DESIGN AND DEVELOPMENT OF FLIGHT CONTROL SYSTEM FOR LIGHT COMBAT AIRCRAFT - TEJAS AT ADE

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Abstract

The design and development of Flight Control System (FCS) for LCA was started in early 1993. In order to stabilize the airframe and achieve the desired performance over the entire flight envelop, it incorporates a quad redundant full authority Digital Fly by Wire (DFBW) flight control computer. The system is built around Digital Flight Control Computer (DFCC) containing four identical channels. The processor outputs drive the actuators through pulse width modulated amplifier for primary actuator of Direct Drive Valve (DDV) type. The Operational Flight Program (OFP) software executing in all the channels is identical and is configured as a single Computer Software Configuration Item (CSCI). The control inputs are provided by the pilot control sensors, inertial sensors, airdata sensors, cockpit panels etc. The FCS outputs include driving the flight control actuators, 1553B avionics data etc. The OFP software includes functions of real time execution, cross channel synchronization, device driver, analog and discrete I/O, redundancy management, control law implementation, continuous built-in-test (BIT) and pilot initiated BIT and maintenance BIT. Such a complex Digital Flight Control System (DFCS) has been extensively tested for verification and validation to check the performance against requirements respectively in sophisticated test rigs. A cohesive design of various systems of aircraft to satisfy the demands of FCS requires a robust Control Laws (CLAW). To design and develop the control law, ADE has developed a Real Time Simulator (RTS). This is used for evaluating control laws and handling quality assessment by LCA test pilots. Due to its robustness this simulator has been upgraded to Full Mission Simulator (FMS) for training LCA squadron pilots. Some of the cockpit panels like Flight Control Panel (FCP) and Flight Test Unit (FTU) which are required to evaluate the performance such as flutter effect and parametric identification are also developed at ADE.

Introduction

There has been revolutionary development in the areas of combat aircraft FCS and avionics system in last 3 to 4 decades with the advances in electronic technology. Digital computers have replaced the analog ones and using complex real time software algorithms, these controllers have optimized the performance of A/c being controlled and execute in real time beyond human capabilities. The reliability of the electronics system has been obtained to the same degree of earlier mechanical systems by use of redundant computers, sensors and actuators etc. Also the associated software reliability has been ensured by following highly controlled software development process and exhaustive testing/ verification and validation at various levels to eliminate software errors.

For Indian Light Combat Aircraft (LCA) and its variants like LCA-Mk2, LCA Air Force trainer, LCA Naval trainers, LCA navy fighter, Quadruplex digital fly by wire flight control system has been developed by Aeronautical Development Establishment(ADE) and the system has been integrated and flight tested in LCA and its variants, except LCA Mk2.

System Architecture

Since LCA and all variants are unstable, they can be flown only by using a fly by wire system without which the oscillation will set in very quickly and the aircraft will become uncontrollable.

The LCA FCS is a full authority Quadruplex DFBW flight control system with no back up. The system is built around DFCC containing four identical channels of computer. Although packaging is one, all channels are electrically independent including the input power supply to the computers. Air data system is built around the airdata computer. Four distributed Air Data Computers (ADC) are connected to DFCC's corresponding channel through RS 422 link. For LCA naval variant the DFCC is same, while the ADC is replaced with LEVCON Air Data Computer (LADC) so that additional LEVCON actuator, required for naval LCA can be driven by LADC. LCA trainer version has front and rear cockpit. For this Rear Flight Test Panel and Digital Interface Unit which is interfaced with front and rear cockpit, instead of directly connecting to DFCC are developed at ADE, so that a complete solution of flight control system is available. The basic system architecture is shown in Fig.1. For LCA Mk2 servo-controlled Airbrake actuator and second Angle of Side Slip (AOSS) vane are added. Accelerometer Sensor Assembly (ASA) includes longitudinal sensors also. The system architecture with variation is shown in Fig.1. The control law designed and developed by national control law team is evaluated and verified by test pilot on real time flight simulator facility. The real time simulator facility is upgraded to full mission simulator to be used as a training simulator.

