AIRWORTHINESS CERTIFICATION OF TEJAS - LIGHT COMBAT AIRCRAFT (LCA) FOR INITIAL OPERATION CLEARANCE (IOC) AND CHALLENGES FOR FINAL OPERATION CLEARANCE (FOC)

M. Peter Arun; Pradeep Mahuli; P. Jayapal
Centre for Military Airworthiness and Certification (CEMILAC)
Marathahalli Colony Post
Bangalore-560 037, India
Email : peter.arun@cemilac.drdo.in

Abstract

Tejas - Light Combat Aircraft is an indigenously designed and developed fighter aircraft, with cutting edge, State-of- the- Art technologies. The technologies include, Quadruplex redundant digital Fly-by-wire control system, advanced Avionics, Glass cockpit, Composites for primary structures and dual redundant processor based utility services management systems. LCA development with over 2500 plus successful flights has been accorded the IOC. The IOC marks the culmination of a long journey of aircraft development and rigorous testing to meet international standards of safety and reliability so that the aircraft can be inducted into the country's Defence forces to serve its intended purpose.

Introduction

Any ab-initio developed military aircraft that enters Indian Airforce must possess Airworthiness Certification from the Centre for Military Airworthiness and Certification (CEMILAC, DRDO), Govt of India, and Tejas-LCA is no exception to that. CEMILAC is an independent organization that takes the responsibility to declare that the aircraft produced is Safe, Reliable and also meets the desired Performance as specified for IOC. This paper describes the Certification approach and methodology adopted for certifying LCA. The challenges for FOC are also described herein.

Certification Methodology

Several generations of technology had to be caught up during the making of LCA to make it contemporary. This has put a huge onus on the designers as well as the certification agency. As several technologies had to be developed from scratch with practically no prior wherewithal, it has been a challenge to both designers and certification agency to cope with the technological demands and the safety they needed to posses. Certification methodology therefore, had to be exclusively evolved and rewritten in the case of LCA. Considering this situation, Certification of LCA had to be approached concurrently and progressively, where the certification team is involved right from the conceptual stage and throughout. The methodology could be broadly classified into four stages

- Design Evaluation
- Ground Testing
- Flight Testing
- Certification

This has been addressed at three levels, LRU level, System level and finally Aircraft level.

Design Evaluation

The top level requirements of the Air Staff Requirements (ASR) are broken down into quantitative individual system requirement specifications. Since the specifications will henceforth guide the design and development of the program, it is extremely important to bring in the certification requirements of Safety and Reliability at this stage. Guidelines from Military Standard and other globally accepted standards are imbibed in the specifications. The feasibility of the design to do the intended function is verified with analysis and simulation. Safety through FMECA and Hazard analysis is also established in this stage. The design is progressively frozen through PDRs, CDRs and other reviews, through constant interactions with designers, addressing every aspect of design and certification.

Program Reviews: A project of this magnitude can only be monitored and accelerated through reviews, addressing

various design, manufacture, maintenance and certification issues. Apart from the Preliminary and Critical Design reviews in respect of each system, some of the important reviews where CEMILAC was an active memberare discussed herein.

Yearly Review:

- To monitor the progress of the program by Raksha Mantri

Half Yearly Review:

- To monitor the progress of the program by Scientific Adviser to Raksha Mantri

Quarterly Reviews:

- Empowered committee, to monitor the progress of the program by Chief of Air Staff, Air Head Quarters
- AOMs review, review of maintenance aspects by AOM, Air Head Quarters

Monthly Review:

- Tejas Program Review, for project monitoring by DCAS, Air Head Quarters
- Progress review by Director General, ADA

Weekly Review:

- Program Co-ordination Team (PCT), to resolve design issues amongst various system designers
- Flight Development Program review (FDPR), to resolve issues between design and development teams for system and LRUs.
- Design, Development Certification Review (DDCR), to address certification issues and design
- Design Production and Quality review (DPQR), to address quality and manufacturing issues
- Flight Test requirement Generation and Certification (FTRG&C), to address flight test requirements towards Certification
- Technical control group (TCG), to maintain shop floor activities towards availability and readiness of aircraft for flight testing and plan weekly flight activities.

Apart from these reviews, Flight Readinesss and Review Board (FRRB) and Safety Review Board (SRB) were conducted to address Safety issues before the first flight and flights after major design change to the prototype. CE(A) CEMILAC chairs the FRRB and SRB, with independent external experts as members along with the stakeholders.

