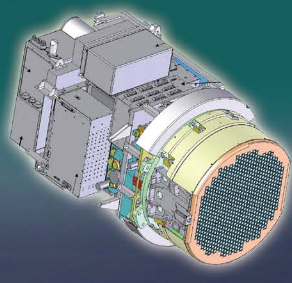
Avionics Systems:
Design, Development and Integration

P.N.A.P. Rao



Defence Research & Development Organisation
Ministry of Defence, New Delhi - 110 011

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Ministry of Defence, New Delhi – 110 011
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AVIONICS SYSTEMS: DESIGN, DEVELOPMENT AND INTEGRATION

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Contents

Foreword

This monograph is the outcome of labour of love, dedication and distilled knowledge of P.N.A.P. Rao who is among the finest avionics system designers of India. He is one of the very few avionics engineers who have worked extensively in both military and civil domains.

P.N.A.P. Rao was the Head of the Avionics System Group of Aeronautical Development Agency (ADA), the organisation responsible for design and development of Light Combat Aircraft (LCA)-Tejas, the 4plus generation state-of-the-art fighter. The avionics system, the subsystems, equipment were developed under the leadership of P.N.A.P. Rao. In addition to on-board systems, the team developed an array of simulators, test rigs, weapon system test facilities, cockpit evaluation facilities, and many other enabling tools and technologies. The team under the leadership of P.N.A.P. Rao succeeded in developing a robust avionics system package for LCA that not only met the customers' expectations but was done at a fraction of cost while fully meeting the airworthiness standards related to safety, reliability, and maintainability.

Until the advent of LCA, there was very little interface between avionics systems and utility systems of aircraft. Even today, none of the aircraft operated by Indian Air Force have any such interface. In LCA, it was decided to integrate the utility systems (fuel, environment control, hydraulics, landing gear, electrical systems, etc.) with the avionics bus. This was achieved by developing an utility management computer that enabled control/monitoring of all the key parameters of utility systems and integration with avionics bus and with other on-board systems. This important subsystem of avionic system enabled close monitoring of all key parameters of on-board systems and timely intervention that enabled accident free operations.

Another important innovation was development of open system architecture for on-board computers. Taking into account the availability and logistics issues related to MIL grade components, a decision was taken to use COTS components and ruggedize the on-board computers to meet the severe environmental demands of fighter aircraft. Thanks to this major decision, obsolescence management became easy and on-board equipment could be upgraded without impacting the core systems and architecture. P.N.A.P. Rao and his team were responsible for these major innovations.

In addition to designing total avionics system and integrating on to aircraft successfully, he has overseen development of almost all the equipment/attendant software/algorithms at many small/medium scale industries, R&D laboratories, and academic institutions. The team has also succeeded in integrating a wide variety of missiles, bombs, rocket pods, precision weapons, drop tanks, EW pods, and laser designation pods very successfully. It is the kind of expertise that very few in the world possess.

It is this unique experience and expertise that P.N.A.P. Rao has brought out in this monograph for the benefit of young engineers.

After an extraordinarily successful innings at ADA, P.N.A.P. Rao has worked extensively on civil aircraft avionics systems at Honeywell, India. His stay at Honeywell, India has given him a unique opportunity to study the similarities, differences in civil and military aircraft avionics' requirements, standards, processes, and attendant challenges.

In this monograph, P.N.A.P. Rao, with enormous effort, has succeeded in putting together his vast experience in civil and military avionic domain.

I do believe this monograph will be a great help to students, young engineers, industry professionals, aircraft operators, and a host of other professionals belonging to this field.

Kota Harinarayana
Distinguished Scientist and Former Director, ADA and
Former Programme Director and Chief Designer, LCA(Tejas)

Preface

This monograph deals with the subject of avionics systems of both fighter aircraft and civil aircraft. As the author of the monograph has experience in both civil avionics and fighter avionics, both these systems have been covered in detail under various chapters. Though there are many common features and some common subsystems, there are many differences in the functionalities and in the system design of these two systems. This monograph will enable engineers working in either area to benefit from the knowledge in the other area.

