CIVIL AIRCRAFT ADVANCED AVIONICS ARCHITECTURES – AN INSIGHT INTO SARAS AVIONICS, PRESENT AND FUTURE PERSPECTIVE

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Abstract :
Traditionally, the avionics architectures being implemented are of federated nature, which means that each avionics function has its own independent, dedicated fault-tolerant computing resources. Federated architecture has great advantage of inherent fault containment and at the same time envelops a potential risk of massive use of resources resulting in increase in weight, looming, cost and maintenance as well.

With the drastic advancement in the computer and software technologies, the aviation industry is gradually moving towards the use of Integrated Modular Avionics(IMA) for civil transport aircraft, potentially leading to multiple avionics functions housed in each hardware platform. Integrated Modular Avionics is the most important concept of avionics architecture for next generation aircrafts.

SARAS avionics suite is purely federated with almost glass cockpit architecture complying to FAR25. The Avionics activities from the inception to execution are governed by the regulations and procedures under the review of Directorate General of Civil Aviation(DGCA). Every phase of avionics activity has got its own technically involvement to make the system perfect.

In addition the flight data handling, monitoring and analysis is again a thrust area in the civil aviation industry leading to safety and

reliability of the machine and the personnel involved. NAL has been in this area for more than two decades and continues to excel in these technologies.

1. INTRODUCTION

Reliable and timely transfer of data between avionics systems is a necessity in military and civil aircraft design. A powerful motivation for development of new data transmission systems has been the prolific growth in digital computing technology providing increasing opportunities for more modular, flexible and reliable avionics systems. This has resulted in a universal move from analog to digital data transmission and the emergence of the a*vionics data bus* system. Over the last 30 years, much work has gone into exploring new techniques for the transmission of information in aircraft. ARINC 429 has emerged as a truly internationally recognized standard in the avionics industry.

Presently, Avionics plays an important role in civil aviation. The avionics function are:

- To detect and process the data about environment inside and outside the aircraft
- To derive information in a form suitable for crew utilization
- To accept crew inputs and combine with other derived information
- To activate controls within the aircraft and simulate the outside environment as dictated by mission requirements of the system

1.1 Modern Avionics System

As in other fields, digital computer systems have been incorporated in system aircrafts avionics design. Digital avionics computers are coupled with multifunction displays with aircraft flight decks optimizing the man machine interface and enhancing the economy and safety of flight operations. This has resulted in modern digital avionics system to work in coordination, to function efficiently in terms of speed and capacity.

Digital systems have better reliability, lower weight and greater flexibility for change or modification and potential for self-test function checks for faulty signals before takeoff. The need for rapid and automatic configuration is very much in case of a FLY BY WIRE

(FBW) flight control systems (FCS) in which a faulty channel has to be switched out before it can jeopardize the safety of an aircraft. Another advantage of self-check facility is its ability to isolate a fault to one or more electronic card within a box (at Line Replaceable Unit LRU), so that the task of the maintenance engineer is eased.

Flight Control System (FCS)

This is an advanced auto pilot system that could isolate pilot from dangerous RAW handling of characteristics and replacing them with computer designed synthetic ones. Such a system can operate with full authority from take off to touch down.

One of the most important functions of Avionics is the presentation of data to pilot when human senses such as direct vision have been cut off because of poor or zero visibility at night, rain, snow or fog.

2 SARAS Avionics Architecture

The Light Transport Aircraft – SARAS is a twin turbo-prop, multi role aircraft, with air taxi and commuter services as its primary roles. It can carry 14 passengers in high density version and has a maximum take-off weight of 7100 kg. and a cruising altitude of 30000ft. SARAS aircraft requires airworthiness and operational certificate from Directorate General of Civil Aviation (DGCA) to fly in the Indian sky and FAA certificate to fly globally.

SARAS is an all weather aircraft and needs to be equipped for day and night flying. The aircraft instrumentation suite satisfies Visual Flight Rules (VFR) by day and night and Instrument Flight Rules (IFR). The aircraft has approved transponder and automatic pressure altitude reporting equipment. **Error! Reference source not found.** Fig, 1 shows the architecture of the SARAS avionics system with data communication information.

The SARAS Avionics suite[1] is grouped into six groups based on the functionality

- Display system
- Communication System
- Navigation system
- Recording System
- Radar System
- Engine instruments and other cockpit displays