Design Features of Flight Simulator

The system has evolved over the years with LCA programme and at present a state-of-the-art facility established inside a 9 meter dia. FRP dome is supporting the evaluation of the handling qualities of Control Law before the software is integrated on to the Quadruplex Digital Fly by wire Computer. The RTS (Fig.2 and 3) developed on distributed Open Architecture uses extensively COTS based systems for the development and has high speed deterministic data link for low latency data exchange on the simulator sub systems to ensure behaviour very close to actual aircraft flight. With a wide field of view (180 deg - A_Z and 80 deg EI), provides a good coverage of the real world scenario for effective evaluation.

With the variants of LCA such as trainer, Production standard, the evaluation workload called for setting up of an independent facility in one more 9 meter dia. FRP dome. This was specifically configured for the evaluation of LCA Naval variant control law. The projection system provides 200 deg (A_Z) and 110 deg (EI) enabling wider coverage during landing phase for smooth deck landing. As the naval variant was required to fly from Goa airbase, and from m a static Shore based test facility including the ramp that is similar the deck take off, entire simulation set was created on the new facility including Goa airbase visual scenery including sea with its current and change of states, ramp creation and integration of the flight software cleared d for Ski Jump (Fig.3) take off and its evaluation and training for the first sortie by the test pilots.

An essential requirement o of LCA squadron is the training device for r imparting training to the ab-initio pilots of LC CA squadron from IAF. The RTS developed at ADE with its very high level of fidelity w was the obvious choice for this task and at t present the dome based RTS has been upgraded to a Full Mission Simulator (FMS) (Fig.2). The FMS has at its core a cockpit environment that is very nearly a replica of the LLCA cockpit with all the avionics displays, indicators, front and side panels fitted with the actual aircraft units. The Mission computer that is used on the aircraft is used for mission planning and training. In addition the trainee pilot gets trained on the start u up procedures, fault and emergency procedures s etc. A state-of-the-art Instructor Operator Station (IOS) is used to operate, monitor a and control the FMS. Thus an indigenous solution both for design and training support t has been established in ADE.

Design Feature of Computers (DFCC, ADC, and LADC)

DFCC (Fig.4) is based on Intel 8096 60MC 32 bit microprocessor. The I/O control for various types of analog and discrete inputs are carried out by a state machine called serial interface link controller. The processor outputs derive the actuators s through Pulse Width Modulated (PWM) amplifier for primary actuators of Direct D Drive Valve (DDV) type. A high speed serial link called Cross Channel Data Link (CCDL) is used for communication among the four channels. The communication between processor and the external ground test equipment is controlled through 32 bit transputer based Serial Peripheral Interface Link (SPIL) or link controller. DFCC incorporates the state-of-the-art technology for chassis, Printed Wiring Boards (PWB) assembly and inter connections between front panel connectors and motherboard. The e packaging density on PWB is very high using m mostly SMDs. The chassis is redesigned for LCA Mk2 for easy maintenance with ARINC connectors. The computer is forced air cooled but has been designed to operate for one e hour without cooling air to allow pilot too safely bring back the aircraft to land.

Since operational flight program functionality exceeded the execution time limit of more than 75% of 12.5 msec and the obsolescence of airdata transducers, ADE developed a single node Qadruplex Air Data Computer (Fig.4) system that collectively handles the air data processing based on Intel 80960MC 32 Bit processor with following salient features

- High and Re-Programmable XILINX FPGA host IP Core
- Inter ADC communication controller
- Integrated motherboard and flex assembly
- Built-in-testability feature with 90% coverage
- Design compliance to MIL-STD-704D, Mk-STD-461 C and MIL STD 810E IEEE 1149.1 compatible scale chain

Naval variant of LCA require LEVON actuators to be scheduled by flight control computer to meet this requirement and to aid for other functionalities like

- Ski-Jump ADCs are replaced with LEVCON Air Data Computer (LADC) based on Intel 80960MC 32bit
- Re-programmable XILINX FPGA hosts FDC
- Glue Logic event scheduling
- Cross channel data link and communication controller
- Closed loop servo electronics with built in testability feature
- Design compliance is same as that of ADCs standard

To cater the additional requirement of LCA-Mk2, maintenance issue on A/c, component obsolescence, ADE is currently designing DFCC Mk2 which uses mpc5566 microcontrollers. MIL-38999 connectors and 1553B connectors in front panel are replaced with ARINC-600 series connectors for ease of maintenance.

