Defence Science Journal, Vol. 61, No. 4, July 2011, pp. 289-298, DOI: 10.14429/dsj.61.1090

REVIEW PAPER

Avionics Systems, Integration, and Technologies of Light Transport Aircraft

C.M. Ananda, K.G. Venkatanarayana, Preme M., and Raghu M.

National Aerospace Laboratories, Bengaluru-560 017
E-mail: ananda_cm@css.nal.res.in

ABSTRACT

Avionics of the present day comprises advanced technology and software-intensive systems. Earlier generation avionics constituted federated architecture and used line replaceable units (LRUs) having individual resources for each application with redundant hardware and software. However with the advancement of technology, methods, and mechanisms, the industry moved quite rapidly towards the integrated architecture called integrated modular avionics (IMA). Over the last decade there has been tremendous growth in these technologies which has resulted in reduced weight, volume, and developmental efforts. Usage of complex systems with advanced technologies and their certification for use in civil aircraft are the key issues to be addressed even today. Avionics of general aviation aircraft consists of typical systems like communication, navigation, display, radar, engine indication and data acquisition and recoding systems. These can be realised in federated as well as integrated architectures. The LRUs requirements for avionics sub-system depends on the certification standards like FAR 23 or FAR 25. The whole cycle of architecture definition, integration, testing and means of compliance of the complete suite is the major activity in any new aircraft development programme. Development of ground-based test facilities and proper maintenance of the entire system on aircraft are other important activities in such programmes. These issues are presented in this paper for a typical light transport aircraft (LTA). The new technologies with their relevance, merits/de-merits, awareness of the global systems being adopted, etc., which are being attempted as indigenous design and development, are also presented.

Keywords: ARINC 429, integrated modular avionics, engine instrument and crew alerting system, automatic flight control system, real-time simulation, failure mode effect analysis, light transport aircraft, line replaceable units, EICAS

NOMENCLATURE

AFDX	Avionics full duplex ethernet
AMLCD	Active matrix liquid crystal display
APEX	Application executive
API	Application programming interfaces
ARINC	Aeronautical radio incorporation
COTS	Commercial off-the-shelf
CSIR	Council of Scientific and Industrial Research
CTQ	Critical to quality
DGCA	Directorate General Civil Aviation
EICAS	Engine instrument and crew alerting system
FAA	Federal Aviation Authorities
FARs	Federal aviation rules
IFRs	Instrument flight rules
HIL	Hardware-in-the-loop
HMI	Human-machine interface
IAP	Integrated aircraft platform
ILS	Instrument landing system
IMA	Integrated modular avionics
ISIS	Integrated standby instrument system
IVHM	Integrated vehicle health monitoring
LAN	Local area network
LRUs	Line replaceable units
LTA	Light transport aircraft
MDD	Model-driven design
MEL	Minimum equipment list
NAL	National Aerospace Laboratories
OAT	Outside air temperature
PVI	Pilot-vehicle interface
RDC	Remote data concentrator
RTOS	Real-time operating system
TAT	Total air temperature
TAWS	Terrain awareness warning system
TCAS	Traffaic alert and collision avoidance system
TSO	Technical standard order
VFR	Visual flight rules
VHF	Very high frequency

1. INTRODUCTION

Typical light transport aircraft is twin turbo-prop, multi-role aircraft, with air taxi and commuter services as its primary roles. In its high density it has 14 passengers capacity and has a maximum take-off weight of 7100 kg and a ceiling altitude of 30,000 ft with an approximate range of 2500 km. LTA requires airworthiness and operational clearance from Directorate General of Civil Aviation (DGCA) to fly in the Indian sky and FAA Certificate to fly globally. LTA is an all weather aircraft and needs to be equipped for day and night flying. The aircraft instrumentation suite satisfies

Received 23 March 2011, published online 25 July 2011

visual flight rules (VFRs) and instrument flight rules (IFRs) for both day and night flying. The aircraft is equipped with glass cockpit avionics with architecture supporting both federated and integrated modes. The avionics is developed with digital communication, all glass cockpit with AMLCD and current requirements of facilities like traffic alert and collision avoidance system (TCAS), digital autopilot and engine instrument and crew alerting system (EICAS) etc. The avionics suite is grouped into six major sub-groups based on the functionality: display system, communication system, navigation system, recording system, radar system and engine instruments and other cockpit displays. LTA is being flight-tested and it has completed good number of flight hours covering considerable test points in terms of avionics functionality tests.

Compared to the similar class of aircraft in the world, the CSIR-NAL LTA programme has adopted lot of advanced technologies in terms of near-glass cockpit, multiple redundancies for displays, COM-NAV systems and critical sensors for navigation. LTA has pressurized cabin with cursing altitude of 25000 ft and limited authority digital autopilot.

2. CIVIL AIRCRAFT AVIONICS

Conventional federated avionics architectures consists of set of hardware units called line replaceable units (LRUs) with built-in functionalities having their own computing resources. These are interconnected by external wiring schemes. This calls for proper maintenance to meet day-to-day operational requirements. The requirements for a typical avionics system with state-of-the-art technologies are low maintenance cost and higher system availability. The objective is to address the requirements using integrated modular avionics with distributed architecture. The avionics system has to be compliant with statutory requirements like FAR 23/FAR 25/FAR 121, DO 160F, DO 254 and DO 178B/C for airworthiness/operational, environmental qualification, hardware design and software development etc. respectively. The avionics system definition is critically looked in terms of the top level aircraft critical to quality (CTQ) and few of them are as follows:

- Reduce acquisition, operating and maintenance costs
- Utilisation of widely available technologies
- Third party systems integration
- Operation from unequipped airports
- Time to delivery period

The above CTQ will then lead to the following attributes of the avionics system:

- Use of open system architecture with commercial open standards.
- Use of ruggedized commercial off-the-shelf (COTS) components & sensors
- Use of open standards for systems and software
- Provide scalability/growth potential by building in modularity
- Provide reusability of hardware and software modules
- Build in extensive built in test for all systems at LRU and system level (end-to-end)
- Provide real-time online and offline health monitoring for all systems
- Provide extensive diagnostics and prognostics for all systems.