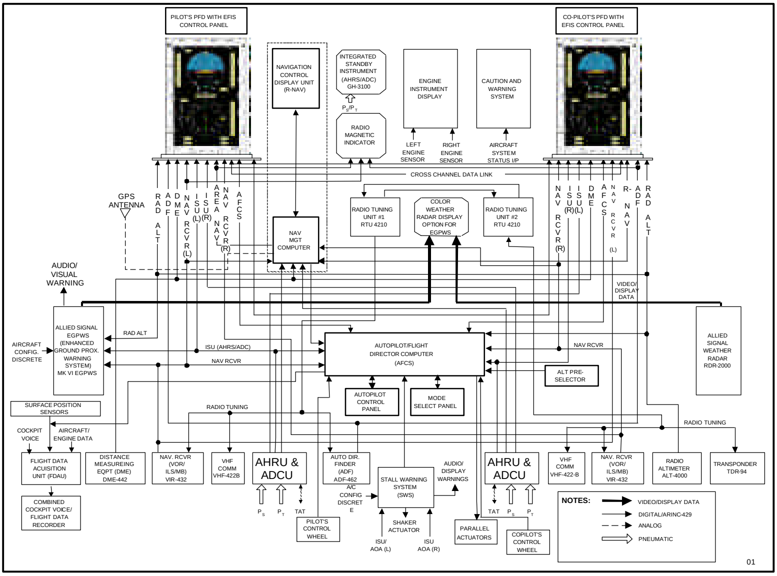

Fig. 1 SARAS Avionics Architecture

Study and design phase of avionics system plays a major role in the avionics life cycle with testing and integration being a major phase in the whole exercise and the system tested to perfection till it proves on the flying aircraft.

Design of a test case for civil aircraft avionics integration test requires critical and in depth study of the system and factors which influence the final test case design. Some of these aspects are:

- study the Requirements
- study the operation of LRU's
- study the certification/FAR/FAA/JAA & other AC
- identify the Tests to be done
- separate the type of tests to be done (Sub tests) clearly
- identify the test cases to be tested in each sub test
- choose the test data, conditions, modes effectively
- design the Test Schedule with Clarity, Ease to understand

Various Phases of Avionics System from Inception to execution

Some of the major phases of Avionics design and development are

- Requirements Capture
- Feasibility Study
- System Design
- System Development / Partial Integration
- System Integration
- Testing and Acceptance

For an efficient and effective test case design, the above steps / has an impact on the coverage and compliance to the aviation standards. The approach of a test case design for a specific functionality when methodical unfolds the hidden aspects of the integration tests.

Steps involved in a typical test integration activity.

Avionics Integration calls for various important steps to be taken during the process for efficient handling of procedures and systematic execution of tests. Some of the critical steps to be followed for smooth process are

- Identification of test
- Study requirements, LRU operation and regulation requirements
- Identification of approach and methodology
- Identification of hardware and software tools
- Design and preparation of test schedule and test plans
- Review of test schedule and plans
- Execution of tests as per test schedule and plan
- Preparation of test report and submission to certification authority for verification and approval

2.1 Avionics Communication Bus

ARINC 429 and its predecessor ARINC 419 had their origins back in the 1960s. ARINC 419 is the oldest and is considered obsolete. The vast majority of avionics terminals employ ARINC 429 for their avionics bus. ARINC 429 is now a very well established system employed on most civil airliners like Airbus A310/A320 and A330/A340, Bell military and civil helicopters, Boeing 727, 737, 747, 757, 767 and military transport aircraft. SARAS Avionics system is designed in full using ARINC 429 digital communication bus.

ARINC Organization and Standards Specifications

ARINC itself is not a standard nor is it a piece of equipment. ARINC is an acronym for *Aeronautical Radio Incorporation*. The ARINC organization is a technical, publishing and administrative support arm for the *Airlines Electronic Engineering Committee* (AEEC) groups.

The ARINC 429 specification describes the avionics bus as an "open loop" transmission model. This "shout" or "broadcast" bus is described as a simplex bus with multiple receivers. On a 429 bus, the transmitting *line replaceable unit* (LRU) is known as the "source" while each receiving LRU is known as a "sink." Any particular LRU may have multiple sources and/or sinks. A twisted shielded pair carries the ARINC 429 signal, and the sets of information are transmitted at periodic intervals. The transfer of graphic text and symbols used for CRT maps and other displays has not been defined. ARINC 429 documents are not *standard*s; they are *specifications* developed to provide a high degree of interchangeability between common functional units, typically known as LRUs.

3.0 Current Technologies under development for SARAS programme

ALD is continuously updating on par with the technology growth particularly in the civil aviation industry catering to the growing demands of the industry. ALD has already progressed appreciably in the following major programs

- Integrated Modular Architecture (IMA)
- Autopilot
- Engine Instrument and Crew Alert System (EICAS)
- 3D Flight Data animation

The current day architecture of the latest avionics suite is based on the integrated approach, which is driven by the open architecture concept. With the drastic advancement in the computer and software technologies, the aviation industry is gradually moving towards the use of Integrated Modular Avionics (IMA) for civil transport aircraft, potentially leading to multiple avionics functions housed in each hardware platform. Integrated Modular Avionics is the most important concept of avionics architecture for next generation aircrafts.