CPU module is redesigned to replace i960 with power PC5556 and FPGA used in place of CPLP1, analog I/O modules are redesigned to address the additional requirements and change in sensor and actuators.

Design Features of FCS Sensors

Redundancy level of LCA FCS sensors vary with their importance to meet the probability of loss of control requirements. The critical rate, acceleration, pilot command sensors are quadruplex, airdata sensors are triplex and few non inertial parameters like probe heaters currents are simplex. The sensors are designed to able to perform BIT tests from the DFCC to ascertain their health before each flight. A few leading specifications of some of the sensors are follows.

Rate Sensor Assembly (RSA) has a natural frequency of 50 Hz and senses rates, which range between ±300°/s (Roll), ±60°/s (Pitch and Yaw). The resolution and thresholds are 0.005°/s. Acceleration Sensor Assembly (ASA) has a natural frequency of 100Hz and measures normal and lateral accelerations in the range ±13 g and ±4.5 g respectively. The thresholds are 2 mg (Normal) and 0.2 mg (Lateral).These are forced balanced type in nature.

There are four pressure transducers fitted inside each ADC. The pressure transducers get the input from various air data probes and then measure total pressure, static pressure and differential pressures. Theses ranges from 35 to 1300mbar (Ps); 35-2700mbar (Pt), 35-1500mbar ($P_{\alpha1/\beta1}$ and $P_{\alpha2/\beta2}$) within an accuracy of 0.02% F.S. Apart from probes there are Angle of Attack (AOA) sensors, AOSS sensor which have qudruplex LVDT and measure a range between ±45°.

Design Features of FCS Actuators

Primary control surface actuators consist of Elevons and Rudder actuators. They are quadruplex in electrical and dual in hydraulics. The operating pressure is 280 bars. The state-of-the-art DDV type of control is employed in these actuators for weight reduction for a given redundancy level. These actuators are designed to be able to perform BIT tests automatically from DFCC. The secondary control surface actuators consist of 6 leading edge slat actuators, which are of 3 types. Secondary actuators are single hydraulics operated with electro-hydraulics servo valve and controlled by dual electrical system. The air-brakes use open loop jacks operated from the cockpit by electro selector valves. These servo actuators have a frequency response of 9 Hz and have a stall load capability of 2-10 tons.

Design Features of OFP

The LCA FCS OFP software is developed using 'Ada' language. The reasons to choose 'Ada' include: standardization, support for software engineering principles, strong data typing, readability etc. The development was carried out using software tools like cross compiler, in-house developed test tools and configuration tools. The design, development and technical reviews of the software have been carried out as per tailored version of DoD standards. The Software Development Plan (SDP) thus generated describes the standards to be followed for design, coding and testing. The phases in the life cycle of LCA FCS software development include: system requirement analysis, software requirement generation and analysis, preliminary and detailed design, coding, CSU/CSC and system integration testing. The software primarily consists of: initialization, input acquisition, redundancy management, control law computation, perform output drive, built in tests, synchronization and executive. The general feature of the software reflects a unique type of system, which includes closed loop real time operation, relatively high iteration rate, redundant computational channel, safety critical, frame synchronization. Timing consideration is the most distinctive and challenging characteristics of this software. Various tasks are scheduled at different rates for which a pre-determined multi-rate scheduler is designed. Other design constraints depend upon frequent requirement changes, load balancing, between time frame and computational speed optimization. Over the years the OFP software have undergone a number of updates incrementally for expansion of envelop of the aircrafts and various store configurations. The emerging computational needs in the flight control laws and requirements of the advanced Air Data Algorithm necessitated offloading of airdata computations into a new on board computer called Air Data Computer. The flight control computer (DFCC) software is already upgraded with necessary change with respect to inclusion of airdata computer. The various configurations of the aircraft for Airforce and Navy in fighter and trainer modes incorporates many advanced features like auto pilot, wake protection features, estimation of attitude based on Kalman filter etc. Most of the features required for carefree maneuvering of aircraft is flying or in advanced stages of development. To meet the squadron operation requirements and maintenance requirements Built-in-test features have been upgraded. The navy aircraft operational flight program incorporates the ramp take-off functionality and higher modes of SKI jump take off are in development. The software also had to cater the configuration differences in Air Force and Navy configuration in fighter and trainer modes of the aircraft.