Civil aircraft avionics systems and sub-systems are completely defined and well documented by industry standards. Major applicable standards include:

- DO 160F or later for the environmental qualification
- DO 254 or later for the electronic hardware design
- DO 178 B or DO 178 C for software certification
- FAR 25, 121 and 91 for airworthiness, operational and transponder requirements
- Applicable FAA advisory circulars, reports
- Applicable technical standard order (TSO) for each system and sub-system functionality
- Aerospace best practices
- Others relevant to FAR 25 compliant civil aircraft certification

Civil aircraft avionics can be broadly categorised based on the functionality like display, utilities, computing platform and maintenance as shown in Fig. 1.

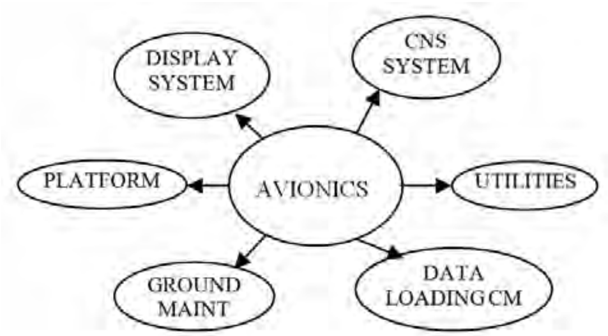

Figure 1. Civil aircraft avionics systems.

2.1 Display System

Display system is the main interface between the pilot and the aircraft called pilot-vehicle interface (PVI) or human-machine interface (HMI). This system provides required navigational aids and information for piloting activity. Primarily display system consists of the following:

- Primary flight, multifunction, navigation, standby displays
- Engine indication crew alerting system (EICAS)
- Electronic flight bag display, maintenance terminal displays
- Others like
  - Head up displays, warning management, Airport surface situation awareness systems
  - Synthetic vision systems with 3-D maps and charts
  - Enhanced visions systems, digital moving maps

However, all the above displays are not mandatory for certification. Some of these are over and above the minimum mandate equipments called minimum equipment list (MEL), but are required based on the requirement as part of pilot comfort, easy navigation, and redundancy requirements.

2.2 Communication, Navigation and Surveillance System

The system for communication, navigation and surveillance (CNS) are the key systems for aircraft navigation and consists of the following:

- Navigation systems like
  - Inertial systems, GPS/WAAS/LAAS
  - Radios like ADF, DME, VIR(ILS), Radalt, TDR, etc.
  - FMS, Air data and heading reference
- Communication systems like
  - VHF, HF radios and communication management functions
  - SATCOM
- Surveillance systems like
  - TAWS, TCAS
  - WxR, Sat WxLink, ADS-B

2.3 Processing Platform

This is primarily the processing computer system houses the functionalities related to various avionics and flight control applications. The systems are housed in such integrated common resource computers called integrated modular avionics (IMA). Platform systems consist of open architecture processing systems, global communication bus protocols, remote data concentrators (RDC) and architecture supports integrated vehicle health monitoring (IVHM).

The integrated architecture has same common hardware and system software to accommodate multiple avionics functionalities. Integrated architecture by itself does not define the boundaries of natural fault containment very clearly. Partitioning uses appropriate hardware and software mechanisms to restore strong fault containment to maximum extent in such integrated architectures[1,2]. Major resource management in integrated architecture is time and memory. Both are shared among multiple avionics functionalities across the same platform with effective protection mechanisms provided by ARINC 653. One such standard is the integrated modular avionics (IMA)[1-3] applications supporting distributed multiprocessor[4] architecture with shared memory and network communication called avionics application software standard interface or application executive (APEX)-ARINC 653[5]. This APEX standard consists of a set of operating systems application programming interfaces (API)[5]. However, the basic definition of APEX is based on the ARINC 659 backplane data bus[6] and the global communication protocols like ARINC 629 data bus[7], avionics full duplex ethernet (AFDX)[8]/ARINC 664[9,13] and time-triggered ethernet[14]. ARINC 664 and AFDX standards are more or less the same except that specific additional safety layers are added in AFDX for jitter, schedule and bus arbitration issues. Full realisation of IMA requires adoption of good real-time concepts and methods[15]. Therefore the IMA partitioning should be implemented with the ARINC 653 complaint real-time operating system (RTOS).

2.4 Data Loading Functions

The functions are support systems like local area network, satellite weather link and ground utility management. These systems are used by other avionics and flight control systems for data handling and secondary functionality.

2.5 Utility Functions

These functions are secondary but still play important roles as for as overall systems performance is concerned. Few of the utility functions are

- Software service management, In-flight entertainment and Avionics health monitoring functions
- Flight data recording systems with acquisition unit
- Emergency locator transmitter
- Other sub-system support (Mechanical system monitoring/ control like hydraulics, electrical, fuel, LDG, etc.).

2.6 Maintenance Functions

The functions are purely addressing the ground handling and data management like configuration management, maintenance data management, troubleshoot and calibration check functions. The overall requirements of the affordable avionics system are shown in Fig. 2.

Light transport aircraft (LTA) avionics system architecture designed and integrated in India is broadly classified into six groups as communication system, navigations system, warning system, radar system, display/flight instruments, and

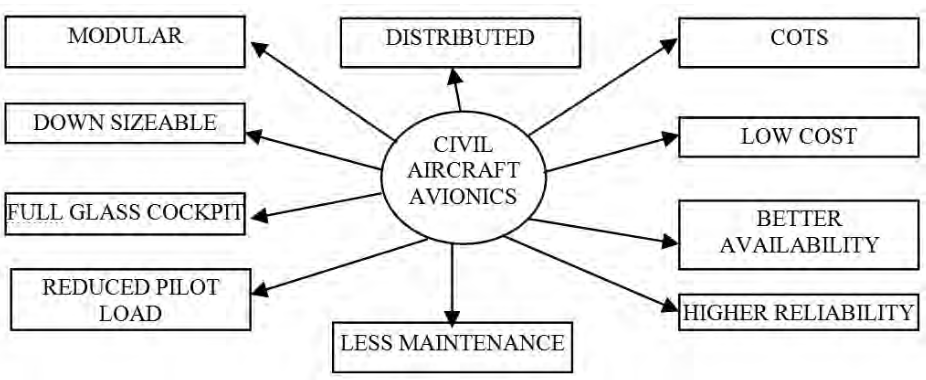

Figure 2. Civil aircraft avionics requirements.

recording system. Typical architecture of avionics system of LTA includes:

- Dual VHF system for communication
- Dual VOR/ILS, single ADF, DME, FMS for navigation
- A weather radar with indicator, a radio altimeter.
- Dual EFIS with AMLCD and EICAS displays
- A stall warning system
- An enhanced ground proximity warning system
- A 3-axes digital automatic flight control system
- Integrated sensor units with TAT, P(s), P(t) interface
- A digital clock, magnetic compass, OAT indicator and a standby ISIS.