IMA architecture includes several avionics functionalities combined in a single computer system with critically allocated resources for each of these functionality. Allocation of resource in IMA means the allocation of memory and CPU time for each avionics function which is critically done to avoid any fault propagation from one hosted function to the other. These mechanisms are governed by -established procedures and standards from Aeronautical Radio Inc (ARINC). The ARINC 653 relies on Integrated Modular Avionics.

An important concern for IMA is ensuring that applications are safely partitioned a they cannot interfere with one another, particularly when high levels of criticalities are involved. On the other hand, such applications routinely cooperate, so strict separation cannot be enforced. The formalization draws from the techniques developed for computer security models based on noninterference concepts.

3.1 Integrated Modular Architecture (IMA)

Integrated Architecture has superseded the federated architecture in many ways with improved reliability, availability and redundancy. Integrated architecture has many advantages over federated architecture, viz.,

- Different levels of software in the same IMA box
- Number of functionality in the same system
- Reduction in the aircraft wiring length and hence reduction in weight
- Simpler and maintainable
- Global communication network with plug and play architecture enabling easy maintenance of LRU/IMA Box.
- Additions and modification of avionics functions are easy as it is software intensive functionality.
- First time effort is re-used for the next projects to a tune of up to 40 % in terms of the software code, expertise, hardware exposure and the technical experience.
- IMA activity at ALD has very definite objectives in terms of developing the technology in-house for the next generation avionics architectures in civil aviation sector of India.

What is Integrated Modular Avionics (IMA)?

Integrated Modular Avionics (IMA)[2] is a blanket term used to describe a distributed real-time computer network aboard an aircraft. This network consists of a number of computing modules capable of supporting numerous applications of differing safety criticality levels.

Figure 2 shows the IMA Architecture. IMA uses time and memory partitioning mechanism to host multiple avionics applications on the same computing environment[3].

Elements of IMA and IMA Goals

1. Technology Transparency - The underlying hardware should not have any impact on an application either during development or execution
2. Scheduled Maintenance - The system should have inbuilt capability to operate in the presence of failures so that Maintenance Free Operating Periods (MFOPS) can be achieved
3. Incremental Update - The system should be designed such that the applications can be inserted/altered with minimum impact on other applications and on the supporting safety case

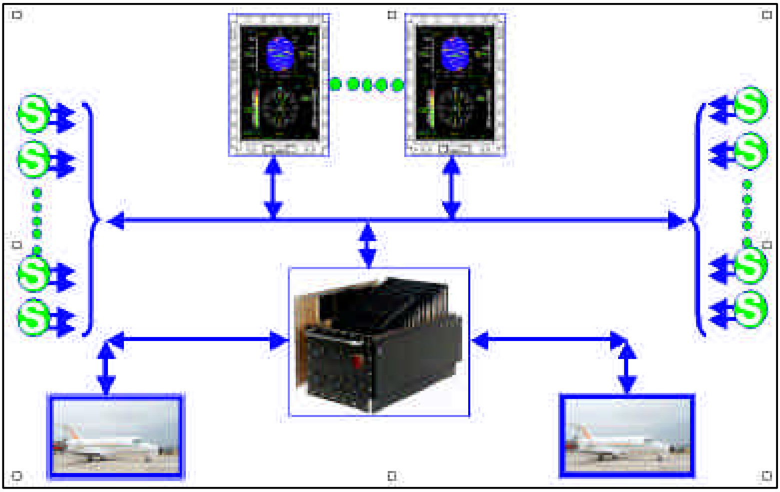

Figure 2 Integrated Modular Avionics scheme

Features of IMA

1. Layered architecture using standard programming interface layers to hide hardware and applications from one another
2. Reconfiguration of applications on the modules. This can be static re-configuration (whilst the aircraft is not in use) or dynamic reconfiguration (in flight)
3. Protection mechanisms to allow resources like memory to be shared by multiple criticality level applications and to allow applications to be inserted/altered without impact on the rest of the system. This is called partitioning.
4. Flexible scheduling to meet the deadlines of all the applications, for each viable configuration and when system is upgraded.
5. Code re-use and portability
6. An operating system to manage the applications
7. Physical integration of networks, modules and IO devices
8. Design for growth and change

3.2 Autopilot / Automatic Flight Control System (AFCS)

SARAS aircraft is being designed as FAR Pt. 25/121 certifiable aircraft and AFCS shall be designed to be certifiable for IFR and VFR operation and providing landing guidance and control up to Cat. II minimum. The AFCS, as installed in the SARAS aircraft, provides the following functions:

- Autopilot (including yaw damper, automatic and manual pitch trim functionality)
- Flight director guidance

AFCS design is based on aerodynamically stable aircraft with mechanical primary flight control system that provides Level 1 handling qualities as per Cooper-Harper Rating. The elevator, aileron and rudder servo actuators are parallel actuators with typical position/displacement authority limited to 10% to 15% of max. control surface deflection and rate authority limited to corresponding performance limits. The AFCS architecture will be “fail-safe” or “fail soft” to ensure that no single point failure shall result in an “catastrophic” or “hazardous” failure/conditions for aircraft.

