the aircraft.

The Potential

Tejas two-seat aircraft has been designed not only as a “Type Trainer” but also as a precision weapon launch platform for air-to-air, air-on-ground, and air-on-sea missions with effective stores management system (SMS) capable of handling a wide range of weapons and stores. It can be equipped with variety of sensors like multi-mode radar, fire control radar, electronic pod, and helmet-mounted display and sight (HMDS). Tejas trainer has very good potential in the world market primarily as a supersonic fighter trainer capable of handling precision weapons and state-of-the-art sensors.

LCA Programme Status

On 10 January 2011, Air Force version of LCA single-seat fighter was certified as operationally capable (IOC-Initial Operational Clearance) for release to service (RSD) by CEMILAC. The RSD document was formally handed over by Honorable Defence Minister Shri A.K. Antony to IAF Chief Air Chief Marshal P.V. Naik. The remaining development activities will be completed by Final Operational Clearance (FOC) by December 2012.

From programme’s formal commencement in 1993 to January 2011, 11 aircraft have been built including two Technology Demonstrators (TD1 and TD2), three prototype vehicles (PV-1, PV-2, and PV-J) and one twin-seater (PV-3). Based on system development status, five LSP (Limited Series Production) aircrafts have been built to prove all performance and system development for certification of IOC.

As on date, over 1500 sorties, 900 hours of flight have been flown during the flight test programme across the entire performance envelope to operationally prove all IOC sensors, weapons, and stores. Trials have encompassed hot and cold weather trials, sea level and high altitude trials, missile firing and bombing (practice bombs and 1000 lbs) to clear the IOC operational envelope. Also, sensors (Multi Mode Radar and Helmet Mounted Display System) and all onboard avionics (IN GPS, IFF, PWR, VOR-ILS and TACAN) have been flight tested successfully. The countermeasure dispensing system (CMDS) for self-defence has also been successfully flight tested.

The joint efforts of ADA and HAL, along with a host of DRDO, DGAQA, CSIR labs, PSUs, private industries and academic institutions have successfully brought the Tejas to its IOC with CEMILAC having certified it for release to the IAF in production.

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