3. AVIONICS ARCHITECTURES

Traditionally avionics systems are more functionality-centric with dedicated hardware and software. Avionics architectures plays very important role in robustness of the systems. Avionics architectures are classified as two major sectors as Federated architectures and Integrated architectures

3.1 Federated Architectures

Federated architectures are of 1980's technology and use individual LRUs. Functionalities are realised by dedicated hardware boxes (LRUs) having independent hardware and software resources. Fault management, fault containment and the electrical power requirements are met individually in LRU level. Federated architecture does not share any resource across the LRUs except the communication data bus externally. A typical federated system like LTA avionics[16,17] having independent hardware units for each of the functionality. The federated architecture is advantageous in terms of fault tolerance having penalty of huge resource demand.

3.2 Integrated and Distributed Architecture

Present day architectures are integrated in nature with centralised resource management using open architecture systems. Integrated avionics architectures accommodate multiple avionics functionalities on the same hardware using supported real-time operating system or kernel. The application software for each of the avionics functionality differs and is part of the architecture in an integrated environment. This type of architectures have evolved rapidly during the last two to three decades, migrating from federated architecture to the integrated architecture[18,19]. Unlike lot of dials and gauges, the pilot now interacts with primary flight displays (PFD), multifunction displays (MFD), automatic flight control system (AFCS), and engine indication crew alerting system (EICAS). This means that the systems are coupled well with multifunction displays, communication and navigation radios with control units, multi-mode interactive instruments for control and navigation, recording and fault management systems, airframe and health monitoring diagnostic capability. Pilot-vehicle interface is important measure of good avionics and cockpit layout, which implies the optimisation of man-machine interface, enhancement of economy and safety of flight operations. The architecture is based on common and modular resources integrated over a modular architecture. Integrated architectures are structured over the avionics cabinets or processing cabinets which house the hardware modules and software partitions. These systems are called integrated modular avionics (IMA). Typical architecture with two avionics cabinets along with remote data concentrators is shown in Fig. 3. Currently the architecture is more of distributed integrated architecture than just integrated architecture. The avionics cabinets are distributed across aircraft for various sub-systems and connected by an integrated global digital bus AFDX.

Remote data concentrator is used to digitise the aircraft sub-system sensors and re-transmit into a digital bus like AFDX. AFDX channel connects the RDC and rest of the processing computers. Since AFDX is of network topology, the interconnects of the bus is through the network switch (NS). Network switch

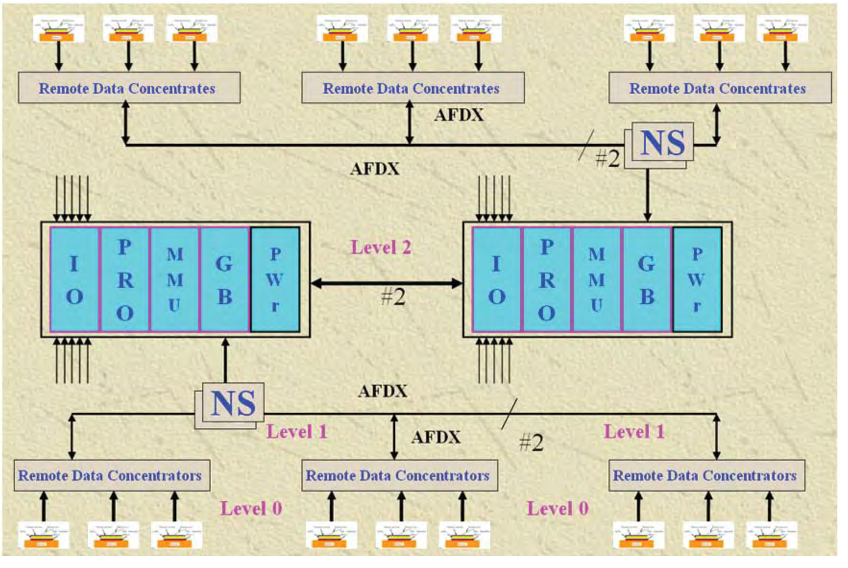

Figure 3.Typical integrated architecture with remote data concentrators.

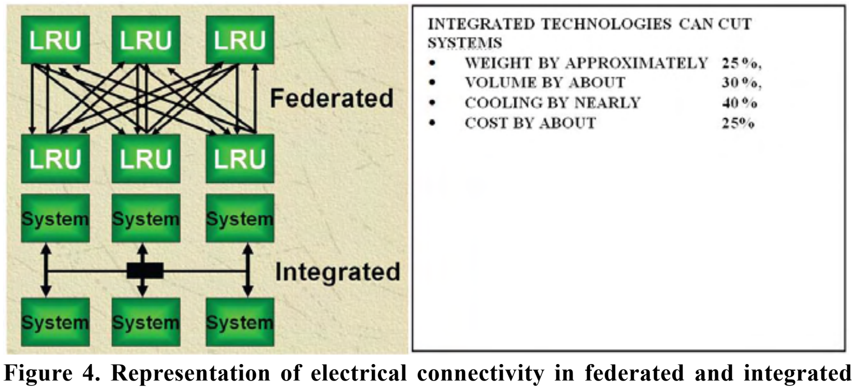

Figure 4. Representation of electrical connectivity in federated and integrated systems.

schedules and manages the real-time determinism of the communication of data across the sub-systems.