Modern avionics systems play a major role in the implementing various complex functionalities of the aircraft. Avionics system has interfaces with all the other systems on board of the aircraft. This makes the design and development of avionics systems a complex process. One of the important requirement of the avionics system is design for safety which requires adoption of fault tolerant features– both in hardware and software. As the avionics systems are software intensive (6 to 10 millions lines of code), software engineering processes and tools have to be adopted. Avionics system development adopts modern system engineering processes including model-based methodology which includes simulation and modelling techniques. This monograph covers all these aspects.

Subjects covered include: Avionics system functionalities, subsystems, system design, development, integration, testing, and certification. It also covers lessons learnt in most of the topics based on the experience of the author in the Indian Light Combat Aircraft (LCA)-Tejas program.

This monograph is expected to be beneficial to practicing avionics engineers and also students of avionics systems.

Chapter 1 gives a general introduction to the subject of avionics system and covers the design attributes of integrated avionics system. Chapter 2 covers the avionics system top level functionalities of both civil and fighter avionics. Chapter 3 covers description of various avionics subsystems which are common to all aircrafts. These include navigation systems and landing aids. Chapter 4 gives description of avionics subsystems specific to civil aircraft. This includes surveillance systems and civil aircraft communication systems. Chapter 5 gives details of avionics subsystems of a fighter aircraft. These include navigation system like Tacan, communication systems, electromagnetic and optical sensors, self protection systems against missile threat, targeting and reconnaissance pods, and electronic warfare systems.

Chapter 6 is devoted to Multi Mode Radar (MMR), its functions, description, configuration, and technologies including ECCM features. It also covers Active Electronically Scanned Array Radar (AESA) with advanced features. Chapter 7 deals with the important topic of Pilot Vehicle Interface (PVI) and the associated topic of Human Factors (HF). It covers the subjects of human-centred design, human errors, safety, and accidents. The HF and automation are discussed in detail based on FAA documents. Chapter 8 describes the evolution of aircraft cockpit displays leading to the modern glass cockpit with AM LCD displays. The other topics covered include back up/standby displays, Head Up Display (HUD) and Helmet Mounted Display (HMD). Hardware and software aspects of display systems are part of this chapter. Avionics system architecture has been evolving rapidly to meet the growing functional requirements.

Chapter 9 gives the evolution of the architecture from federated to open system architecture and IMA. Various data buses used for both civil avionics systems and fighter avionics system are discussed. As the avionics system is highly software intensive, the software development life cycle should follow well laid own processes and standards.

Chapter 10 gives details of the software development standards like DO 178B/C, Mil Std 2167 A and Mil Std 498. Real Time Operating Systems (RTOS) and formal methods are also covered.

Chapter 11 describes the avionics hardware development process as per DO-254.

Fly by wire Flight Control System (FCS) is an important system on the aircraft with interfaces to avionics system. Chapter 12 gives a brief description of FCS design and its interface with the avionics system.

Chapter 13 covers the important topic of avionics interface with Vehicle Management System (VMS) like hydraulics, FCS, propulsion, electrical, undercarriage, etc. In LCA–Tejas these avionics subsystems which interface with other vehicle systems are called Utility Services Management System (USMS). Both VMS and USMS are covered in detail in this chapter.

Chapter 14 deals with the fault tolerant system design and safety analysis, this is an important topic in the design of FCS and avionics system to achieve desired values of safety. Safety assessment process as laid in ARP 4761 is also discussed in detail in this chapter.

Chapter 15 covers the role of avionics system in the maintenance of an aircraft including Built In Test (BIT). It also covers the modern topic of Integrated Vehicle Health Management (IVHM) system which is an integral part of avionics system and which reduces maintenance time and cost while improving safety.

Chapter 16 deals with avionics system integration and testing. This includes integration and testing on the avionics rig, ground testing on the aircraft, and flight testing. As avionics system is a 'system of systems', its design, development, integration, and testing is a complex process. Systematic System Engineering (SE) processes should be followed throughout the life cycle of the project.

Chapter 17 describes these SE processes including model-based system engineering methodology which emphasises modelling and simulation techniques.

Chapter 18 covers various 'specialty engineering' subjects like electromagnetic environment effects including EMI/EMC and lightning and quality engineering.

Chapter 19 covers certification and airworthiness aspects of avionics systems of both civil and fighter aircrafts.