Flight Control Panel and FCS Test Unit

ADE has developed the two panels also which house some important switches and lamps required for Flight Control System in the cockpit (Fig.5).

Rigs Development for FCS

Flight control system being safety critical, it requires a process oriented critical tests to be conducted. Each type of LRUs of the flight control system are subjected to acceptance test/ performance tests, qualification tests. To carryout these tests special type test equipments are built. In addition integrated testing of flight control system, hardware software integration tests and validation tests at iron bird rigs are also necessary. To carry out the integration tests ADE has developed engineering test rigs. Engineering test station is a real time automatic/ manual test station used for functional verification of the flight control system of LCA. It is used for DFCC ATP, hardware software integration, Verification and Validation of FCS in the environment Lab, Minibird and the Iron Bird sites. It provides the facility to simulate the FCS related sensors, actautors, aircraft interfaces with provision for connecting real sensors and actuators including fault insertion capability. For testing ADC with onboard software AIRDATS and for testing LADC with onboard software AIRDATS-ENHANCED rigs are used.

ETS consists of following :

- VAX based host computers
- Multibus I based I/O subsystems
- DIN 9U I/O simulator

VAX provides non-real time user interface and control. Multibus I/O subsystem performs real time checks, execution of the actuator models and control and monitor of the signal conditioning function. Laboratory Test Monitor (LTM) provides all the capabilities required to test DFCC including downloading of operational flight program. All the resources and interfaces of DFCC and ETS are the memory mapped and can be accessed from LTM through predefined symbols. Obsolescence of multibus based electronic subsystem hardware and associated software components necessitated the development of Advanced ETS (AETS) (Fig.6). AETS is the real time multi processor state-of-the-art cPCI based electronic subsystem including the latest system controller and RTOS along with custom designed I/O cards. VAX based host computer which was a separate subsystem is now an integral part of AETS which is handled by system controller along with electronic subsystem. Advanced iNtegrated Test Environment System Software (AITESS) provides user friendly graphical interface along with the advanced test script feature to carry out manual and automated tests on the hardware and software exhaustively. The reduction in weight and volume, AETS has got improved mobility.

AIRDATS (Fig.7a) and AIRDATS-E (Fig.7b) are real time multiprocessor PCI based system using current state-of -the-art hardware and software (RT-Linux) for verifying all the four ADC/ LADC simultaneously. ITESS software enables the test engineers to carryout manual or automated tests on the target hardware and software extensively

Conclusion

It is a testimony that more than 3000+ flight trials of Tejas (LCA) and its variant flown by more than 30 test pilots without any real failure in FCS System.

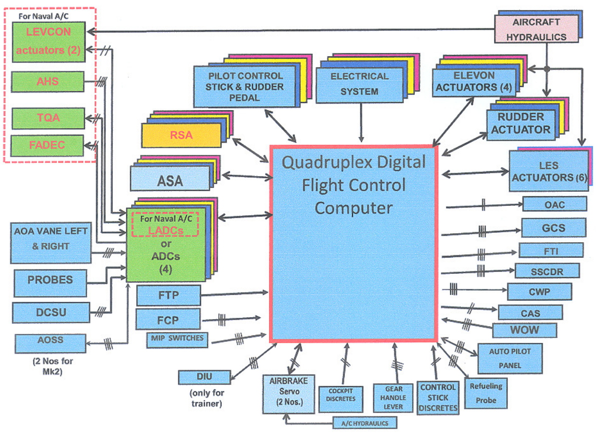
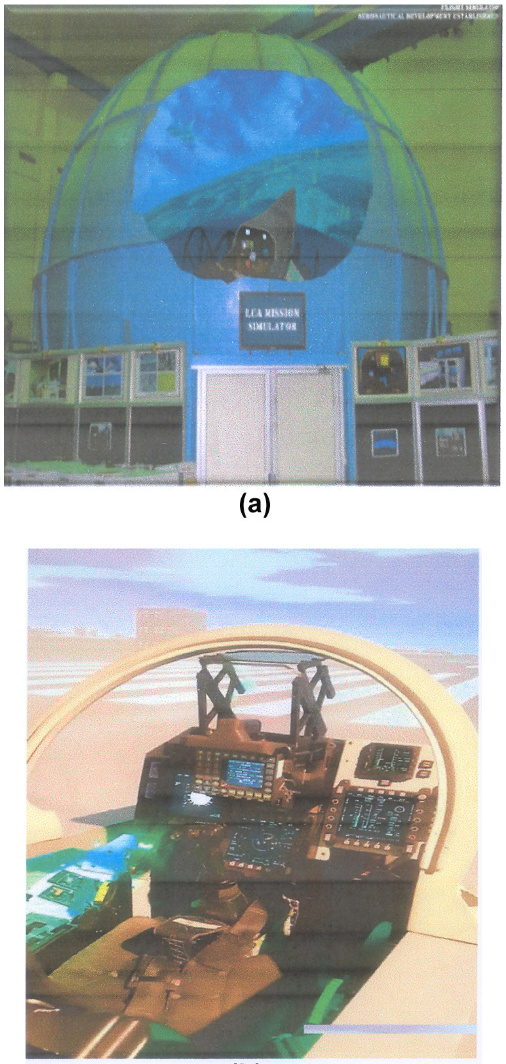