Ground Testing

Verifying whether the design is correct and validating if the system is doing the intended function can only be checked through testing. The testing requirement has enabled setting up of various ground test facilities for functional and failure mode testing of all systems. Test rigs help in verifying the design, identify design flaws and also help in fine tuning the design. CEMILAC is a party to defining the technical specification and the Acceptance Test Schedule of the test rig. The test case matrix and schedule for testing the system is thoroughly examined for its adequacy and correctness. The pass-fail criteria is also established before the commencement of the tests. The test results are closely examined for the adherence to the Pass-Fail criteria.

Flight Testing

Flight testing enables further validation of the system and aircraft performance in totality. Before the first flight of a prototype a Flight Clearance Note (FCN) is generated capturing all the operational conditions, limitations and flight envelopes. Safety of flight is thereafter ensured through adherence to the FCN. Every test flight is accompanied by a Flight Test Schedule, thoroughly scrutinized and co-ordinated by CEMILAC for its safety.

Flight Clearance Note: In case of certification of LCA, there were 12 different types of prototype and LSP aircraft manufactured for flight demonstration with different ESOP, store configuration and flight envelope. CEMILAC issues FCN for each vehicle for development flight trials with the conditions of release and limitations. The envelopes would be expanded progressively after gaining sufficient confidence from the flight data analysis of previous flight. The FCN covers the overall objective of flight trials on a particular prototype vehicle. Each sortie however is preceded by a flight schedule duly co-ordinated by CEMILAC.

Route to Certification for LCA towards IOC

CEMILAC, has consolidated the IOC certification requirements through a "Route to Certification for LCA towards IOC" document. The primary objective of this document is to consolidate the activities already completed towards certification and the pending tasks such as analysis, ground trials and flight testing towards achieving IOC requirements. This document also brought the compliance methodology for various tasks such as the Military Standard, System specifications, ASR, store configura-

tions, Qualification of LRUs followed by flight demands. ADA/HAL/NFTC were required to submit the appropriate inputs with relevant documents towards completion of certification activities. In addition, ADA and HAL were also to prepare and submit the documents with compliance matrix of ASR/ MIL-specs duly co-ordinated by CEMILAC. This document became the guideline document for all the stakeholders towards certification.

LRUs Certification

A total of 344 LRUs have been identified for LCA to meet the design requirements. 177 LRUs are indigenously developed and 167 LRUs are bought-out-items (BOI) from various foreign sources. The bought out ones were off the shelf items. CEMILAC thoroughly examined the qualification test report which were already available. In some cases, based on Indian conditions, delta qualification tests were also suggested. Some BOI were found to be already in use on other aircraft such as Mirage, Jaguar, etc. These were considered on the basis of similarity / analogy and envelope matching with respect to LCA. In some cases the BOI were selected from IJT aircraft which was not meeting the LCA envelope. These LRUs were required to be re-qualified to meet the LCA requirements. For the indigenous LRUs which were exclusively made for LCA, CEMILAC was involved in framing the technical specifications and also the Qualification test schedule. These LRUs are firstly cleared for development flight tests and based on their performance feedback and the documentation checklist evolved by CEMILAC, they were cleared through the issuance off Type Approval or Service Clearance Certificate.

System Certification

This is an essential stage of aircraft certification. The consistency in system performance in an integrated form can only define the overall performance of the aircraft. In general, the system certification covers the LRUs qualification for its intended role in the system followed by testing of the system in an integrated manner on ground as well as in flight with all other systems working in together. The LRUs clearance accorded to the development flight trials is based on the SOFT/LQT for general systems. However, for flight critical LRUs, the LRUs has to undergo for FQT envelope before undertaking the development flights. Demonstration of the system functions during flight in various environmental condition and full envelope of the aircraft is also an essential requirement for system certification. The system is initially cleared for development flights with a Certificate of Design (COD). The COD contains the system description, the specifications, testing and the limitations. Based on the performance feedback of the system during the development flights, and the detailed documentation checklist, the system is accorded the System Certificate. CEMILAC drafted a detailed checklist for complete certification process of all 17 systems of the aircraft. Weekly reviews with the designers were conducted to take stock of the status and to clarify the certification requirements. This process has helped in expediting the system certification process where every system was individually cleared and certified for it performance and safety over 2500 test flights including outstation trials such as the Hot weather, Cold weather, High altitude, Sea level and Weapon trials.