The complexity in terms of weight, volume, and the electrical interface reduces to a large extent in integrated modular avionics (IMA) Fig. 4. shows the typical electrical complexity in federated and integrated architectures which brings out clearly the advantages of integrated architecture.

4. COMMUNICATION BUSES

Reliable and timely transfer of data among the avionics systems is a necessity in aircraft designs. 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 using avionics data bus system. Over the past 30 years, appreciable work has been carried out in exploring new techniques for the transmission of information in aircraft. Digital communication bus like ARINC 429 has served the industry for the past two decades successfully. However, the aerospace industry demands higher bandwidth and bi-directional bus and commercially successful standard in the avionics industry, is global bus communication like AFDX. Present day advanced avionics architecture uses global bus communication mechanism to gain advantage of reduced volume and weight of cable harness. Also it helps in optimisation of resources 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 to two categories. These are intra- and inter-box communication bus as shown in Fig. 5. Global digital bus for inter box communication is realized by various protocols. Avionics full duplex bus (AFDX), time-triggered protocol (TTP/C), time-triggered ethernet, ARINC 629, SAFEBUS and ASCB are few of the global bus protocols used in the industry. Earlier decade used the ARINC 429, which is point-to-point topology having very good noise immunity and is a reliable bus. It has served the industry for a long period of more than 2 decades. Even today many of the sensor systems still use ARINC 429. However due to the advantage of the global buses like AFDX or ARINC 664 or TTEthernet are being adopted. These protocols[9-13] provide more value in terms of reduced weight, volume and interconnect complexity along with increased reliability using the redundant systems. Also the use of data in aircraft is improved in terms of availability across systems.

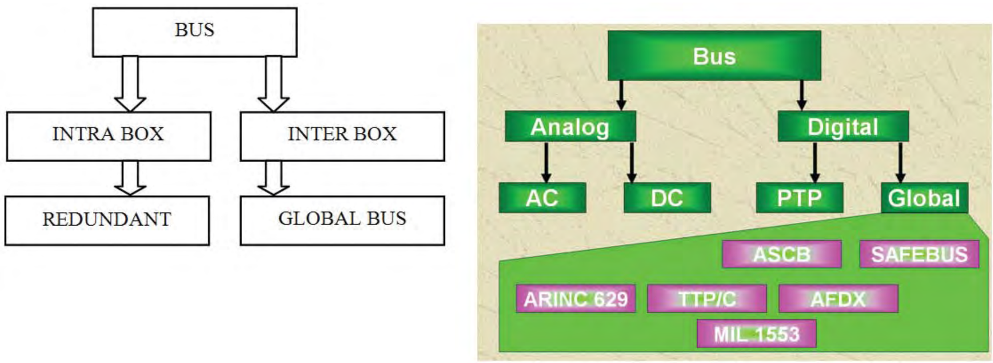

Figure 5. Communication bus in civil aircraft application.

5. INTEGRATION AND TESTING PROCESS

Avionics system integration is a methodical process with predefined objectives and test scenarios. Avionics suite comprises set of LRUs or systems for various functionalities. The systems are tested at various levels, staring from individual box or system up to the full suite integration tests, as shown in Fig. 6. The avionics integration and testing schemes are designed with the following objectives:

- To integrate and test the intended functionality complaint to FAR 25/23/121, programme and FMET requirements.
- To unearth interface and functional issues, if any
- 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
- To study the interface, interference, interoperability issues of the entire avionics suite in integrated mode
- To study the failure scenario-based operations of various display systems with complete suite.

Light transport aircraft avionics suite has gone through methodical process of testing and integration involving bench tests, ground integration tests, ground simulation tests, aircraft integration tests and flight tests. The various phases of tests with scope and objectives are listed below:

Phase I: All avionics equipments were tested for its functionalities as a stand-alone unit on the bench with

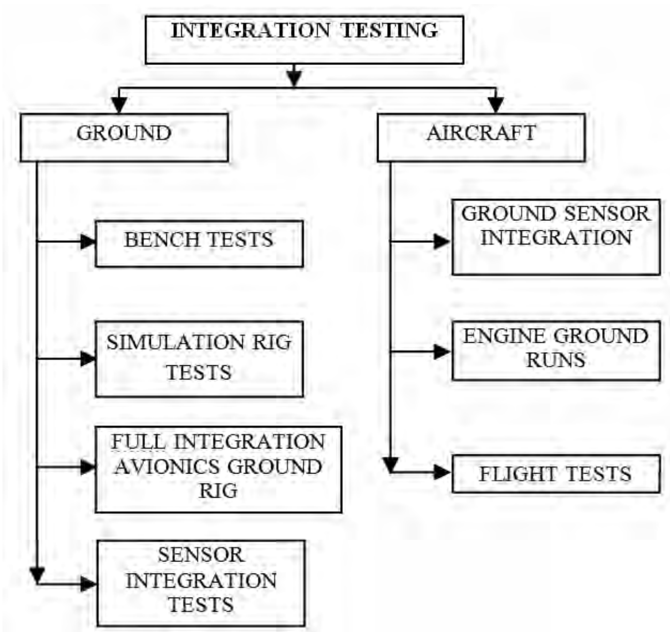

Figure 6. Avionics system integration test mechanism.

appropriate hardware and software test tools. The tests covered basically the major requirements of the system architecture and its functionalities complaint to standards.

Phase II : Complete avionics suite was tested in full integrated mode with all the LRUs interacting with each other via ARINC 429 bus. The test schedules and test cases were designed and tested covering the requirements of LTA, FAA, FMET and the safety. The integration tests were conducted in three iterations to study the repeatability and consistency of the test cases and results. Real-time software simulation system simulates complete ARINC 429 data bus. LRUs are interfaced with full avionics suite connected by displays, radios, and other systems. The ground integration facility used for the functionality verification of the LTA avionics consists of avionics simulation system, test station system, and the data monitoring systems as shown in Fig. 7.

The test rig has the capability to drive the cockpit systems including the PFD/MFD/EICAS either with simulated inputs or with actual equipments using the breakout changeover mechanism as shown in Fig. 8.

As part of software simulation system, the simulation system has the capability to simulate more than 500 parameters along with the failure injection capability for parameter, channel and equipment level in real-time.