The AFCS shall be designed for precision approach CAT-II requirements in compliance with FAR Pt 25/121 and Pt 91 and applicable FAA Advisory Circulars. AFCS design shall ensure that it meets all of its performance, safety and civil certification requirements when interfaced with civil certified (TSO/TC) aircraft/avionics sensors and ICAO approved navigation/ground aids under normal and transient/wind and other conditions.

The Automatic Flight Control System (AFCS) for SARAS aircraft[4] is the Limited Authority Autopilot System which provides the following functional capabilities.

- Provide three axis control, flight director, automatic pitch trim and necessary damping in the appropriate autopilot modes selected.
- Provide steering commands to the pilot and co-pilot for display on the EFIS in the FD mode.
- Provide different modes of operation as listed below depending on the mode selected on the control and mode select panel.

The AFCS consists of the following line replaceable units (LRU’s)

- Flight Control Computer (FCC)
- Autopilot Control & Mode Select Panel (ACMSP)
- Servo actuators for elevator, ailerons, rudders and pitch trim.
- Servo actuator for pitch trims.

3.2.1 Flight Control Computer (FCC)

Flight control computer is realized using Modular Avionics Unit (MAU) that is the integral component of Primus EPIC Architecture. AFCS will use 12 Slot MAU (including AIOP, GIO NIC/PROC and power supply modules) as Flight Control Computer (FCC). As shown in Fig. 3 the AFCS solution is realized using single channel dual lane architecture that may be upgraded to dual channel – dual lane to provide fail-safe / fail-op capabilities in future.

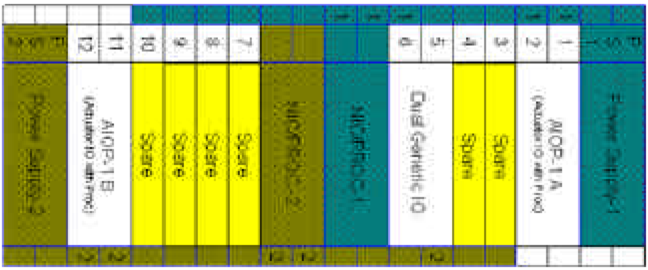

Fig. 3 Flight Control modular avionics computer

3.2.2 Autopilot Control Mode Select Panel (ACMSP)

KMC9200 will be used as ACMSP. The KMC 9200 is a dual channel, panel mounted avionics equipment. It provides the primary flight crew interface for the SARAS Automatic Flight Control System (AFCS), providing controls and annunciations for the autopilot and flight director. It also provides flight crew control of approach altitude minimums as shown in Fig. 4.

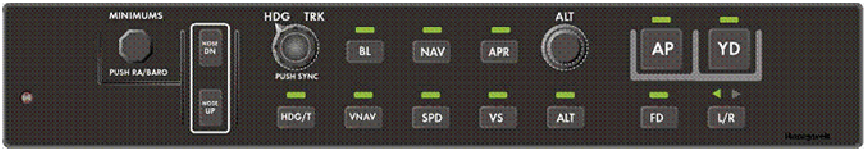

Fig. 4 Autopilot Control and Mode Select Panel (ACMSP) for SARAS Autopilot

3.2.3 All Electric Smart Actuator

SAGEM SM1000 smart servo is identified for use in SARAS AFCS. The function of the servo is to provide the mechanical interface between the FCC and the aircraft primary flight controls surfaces. The servos are driven by fault tolerant digital global bus called Controlled Area Network (CAN Aero Version). It also has smart diagnostics and health status reporting mechanisms with safety features for motor overdrive, over current and clutch control. Fig. 5 shows the smart SM1000 actuator for SARAS application.

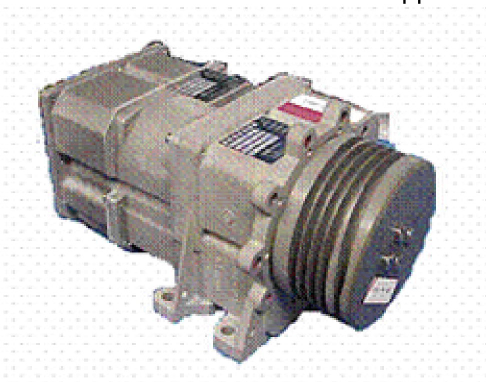

Fig. 5 Smart CAN based Electric Actuastor for SARAS

3.3 Engine Indication and Crew Alerting System (EICAS)

EICAS is a combined Engine Indicator and Crew Alert System. This needs to be developed for high reliability and availability. As an engine parameter indicator, this displays the engine torque, the engine speed, the propeller speed, the oil temp and pressure and the Inter turbine Temperature (ITT). As crew alert system, the unit monitors the health of many systems that are connected to this unit and generates caution and warning messages and specific aural tones for some of the flight critical warnings. The system forms a part of the avionics requirement. The main functional components of the system are a colour AMLCD display unit, graphical capability, interface capabilities and keyboard. EICAS interface with Engine instrumentation system, various other aircraft systems to indicate the sub-system wise warning forming a centralized warning system using AMLCD displays. EICAS would have the multi mode display pages for