The design and testing of individual systems were evaluated as against compliance of top level requirements of the ASR and relevant Military standards. There are 43 top level and several associated Military Standards to comply. CEMILAC has ensured that Tejas is of international standard by complying to each and every requirement of all the relevant Military standards.

General Systems

Structures : Airframe of LCA contains both 55% Metal and 45 % Composite in equal proportion. As composites were used extensively for primary structures for the first time, the material characterization including environmental effects and design features were evaluated extensively. The possible flight load cases were generated and critical load cases were identified. Components and airframe (MAST) were assessed evaluated for strength and stability through extensive analysis and ground tests. Ground Vibration Tests(GVT) were carried out for various configurations on the flight worthy airframe to identify the vibration characteristics and the Aeroelastic analysis were performed on the updated model. The Flutter predictions were verified through progressive envelope expansion by Flight flutter testing. The Servo-Elastic coupling of Flight Control System were assessed and verified through Structural Coupling Tests(SCT) on the flight worthy airframe for various stores configurations. The initial life for the airframe were arrived by analysis and satisfactory strength tests. The full life of airframe will be assessed through Main Airframe Fatigue Testing (MAFT). All applicable Military Standards have been thoroughly verified for design/testing compliance by keeping the safety and performance requirements in view prior to according airworthiness clearance.

Avionics / Electrical : ADA has designed the avionic architecture of LCA with Open Architecture Computer (OAC) as a heart of not only avionic system but driving the parameters from almost all the other systems. The avionic architecture is designed with the contribution of 53 LRUs. The process comprises of study of technical specification and design document, evolve the testing procedure for testing of LRUs in stand alone mode followed by testing in integrated set up. The system is then integrated on the aircraft and again tested for its function in presence of other systems for their Electromagnetic compatibility. Based on satisfactory ground operation, the flight clearance is accorded by CEMILAC for its demonstration under all conditions/ envelop of aircraft operation. The performance and reliability data is looked into before certifying.

Mechanical: Mechanical system consists of Hydraulics system, Undercarriage system, Environmental Control System, Fuel system, Propulsion system, Secondary power system and Fire Extinguishing System, Escape System and Brake Parachute system. There are more than 150 LRUs (indigenous and imported) in the mechanical system. The mechanical systems are mostly software driven and microprocessor based. The system specifications were finalized based on the top level requirements and applicable MIL standards. The design/analysis documents have been examined for design adequacy. The detailed test schedule has been formulated by keeping all the functional, safety/redundancy requirements in view to qualify the system in the test rig and aircraft prior to engine ground run. The test results have been verified for the designed values. All applicable MIL documents have been thoroughly verified for design/testing compliance by keeping the safety and performance requirements in view. The predicted reliability of the system has been verified. The various parameters of the systems which need to be monitored were identified. The flight test points have been formulated to evaluate the system performance. The system performance is assessed for various environmental and weapon delivery conditions. The airworthiness clearance is accorded with limitations wherever applicable.

Certification of Flight Critical System - IFCS : LCA uses quadruplex redundant digital fly-by-wire Flight Control System. This is a flight safety critical system. This comprises of FCS Software and Hardware. The ground test phase involves rigorous testing on a test rig called Iron Bird. This is a system in the loop testing of the entire FCS. The rig consists of an actual flight standard cockpit with flight standard LRUs. The actual flight hardware like the actuators, hydraulic pumps, tubing, plumbing, are installed on the rig, replicating the aircraft layout. The testing is undertaken in a phased manner. The testing comprises of LRU interface tests, end-to-end open loop tests, closed loop pilot-in-loop-tests and the fault free tests. CEMILAC independently examines the test schedule for the adequate coverage of the normal and failure mode functionalities, correctness of the test procedures, correctness of the expected values and the Pass-fail criteria. The test results are scrutinized for their adherence to pass-fail criteria. Every bug found is flagged with a unique Request for Action, which is tracked till it is satisfactorily closed. Version upgradation is address through fault tree analysis and regression testing. CEMILAC also ensures that a strict configuration control of hardware and software is maintained throughout the testing cycle of the FCS. The Flight Test phase involves monitoring and recording of all critical parameters during flight. The performance of the FCS is carefully studied through post flight data analysis of its parameters across all the 2500 plus development sorties.