Phase III **:** The avionics suit was tested with COM/NAV radio test systems like IFR ramp tester. These testers were used for simulation of COM/NAV radio stations with appropriate parameter values. These tests uncovered few problems related to the interface and installation issues. The various ground-based test systems used for the ground integration tests of COM/NAV systems are shown in Fig. 9.

Phase IV: Light transport aircraft avionics suite tested on aircraft with ground power followed by actual engine power to establish the traceability to all the requirements against the ground test results. The results were compared and found satisfactory.

Phase V: Subsequently, the avionics suite was tested for major functions on air as part of actual flight tests with possible modes of operations and it proved to be functioning well without any major snags. The system is being flight-tested and has covered more than 150 flights covering all functionalities spread over number of test flights. Typical flight test data analysis process is given in Fig. 10. Avionics ground test rig was used as part of the snag rectification process along with the communications from the LRU manufacturers. The process has been followed with checks and procedures for each of the test and has gone through the configuration and change management system. During the flight tests, the data of the flight data recorder was used extensively along with the telemetry data for the design validation.

The test matrix of the LTA avionics integration activities carried out using the simulation and ground systems is shown in Table 1.

Undoubtedly there were many problems during bench, ground rig and on-aircraft integration tests. These problems were of various kinds related to interfaces, interference, electrical characteristics, communication speed, update rate,

Figure 7. Avionics ground integration test facility.

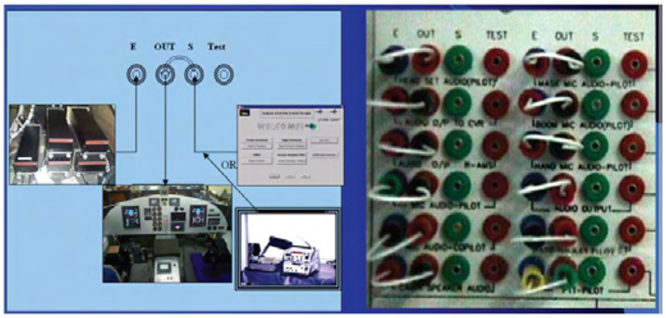

Figure 8. Test rig multi-system interface mechanism.

Figure 9. Ground-based radio testing systems.

Table 1. Statistics of avionics integration tests

Tested & integrated	Main tests	Sub tests	Test cases
30 Equipments	472 x 3	1792 x 3	4104 x 3
	1416	5476	12312

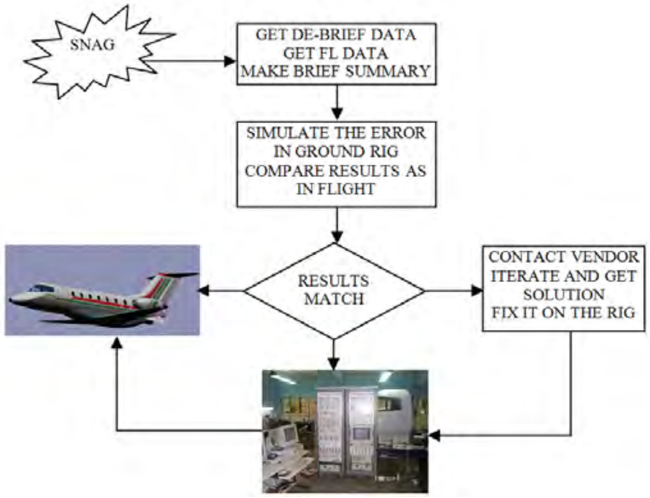

Figure 10. Avionics flight test process.

in-compatible mountings etc. No aircraft programme can succeed without problems whatever the expertise available, but the importance is how well the problems are tackled and solved.

Present day avionics uses the integrated approach for complete avionics suite. Traditional phases of testing and integration are combined with advanced methods and automated toolsets for complete artifact generation.

6. CURRENT TECHNOLOGY TRENDS

Typical avionics systems are being addressed in IMA platform with time- and memory-partitioned systems using ARINC 653 standards. However, the application software design and development is also addressed totally in a different approach. Recent aerospace programmes use model-driven design (MDD)[20] in flight-critical applications for meeting their real-time performances, compact code, safety, reliability and the specialised hardware control that often exists in their environment. Software tools like Rhapsody, Matlab-Simulink, and SCADE focused on the needs of the embedded developer and have always followed the concept of separating functionality and behaviour from implementation detail. MDD is based on the basic principle of separating the specification of the systems operation from the implementation. Present day avionics application development adopted the tool-based design and development as per DO 178B level A flight-critical application.

There has been exponential growth in the tools technology, availability of tools for design, development, testing, and Integration**.** With these advanced toolsets, the flight-critical software design and development efforts could be reduced if the tools and technologies are used effectively. Based on the statistics, up to 30 to 40 per cent efforts could be reduced without compromising the DO 178 process. In the recent past, model-based design (MBD), development, testing, integration, independent verification and validation activities of DO 178B level A process are being adopted with the supported toolset. Model-based tools and systems support the seamless transfer from legacy projects to MBD. Model-based design and development is one of the best methods currently being followed by the industry even for complex flight-critical applications. MBD has appreciable advantage over the traditional approach especially for flight-critical applications of DO 178B level A. However, MBD itself does not provide the required advantage of covering from requirements till the target code. Even using model-based design and development, the life cycle activity is carried out in different platforms with a lot of parallel redundant workflow.

6.1 Integrated Model-driven Design and Development

Typical approach of simulation and design in the area of flight-critical applications is as shown in Fig. 11.