- Left engine parameter indicators
- Right engine parameter indicators
- Both engine parameter indicators
- Caution warning system
- Sub pages for each sub systems on selection like
    - Hydraulic system, ECS
    - Fire system, flap control system etc..
- Separate page for test actuation for each of the sub-system (if provision exists)
- Diagnostics for each system (if provision exists)
- Self diagnostic feature for EICAS status monitoring

The Engine Indication and Crew Alerting System (EICAS) is designed to provide all engine instrumentation and crew annunciations in an integrated format with very high reliability of 10-9 for safety critical applications[5][6].

EICAS system consists of Engine Data Concentrator Unit (EDCU) and Display Unit(DU) as shown in and Fig. 7

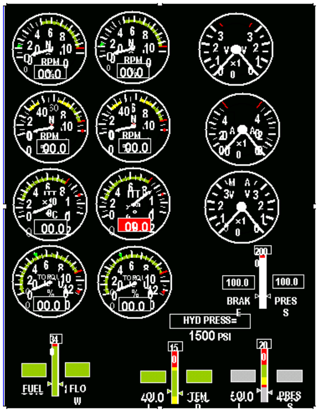

Fig. 6 Engine Data Concentrator Unit for EICAS

Fig. 7 Display Unit with typical symbology for EICAS

Fig. 8 Proposed MIP layout with EICAS display system for SARAS application

The generic features of the EICAS are:

- EICAS is an integrated system with all the signal interfaces for various systems in a avionics integrated architecture rack called as “Avionics Box”
- Two main AMLCD display system with keyboard control unit mounted separately
- There will be two systems and are fully swappable in nature for the functionality
- EICAS would interface to Audio Warning Generator (part of EICAS / separate Unit) system which can generate the synthesized audio warnings along with the visual text warnings on AMLCD displays
- Full fledged self diagnostic page for EICAS health monitoring
- Fully colored text, numbers , meter gauges and other animating displays as per aerospace standards.

Fig. 8 shows the SARAS avionics on MIP with EICAS in place having two redundant displays. The system incorporates more than 120 parameters with approximately 27 analog, 64 discrete, 9 audio generator triggers and couple of communication and ground control signals.

3.4 3D Animation and Visualization System (NALVAS) and NALFOQA Embedded Perspective of NALFOQA – Integrated Monitoring Systems

Close monitoring of aircraft flight operations and systems has made continuous refinement of reliable designs and increased performance. Enabling this operational monitoring has been the continual development of even more sophisticated data recording analysis with growing capabilities to handle huge amount of raw data. Feedback into engineering and maintenance processes and into crew training has raised safety levels. Coupled with accident investigation information, operational data extracted from the flight data recorder have made it possible to refine the air transport operation to a very high standards of efficiency, while at the same time, reducing accident risk exposure. The FOQA (Flight Operational Quality Assurance) developed from Flight Safety Foundation (FSF) studies is being adopted by many airlines throughout the world as an internal system of operations monitoring. Fig. 9 shows the main window of NALFOQA. FOQA data can reveal

- If an airline's trends are out of the norm
- If anomaly is an isolated occurrence or one that has been previously detected by another carrier who may have already developed a solution.
- If occurrence is a significant event that requires prompt decision- making and actions when combined with historical data
- Allow the confirmation of problem areas identified by flight crews through voluntary safety reporting programs
- Flight training, Airline safety improvement
- Human factors study, Operational procedures review.
- And many more safety, quality and trend features of each aircraft, airlines as whole

The B747-400, a Cessna and SARAS aircraft model have been completed and has to be rendered for a professional finish using 3D modeling tools like 3DS.

Architecture of the NALVAS as shown in Fig. 9 easily integrates with the NALFOQA and other utilities of FDAA for flight data analysis. Currently the design activities are in progress for

- ➢ Aircraft Model creation for all the aircraft operated in India by Indian Airlines and Air India
- ➢ 3D Cockpit equipment creation and animation
- ➢ Data search and automation features for analysis
- ➢ Continuous replay of the system for the data visualization
- ➢ Central Error management system
- ➢ Statistics generation
- ➢ Trend analysis of data analysed for preventive actions
- ➢ Improvements on database management for handling dynamic and large volumes of data

Fig. 10 shows the NALVAS capability in terms of adaptability and capability to configure for different aircraft. The detailed analysis was done for LOC dev, GS dev, DME distance, VOR bearing etc,. using the visual software. Full flight data is being analyzed for every flight for exceedences in terms of the performance and functional parameters of SARAS profiles. Fig. 11 shows the software front end used for analysis.