Fig.1 LCA-FCS Architecture

Acknowledgements

This is a team work. The author therefore wishes to place on record the contribution of the personnel of the following groups: Flight Control Computer Division (FCCD), Software Engineering Division-LCA (SED-LCA), Flight Control Test System (FCTS), Flight Simulation (FSIM) and Project Office LCA-FCS of ADE. Other organizations and personnel like IFCS-ADA, RCMA (A/C), DGAQA, BEL-Bangalore Complex, NAL and NFTC associated directly or indirectly with LCA-FCS development are also greatfully acknowledged.



(a)

(b)

Fig.2 (a) Dome Based RTS and (b) FMS cockpit Layout

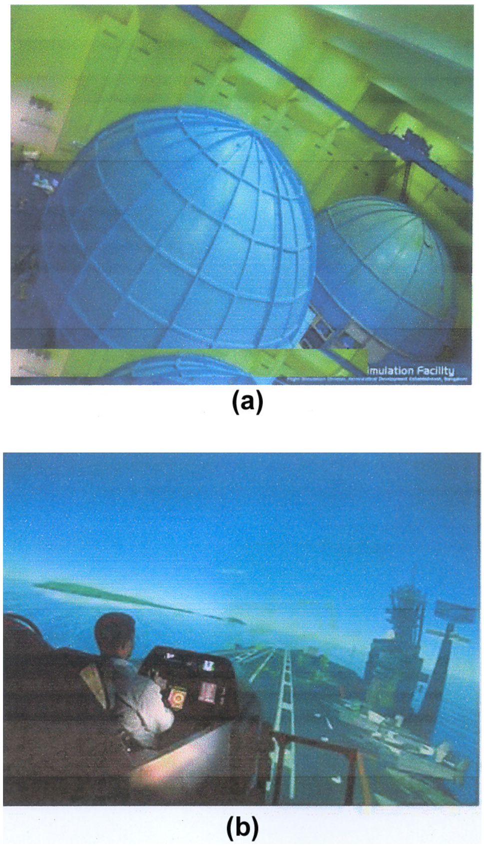


Fig.3 (a) Twin Dome Simulation Facility and (b) Deck Simulation with Ski-Jump

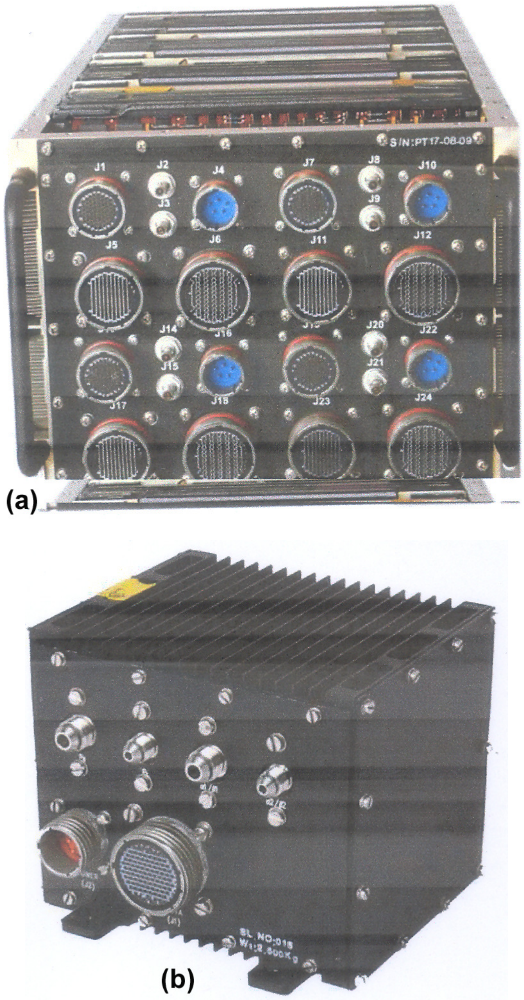


Fig.4 (a) Digital Flight Control Computer and (b) Air Data Computer

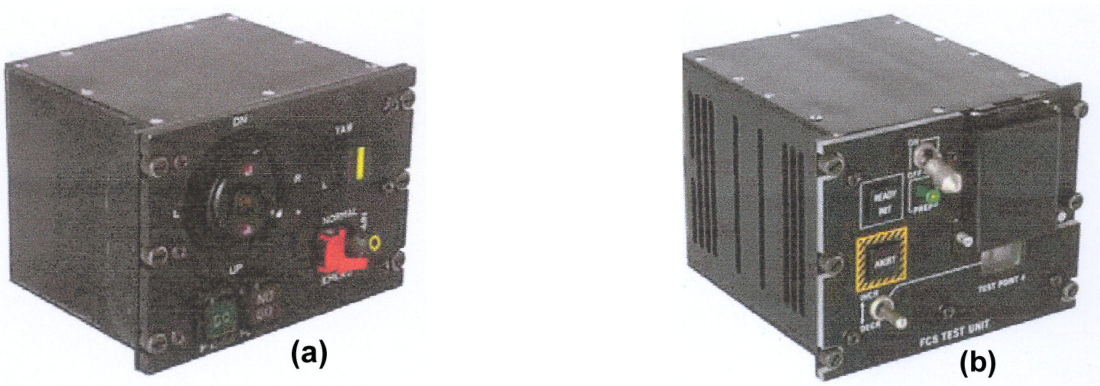
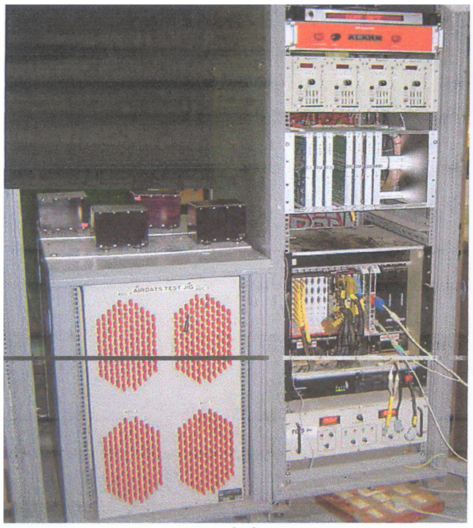


Fig.5 (a) Flight Control Panel and (b) FCS Test Unit

Fig.6 Advanced Engineering Test Station



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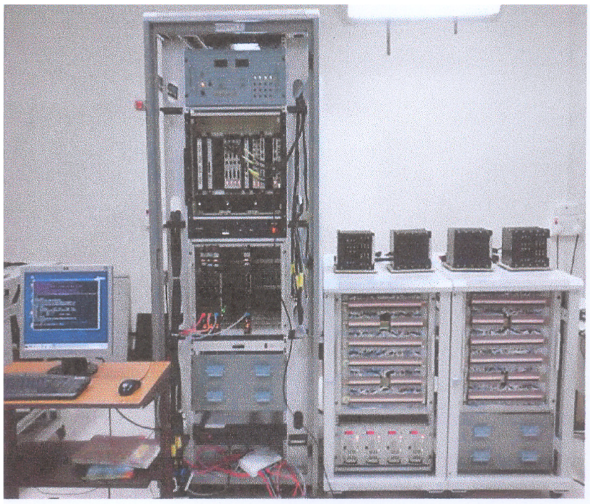

(b)

Fig.7 (a) AIRDATAS and (b) AIRDATS - Enhanced