Integrated model-driven design and development (IMDD) refers to the combination of MBD and total MDD. Therefore model-driven development is a real challenge to all system and software designers and engineers[20]. IMDD allows users to manage the entire project, right from requirements to deployment at the model level. This means that the complete design verification and validation can be done at model level itself including the test and integration. However, still the requirements need to be clearly stated as part of the functionality so that the implementation is close to the real world. This is the real challenge to the success of the project. Integrated approach details the activity in following three stages:

I. Concept-to-model (CTM)
II. Model-to-hardware (MTH)
III. Hardware-to-certification (HTC)

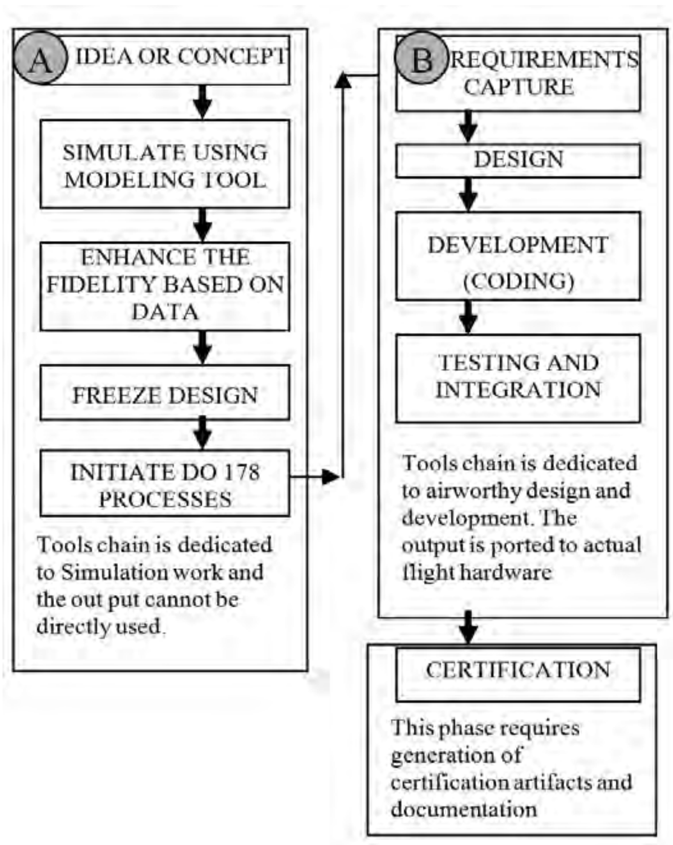

Figure 11. Traditional approach of design and development.

6.1.1. Concept-to-model

Concept-to-model (CTM) in integrated approach addresses Phase A part of traditional approach apart from the model-based attributes and is shown in Fig. 12.

In CTM, an idea or a concept is captured as the base requirement and modelled in modelling framework like Matlab-Simulink. At some point of time, the model is matured enough to be implemented on the real environment. Now the CTM output is ready to be interfaced on to the next stage. This can be interfaced using software model, hardware or combination of both in full or part.

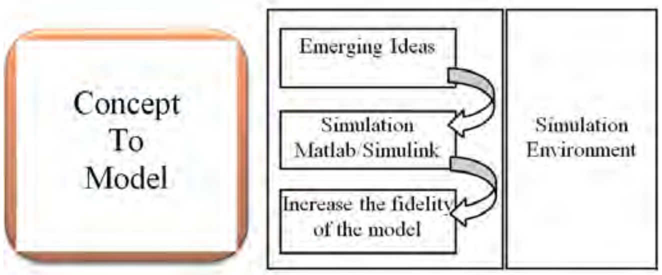

Figure 12. Concept-to-model flow of integrated approach.

6.1.2 Model-to-hardware

Model-to-hardware (MTH) in integrated approach addresses Phase B part of traditional approach apart from model-based attributes and is shown in Fig. 13. MTH starts with the output of CTM and integrates with the COTS toolset for design, development, auto-code generation, test case generation, and test execution. In this model, the design and development environment is seamlessly integrated across in the same platform.

Typical tools used in this phase are DOORS, Rhapsody, Matlab-Simulink, SCADE, Clear Case, Clear Quest, Door Keeper, LDRA, custom toolsets and document generators, etc. Complete DO 178B[21] up to Level A process is followed and the platform supports the method and artifacts for airworthiness requirements. MTH can interface back and forth across platform in different combinations using hardware and software.

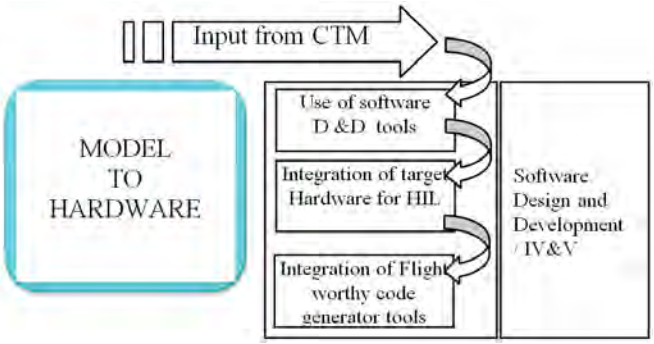

Figure 13. Model-to-hardware flow of integrated approach.

6.1.3 Hardware-to-certification

Hardware-to-certification (HTC) covers the Phase C part of the traditional approach along with model-based certification methods and processes and is shown in Fig. 14.

Hardware-to-certification is the critical phase of the entire process, where the real artifacts and documentation required for the airworthiness certification is submitted and a formal review of the complete process is carried out. Complete application is tested and reviewed with target hardware and test systems. In case of change in requirements, the process is navigated back to CTM, MTH, and back to HTC. This is carried out with impact and safety analysis reports. All the above stages, when integrated together on a single platform called IAP provide the complete solution.

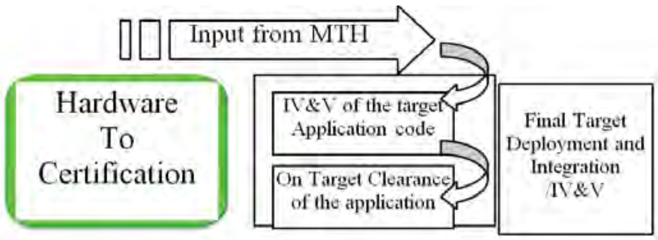

Figure 14. Hardware-to-certification flow of integrated approach.

6.2 Integrated Aircraft Platform

Integrated model-driven design and development (IMDD) adopted in integrated approach of integrated aircraft platform (IAP) covers all the stages of IMDD in the same and single platform. Figure 12-14 show the model-based stages of integrated approach as sub-activities. All these activities are coupled and integrated on a single platform, as shown in Fig. 15 using the same set of tools. However, partial integration is quite easy and useful in understanding the real hardware behavior compared to the software model at various phases of development using iterative process.