NALFOQA and NALVAS software is used for SARAS flight Testing as part of day to day flight data analysis.

Methodology : Architecture

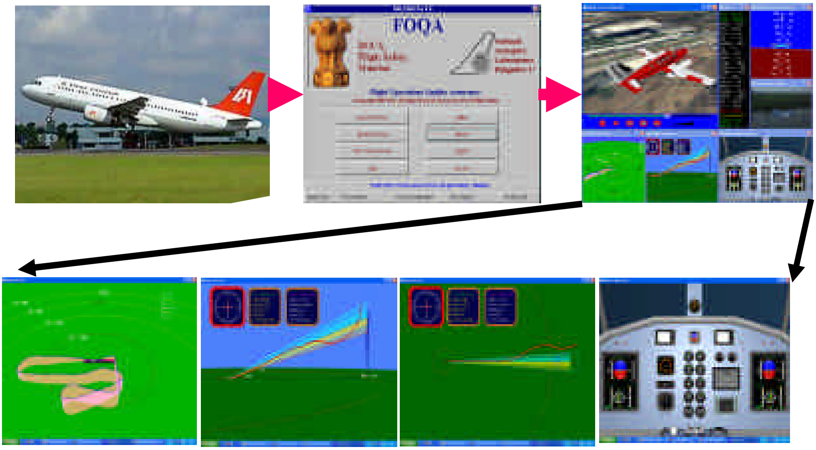

Fig. 9 Architecture of NALFOQA and NALVAS

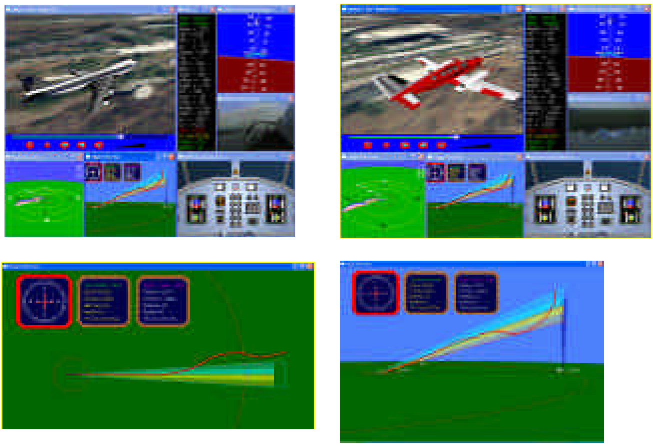

Fig. 10 NALVAS showing the configurable capability for different aircraft models with ILS operation

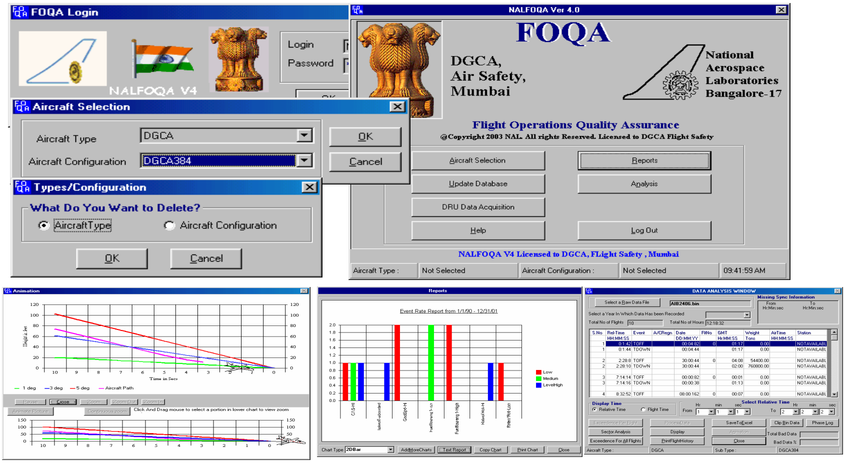

Fig. 11 NALFOQA software used for SARAS flight data anlysis

4 Future technologies

As part of technology advancement in the field of avionics and embedded systems for civil aircraft applications, the following technology is very crucial and one has to explore at the earliest to take advantage of the modular and COTS architecture to achieve the modular cockpit as shown in Fig. 12 :

- Fly by wire /Fly By Light Automatic Flight Control System
- Integrated avionics suite
- Global bus distributed avionics architecture