Software Certification : There are a total of 33 software embedded system on LCA. Software is used in flight safety critical Flight Control System and mission critical Avionics system. A bug in the software could therefore infringe safety or a mission. Software was hence certified through stringent independent verification and validation through out its development life cycle, right from specification, design, implementation and testing at various levels. Flight control system safety is established through IVand V and testing. During evaluation utmost care has been taken to cater for the realization of safety critical functionality and hazards introduced through the software realization. The test schedule is verified for its adequacy, correctness of test scenario and method of testing. Safety critical parameters are monitored throughout testing to capture system level failure tendency and nuisance failures. A Strict configuration control management is ensured during test. The test results are analysed to the required accuracy. Software upgradation is undertaken through impact analysis and regression testing. It can be stated that Safety and Reliability of embedded airborne software are achieved through managed process, product development and systematic certification process.

Weapons and Store Configuration of LCA : Being a fighter aircraft, LCA is ably equipped with weapons and stores to enhance its lethality. Weapons and stores include Missiles, Bombs and Drop Tanks. Integration of weapons and stores on LCA is a critical task. This had to be approached progressively and with extreme caution. The

primary objective of integration is the safety to the parent aircraft during carriage & release and system performance. During the integration of missile, extensive tests on avionics rig to verify the functioning of signal path from pilot press to weapon release point were carried out. It was mandatory to check the effect of exhaust plume on the structure as well as on the engine air intake with firing of static missiles on ground. Static firing of missile was done to verify thrust, plume geometry and temperature map. The results of this firing was useful in fine tuning of the missile motor and fine tuning of the CFD model to simulate the plume geometry for various altitude and mach number. The temperature mapping was essential to verify the structural integrity of the composite structure in the vicinity of the missile, especially the control surfaces and to assess the thermal shock compatibility of the engine blades. Hung firing study was important to establish the controllability of the aircraft. CFD separation studies and stress analysis for safe separation were also carried out during the process of clearance of missile for carriage and release. Being Safety critical, the hazard analysis, fault tree and the FMECA is carried out.

The OAC and SMS software for weapon release in various modes was thoroughly verified in avionics rig. Pit drop test concept followed was followed for the integration of Drop tanks and bombs to verify the functioning of ERU and separation of the store. The strength aspects and the effect of store on flutter and separation studies are carefully studied. CEMILAC conducts a Safety Review Board to ensure compliance to Safety and other certification requirements. The weapon release, jettisoning envelopes and other system aspects are adequately captured in the FCN.

Compliance of Military Standard /Specification

ASR calls for compliance to Military Standard. Also, following Military standard has a commercial viability that would enable world-wide operation of the aircraft and hence it is preferable to follow these requirements. While taking up the task of design and development of LCA, the designers have taken the relevant Military standard into consideration vis- a- vis requirements specified in ASR. A total of 43 main Military stds/specs. associated with several other standards were considered for design of aircraft and its system. CEMILAC has taken a lead role to understand the compliance of these standards with respect to design of LCA and performance expected by airforce during operation of aircraft by squadron pilots. Each paragraphs of these standards are meticulously studied and compliance sought through documentary evidence. Non Compliances are carefully looked at from applicability and safety.

Compliance of Air Staff Requirements

Air Head Quarters released the ASR of LCA on 1985. This broadly captures the qualitative requirements of LCA. During induction to Indian Airforce, it is the role of CEMILAC to declare whether all the paragraph of ASR has been met. In this respect, CEMILAC examined all the ASR requirements and established its compliance through design, analysis and testing (ground and flight).

Weekly Review of Certification Status

Weekly reviews of the development status was an integral part of certification which has also accelerated the certification. The reviews broadly focused on the LRU certification status and the System certification status. System wise detailed reviews were conducted to identify issues to be corrected with respect to certification. The documentation with respect to 17 systems and 344 LRUs were also discussed in these reviews.

Release to Service Document (RSD)

A Certified aircraft is released to Service along with a release to service document. CEMILAC compiled the "Release to Service Document (RSD)". This document clears the aircraft for user trials. This document captures the System Specification, the compliance status of the Air Staff Requirements and the Military Standards. This document clearly defines the Aircraft Build Standard including both the hardware and the software along with the life limitation of the LRUs. The document also clearly brings out the Mass and the C.G requirements with cleared stores configuration along with the cleared Operating Envelopes for trials. RCMA(A/C) also ensures the closure of all Pilot and Maintenance observations during the development. Closure of Defect Investigations and implementation of the recommendations are also captured in the document. Finally the document consolidates all the system limitations for operation. The RSD was handed over to The Chief of Air Staff along by the Honorable Defence Minister to the Govt of India during the IOC function.