This integrated approach allows integrating the combination of both software model and hardware to realize the complete functionality. While integrating the part of the hardware module along with the software model, the interfacing protocols need to be taken care to interact with the software model. IAP is designed to handle such test methods and interfaces.

Integrated aircraft platform handles all the systems and sub-systems of the aircraft like avionics, flight controls, electrical, environmental control system, hydraulics, power plant, etc. During the process of this integration based development stages, need for products or technologies essential for the project are identified. These technologies, which are to be developed as products, are executed in units called product development laboratory (PDL). The complete platform with interaction between the IAP and the technology development labs or PDL is shown in Fig. 16. Even during the CTM stage, the idea is transformed into a working model and may lead to initiation of a technology in parallel. This is also typically handled by PDL and PDL integrates to the IAP very closely. Therefore the IMDD implemented in IAP provides a single platform for complete avionics system development life cycle. This has enhanced the life cycle in terms of resource management and efficient use of toolset.

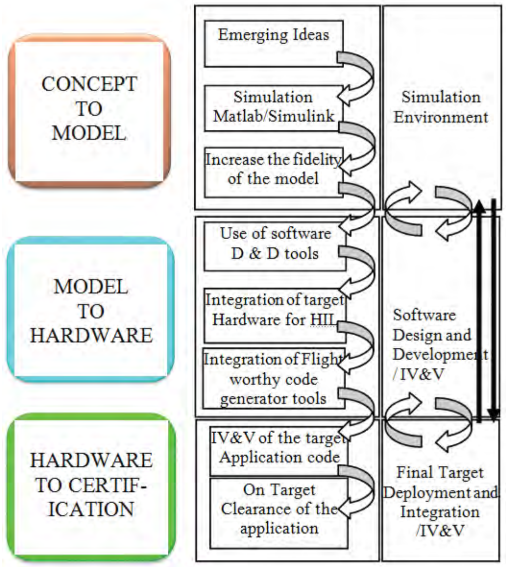

Figure 15. Integrated mode of all three phases.

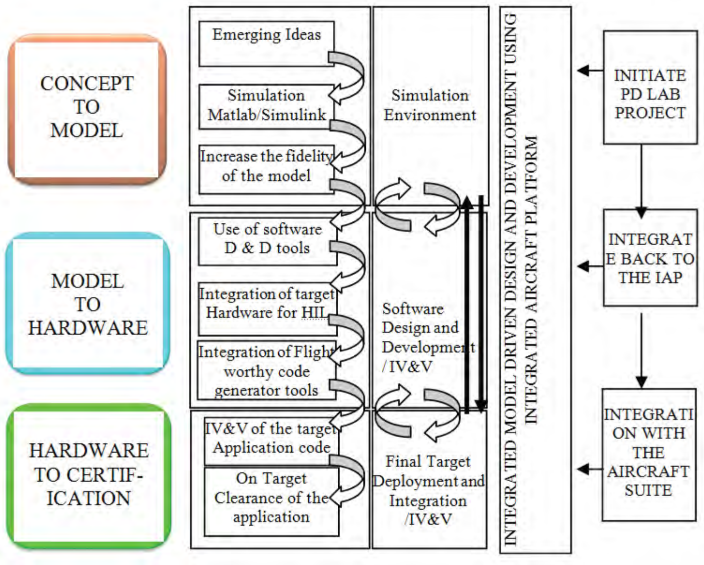

Figure 16. Integrated aircraft platform architecture.

7. CONCLUSIONS

Light transport aircraft has completed more than 150 flights without any major snag in the avionics system. The avionics of LTA has completed three phases of ground integration tests covering nearly 12312 test cases spread over more than 12 months time frame[22-27]. The system has been performing quite satisfactorily as per the requirements. There have been continuous developmental activities in the area of glass cockpit, global bus integrated architectures, fault-tolerant design, etc. The avionics suit of LTA has undergone extensive tests, both on ground as well on aircraft, with varying simulated fault scenarios. The performance of the avionics systems in LTA is satisfactory. However the current trend of integrated modular avionics is driving the future programmes of LTA and civil aircraft development in the country.

Avionics application design and development is based on the integrated approach. Integrated model-driven design and development (IMDD) comprising model-driven development and model-based design architected in a single integrated platform is very effective in terms of the resource utilisation and flight-critical development process. The process is well integrated and the artifact flow between the logical models is effectively utilised for complete life cycle. The bus architecture of the IAP in combination of hardware and software model or in total hardware suite scenario is well designed and interfaced. This is very effective with automated aerospace toolset for design and development.

Integrated modular avionics provides the benefits of reduced volume, weight, complexity of hardware, and is easy to test and integrate. Besides this, IMA has significant advantage in terms of hardware obsolescence as the platform provides the capability to integrate change in hardware/system software. IMA architecture has benefits of the ground integration activities including the aircraft integration with dedicated maintenance built in test (MBIT). MBIT for such systems are hosted on a separate partition. Hence, saving appreciable amount of time and effort in testing complete software for highest severity. During the flight tests, the architecture provides lot of flexibility in terms of software patch upgrades, modifications, and gain tuning for flight controls.

ACKNOWLEDGMENTS

Authors thank Avionics team of National Aerospace Laboratories (NAL) for their hard work and support from time to time, Dr AR Upadhya, Director NAL for support and motivation. Authors acknowledge the Civil Aircraft Design and Development Group, NAL.