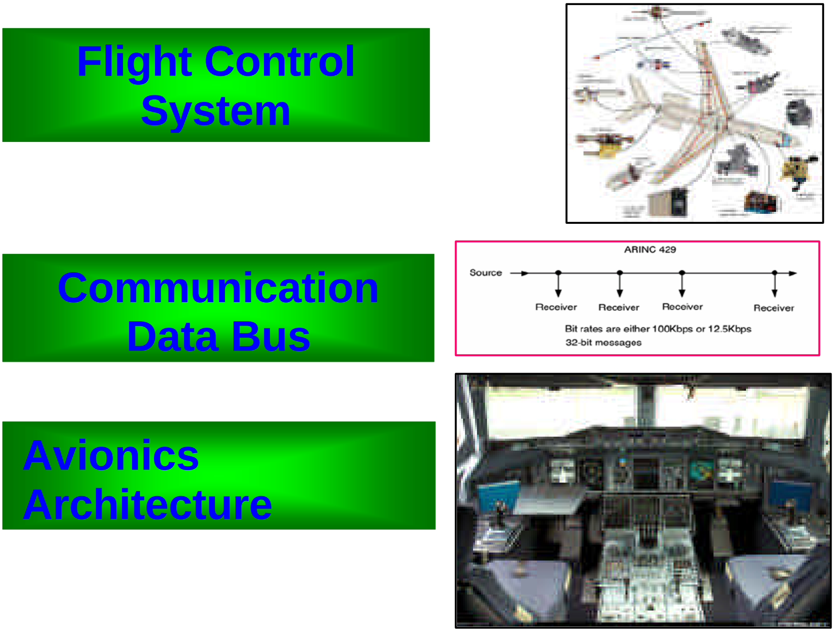

Fig. 12 Future technologies in process

4.1 Flight Control System

Flight Control system can be broadly classified as shown in Fig. 13 with analog and digital version of fly by wire architecture .

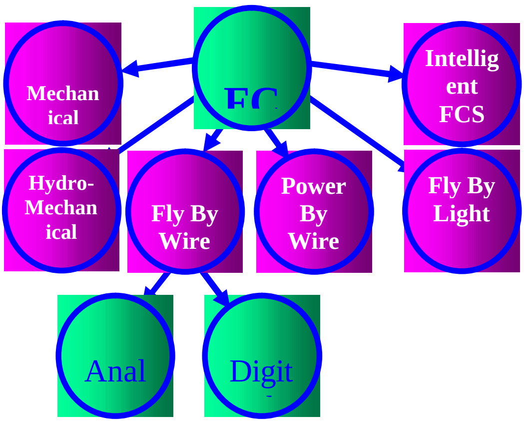

Fig. 13 Classification of Flight Control System

Flight control system of any modern aircraft is the heart of the aircraft as a whole, which has the interfaces to various control elements of the aircraft. FCS interfaced with various sub-systems of FCS by different interfaces. Typical FCS components is as shown in Fig. 14

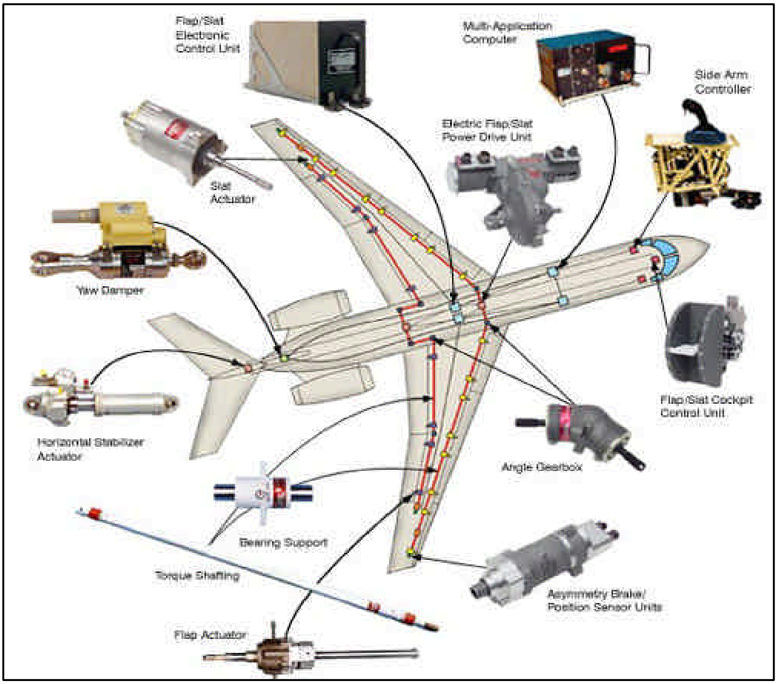

Fig. 14 Typicl components of FCS

4.1.1 Fly By Wire

For airliners, redundancy improves safety, but fly-by-wire also improves economy because the elimination of heavy mechanical items reduces weight. FBW technologies can cut flight control system by weight, volume and enhance the reliability, availability and maintainability. Brief history of Fly By Wire is listed below with events.

- A modified NASA F-8C Crusader was the first digital fly-by-wire aircraft, in 1972.

- In 1984, the Airbus A320 was the first airliner with digital fly-by-wire controls.