Challenges for FOC

IOC is based on the targets set by the user, in this case the Air HQ. Some advanced features are reserved for FOC as desired by the Air HQ. The feedback from the user

evaluation along with the advanced features together make up the requirements for FOC. Some of the FOC requirements and challenges are discussed.

Weapon Integration : The following challenges lay ahead for FOC. Integration of alternate missiles and Bombs, Guns and Guided weapons, clearance of existing stores on alternate hard points and demonstration of all configurations, tandem carriage and delivery of bombs, equipping with anti-shipping and reconnaissance capability and Night weapon delivery. The Certification task will involve, Structural integrity studies, revisiting flutter capability, freezing Wind tunnel test requirements, CFD store separation studies, mass , c.g and stability studies from the CLAW point of view. Defining the envelopes for carriage and release, progressive clearance approach in speeds, Gs, and Mach No and release of Certificate of Design and the FCN.

Drop Tank Integration : Integration of Central line drop tank, existing Drop tanks on alternate hard point and integration of Super Sonic drop tank.The Certification tasks mentioned above holds good for drop tank integration as well.

Fuel System: Integration of Fixed Inflight Air-to-Air refueling Probe. This feature extends the aircraft strike range and therefore its lethality. Issues regarding structural integration, visibility, clearances, functionality needs to be ascertained.

Brake System: Refinement and modification in brake system and brake parachute system its upgraded performance to be addressed.

Radar: Integration and verifying functionality with all modes with alternate radar to be addressed.

Flight Control System: Care free maneuvering and advanced autopilot features are to be added. The certification tasks include software IV&V, freezing of test case matrix, Software level and system level testing at Iron Bird.

Landing Gear: Clearance to higher All-Up-Weight and refinements based on user feedback. The certification tasks include design evaluation, identification of qualification requirements and testing.

Outstation Trials: Demonstration of aircraft capability during the High altitude Cold weather, High Altitude Hot weather, Low altitude high speed run in hot weather and the armament trials. Ensuring freezing of SOP and identification of appropriate flight test points for demonstration and certification will be the required tasks.

Avionics and Instruments: Integration of HUD with raster scan, Night Vision compatible, evaluation of IFF in Air-to-Air mode. Design evaluation and testing will form the major certification task.

Pilot Percentile Population: Clearance of Ejection seat and cockpit assessment with the specified pilot percentile population to be addressed.

Aircraft Performance: The short fall in performance requirement with respect to max-min ‘g’, sustained acceleration, instantaneous and sustained turn rates to be met for FOC.

General System: Clearance of long duration sortie in respect of AMAGB and integration of advanced JFS to be addressed.

Survivability and Reliability: Meeting the reduced RCS requirement, demonstration of reliability figures and clearance of LRUs for Full Life will be quite a challenge for FOC.

Wake Penetration: Qualification of 6g upon 6g penetration. Establishing aircraft safety during penetration is quite a challenge.

Miscellaneous Issues: Closure of all flight and maintenance RFAs, closure of Defect Investigations and other production related issues along with completeness of Publications and availability of TTGSEs will also have to be addressed during certification of LCA for FOC.

FOC of LCA will be a challenge with plenty of design and testing issues to be dealt with. The requirements are well understood and the road map for certification methodology has been laid out. The approach will be concurrent with emphasis on safety.

Conclusion

A novel certification methodology has been evolved and adopted for the airworthiness certification of a complex fourth generation multirole fighter aircraft. CEMILAC had chalked out stringent airworthiness requirements for LCA and meticulously followed them throughout the program development. This has resulted in

satisfactory evidence generation to aircrafts Safety, Reliability and Performance. Tejas-LCA was a big challenge to CEMILAC, as for the first time in the country a project as complex as LCA, has been certified. Yet again, CEMILAC and its associated RCMAs have lived upto their potential and have performed admirably well to meet the demands of this project. The success of LCA IOC, bears testimony to the valuable contribution made by CEMILAC to the Aerospace development of our country. The Challenges of FOC are well understood and CEMILAC is well prepared and confident of meeting the FOC of LCA with proven approach and methodology.

Acknowledgement

CEMILAC is thankful to DRDO for the constant encouragement and support received throughout the project. CEMILAC wishes to remember and thank all its Scientists, both serving and retired, for their untiring efforts and contributions towards IOC of LCA.