REFERENCES

1. Rushby, John. Partitioning in avionics architectures: Requirements, mechanisms and assurance. NASA, NASA Report No. NASA/CR-1999-209347, June 1999.
2. Rushby, John. The design and verification of secure systems. *ACM Oper. Syst. Rev.*, 1982, **15**(5), 12-21.
3. Nadesakumar, A.; Crowder, R.M. & Harris, C.J. Advanced system concepts or future civil aircraft–an overview of avionics architectures. *In* Proceedings of the Institution of Mechanical Engineers, Pt G: *J. Aero. Engg.*, 1995, **209**, 265-72.
4. Walter, C.J. MAFT: A multicomputer architecture for fault tolerance in real-time control systems. *IEEE Trans. Comp.*, 1988, **37**(4), 398-405.
5. Audsley, Neil & Wellings, Andy. Analyzing APEX applications. *In* Proceedings IEEE Real Time Systems Symposium RTSS, 1996, 1052-8725/96. pp. 39-44.
6. Aeronautical Radio Inc. ARINC 659: Backplane data bus. *In* Report of the Airlines Electronic Engineering Committee, Aeronautical Radio Inc., Annapolis, MD, 1993. pp. 1-68.
7. Aeronautical Radio Inc. ARINC 629: Multi-transmitter data bus; Pt 1, Technical Description (with five supplements); Pt 2, Application Guide (with one supplement). Report of the Airlines Electronic Engineering Committee, Aeronautical Radio Inc., Annapolis, MD, December 1995-96.

8. Brajou, Frederic & Ricco, Philippe. The Airbus A380 AFDX-based flight test computer concept. *In* AUTOTESTCON, IEEE, San Antonio TX, September 2004. pp. 460-63.
9. Scharbarg, Jean-Luc; Ridouard, Frederic & Fraboul, Christian. A probabilistic analysis of end-to-end delays on an AFDX avionic network. *IEEE Trans. Indust.Infor.*, 2009, **5**(1).
10. Mauff, Joel Le & Elliott, Jeff. Architecting ARINC 664, Pt 7 (AFDX) Solutions. *In* XAPP1130 (v1.0) 20 March 2009, pp 1-25. www.xilinx.com.
11. Pickles, Bob. *In* Avionics full duplex switched ethernet (AFDX) – SBS technologies. May 2006. pp. 1-12.
12. Rockwell Collins, Inc. Users manual for the avionics full duplex ethernet (AFDX) end-system.
13. Aeronautical Radio Inc. ARINC 664, Aircraft Data Network, Pt 7 – Avionics full duplex switched ethernet (AFDX) network. *In* Report of the Airlines Electronic Engineering Committee, Aeronautical Radio Inc., Annapolis, MD.
14. Time-triggered Ethernet. (http://www.real-time-ethernet.de)
15. Kopetz, Herman. Real-time systems–design principles for distributed embedded applications. Kluwer and Academic Publishers, 1998.
16. Ananda, C.M. General aviation aircraft avionics: Integration and system tests. *IEEE Aero. Elect. Syst. Mag.*, 2009, **25**, 19-25.
17. Ananda, C.M. Civil aircraft advanced avionics architectures-An insight into SARAS avionics, present and future. *In* Conference on Civil Aerospace Technologies, National Aerospace Laboratories, Bengaluru, 2003. pp. 1-7.
18. López, Juan; Royo, Pablo; Barrado, Cristina & Pastor, Enric. Modular avionics for seamless reconfigurable UAS missions. *In* 27th Digital Avionics Systems Conference, DASC 2008, Florida, USA. pp. A3-1-10.
19. Oki, Brian; Puegl, Manfred; Siegel, Alex & Skeen, Dale. The information bus an architecture for extensible distributed systems. *In* 14th ACM Symposium on Operating System Principles, 68, Asheville, NC, December 1993. pp. 58.
20. Ananda, C.M. Model-driven design approach for system and aircraft engineering-tool-based automation, technology-driven process, and need-based approach. *In* 29th Digital Avionics Systems Conference (DASC) on Improving Our Environment Through Green Avionics and ATM Solutions, Salt lake City, UT, October 3-7, 2010. pp. 6.E.1-1-9.
21. DO-178B: Software considerations in airborne systems and equipment certification. RTCA; www.rtca.org.
22. Ananda, C.M. Integrated on aircraft test report of communication system. National Aerospace Laboratories, Bengaluru. Technical Report No. **10**, TR-32, April 2003. pp. 9-100.
23. Ananda, C.M. Integrated on aircraft test report of navigation system. National Aerospace Laboratories, Bengaluru. Technical Report No. **10**, TR-33, April 2003. pp.11-125.
24. Ananda, C.M. Integrated on aircraft test report of display system. National Aerospace Laboratories, Bengaluru. Technical Report No. **10**, TR-34, April 2003. pp.14-160.
25. Ananda, C.M. Integrated on aircraft test report of radar system. National Aerospace Laboratories, Bengaluru. Technical Report No. **10**, TR-35, April 2003. pp. 5-53.
26. Ananda, C.M. Integrated on aircraft test report of data acquisition and reporting system. National Aerospace Laboratories, Bengaluru. Technical Report No. **10**, TR-36, April 2003. pp. 9-52.
27. Ananda, C.M. Integrated on aircraft test report of engine instruments and other display systems. National Aerospace Laboratories, Bengaluru. Technical Report No. **10**, TR-37, April 2003. pp.10-59.

Contributors

Mr C.M. Ananda obtained his MTech (Software Systems) from BITS, Pilani, in 2003. Presently, he is pursuing PhD in Reconfigurable avionics architectures. He is working at National Aerospace Laboratories (NAL), Bengaluru, on embedded systems, digital autopilot, engine instruments crew alerting systems, and stall warning system for *Saras* aircraft. His areas of interest are: Integrated modular avionics, flight-critical systems, embedded distributed system, reconfigurable avionics architectures and safety-critical software.

Mr K.G. Venkatanarayana obtained his MTech (Software Systems) from BITS, Pilani, in 2003. Presently working at NAL, Bengaluru, in avionics, engine instruments crew alerting systems, and stall warning system for *Saras* aircraft. His areas of interest are: Avionics system design and integration, electrical systems and power Systems.

Mrs Preme M obtained her BSc (Electronics) in 1987. She is working at NAL, Bengaluru, in avionics, engine instruments crew alerting systems, and stall warning system for *Saras* aircraft. Her areas of interest are: Avionics system integration, integration testing, calibration and maintenance tests of complete avionics systems.

Mr Raghu M is working as Principal Technical Officer at NAL, Bengaluru. He worked earlier in the development of strain measuring data logging systems, and development of foil type strain gauges. Presently, he is involved in the design and development of electrical drawings and cable harness for *Saras* - production standard aircraft.