- In 2005, the Dassault Falcon 7X was the first business jet with fly-by-wire

4.1.2 Fly By Light (FBL) or Fly By Optics (FBO)

In January 28, 2002 a modified Eurocopter EC135 became the first aircraft in the world to fly by means of a fly-by-light (FBL) primary control system

FBL technologies can cut flight control system weight by approximately 25%, volume by about 30%, cooling by nearly 40%, and cost by about 25%. However there are a number of difficultites in FBL architecture and the major issues are

- How to gather hundreds of optical fibers together in a standard fiber optic connector?
- How to distribute large numbers of fibers to circuit cards within an electronics enclosure?
- How to utilize a single fiber for transmitting multiple control signals or commands?
- How to develop fiber-optic components and sensors that are rugged, durable, safe, reliable and maintainable?

4.2 Global Communication

Current day advanced avionics architecture uses global bus communication mechanism to gain advantage of reduced volume and weight of cable harness. Also it helps in optimization of resources by using distributed mechanisms. Various digital communication bus schemes are in practice in the aviation industry. Basically the communication bus used in integrated avionics applications falls in two categories. They are intra and inter box communication bus as shown in Figure 15.

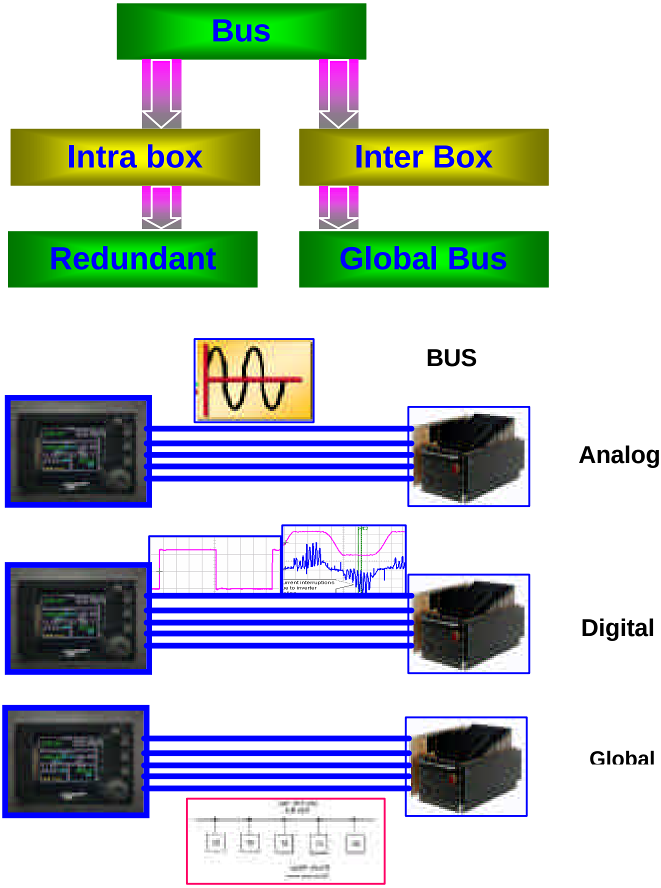

Figure 15 Basic classification of global bus

Global digital bus for intra box communication is realized by various protocols. However the major protocols are

- Avionics Full Duplex Bux(AFDX)
- Time Triggered Protocol (TTP/C)
- ARINC 629
- SAFEBUS
- ASCB

With the use of avionics cabinets (common processing systems for housing avionics applications) and the global bus mechanisms, the aircraft architecture can be realized shown in Fig. 16. The avionics boxes are distributed for various applications, but the software architecture is virtual for all applications as the data and control is through the global data bus. The sensor interfaces to the avionics boxes are sometimes realized by distributed Remote Interface Units (RIU's). RIU will interface the sensor and processes the signal input for signal conditioning, health monitoring and diagnostic management and finally puts the processed data on to the global bus to be used by various avionics applications spread across various avionics boxes.

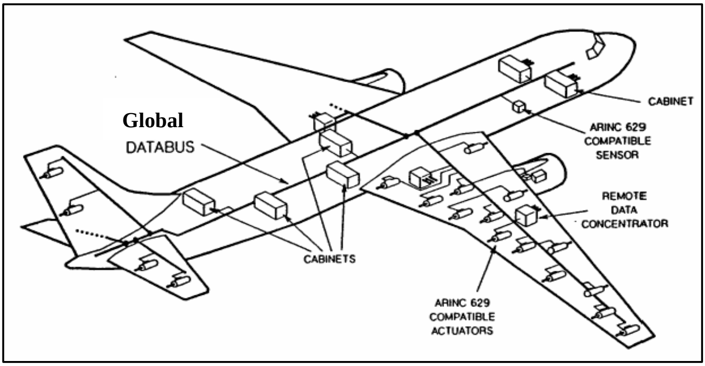

Fig. 16 Gloabl bus based integrated avionics scheme for full aircraft configuration

5 Concluding Remarks

Growing demands by the Aerospace Industry has lead to a considerable technological opportunities. Future plans at NAL includes design and development of many flight critical technologies in the interest of national civil aviation programmes.

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