Chapter 20 attempts to cover briefly some of the modern techniques and future trends in avionics systems. This covers techniques and trends in both civil and fighter aircrafts.

Chapter 21 is the concluding chapter which very briefly summarises topics covered under various chapters.

In conclusion, the author wishes to state that in this monograph he has made an attempt to cover many important topics of avionics systems in both civil and fighter aircrafts. It is hoped that the monograph will be beneficial and interesting to all the readers.

P.N.A.P. Rao

Acknowledgement

I wish to acknowledge the great efforts made by the Indian National team of Avionics System of LCA-Tejas which developed a state-of-the-art Avionics System for LCA-Tejas. This is a major contributing factor to the contents of this Monograph.

The Avionics Team members were from ADA, ADE, LRDE, HAL, IAF, CEMILAC, DGCA and other work centres in the public and private sectors. I sincerely thank all the members of the team whose contribution immensely helped me in writing this monograph.

I acknowledge the inspiration and support given to the Avionics Team and to me personally by Dr Kota Harinarayana, Chief Designer and Programme Director of LCA-Tejas.

I would like make a special mention of the contribution made to the success of LCA-Tejas by the National Flight Test Team under the leadership of Air Marshal Rajkumar. The Test Pilots of IAF with their vast experience contributed to areas of cockpit design, PVI, simulation, human factors, flight testing and other areas of avionics and flight control system of LCA-Tejas.

I would like to acknowledge the encouragement and support given by Dr VS Arunachalam, Dr APJ Abdul Kalam and Dr VK Aatre who were SA to RM and DG ADA during the period I was in the LCA Team (1989 to 2003).

I would specially like to thank the members of Avionics System Directorate at ADA who helped me in understanding the intricacies of LCA-Tejas Avionics System with their deep knowledge of avionics and aircraft systems which resulted in the induction of LCA-Tejas into service in Indian Air Force. This is a dream come true for the entire Integrated LCA-Tejas Team.

I would also like to thank the NCAD Team at NAL which who helped me in getting initiated into civil avionics and get a full understanding of the system.

I would like to thank my wife Dr Kamali Rao and my family members for the encouragement and support given to me in writing this monograph.

Finally, I would like to thank DESIDOC and DRDO for sponsoring me to write this Monograph. Special thanks to the DESIDOC team which helped me throughout the process of writing the monograph, editing it and compiling it. Anitha Saravanan and Alka Bansal of DESIDOC were a great source of help to me.

P.N.A.P. Rao

List of Acronyms

AAC	Airlines Administrative Communications
ADF	Automatic Direction Finder
ADS-B	Automatic Dependent Surveillance-Broadcast
AOA	Angle of Attack
AOC	Airlines Operational Communications
ATM	Air Traffic Management
BER	Bit Error Rate
CCD	Charge Coupled Device
CFIT	Controlled Flight into Terrain
COTS	Commercial Off the Shelf
DBS	Doppler Beam Sharpening
DFCS	Digital Flight Control System
DME	Distance Measuring Equipment
EFIS	Electronic Flight Instrumentation System
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EO	Electro Optical
ESD	Electro Static Discharge
ESMS	Electronic Support Measures System
EVS	Enhanced Visual Display
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control System
FHA	Functional Hazard Analysis

FHD	Functional Hierarchy Diagram
FLIR	Forward Looking Infra Red System
FMS	Flight Management System
FOG	Fiber Optic Gyros
GLS	GPS based Landing Systems
GNSS	Global Navigation System
GPWS	Ground Proximity Warning System
HF	Human Factors
HIRF	High Intensity RF
ILS	Instrument Landing System
IMA	Integrated Modular Architecture
INS	Inertial Navigation System
IRST	Infra Red Search and Tracking System
IVHM	Integrated Vehicle Health Management System
LAAS	Local Area Augmentation System
LGB	Laser Guided Bombs
LNAV	Lateral Navigation Guidance Function
MAWS	Missile Approach Warning System
MFD	Multi Function Display
MLS	Microwave Landing System
MMR	Multi Mode Radar
MSDF	Multi Sensor Data Fusion Systems
MSK	Minimum Phase Shift Keying
NDB	Non Directional Beacons
OOAD	Object Oriented Analysis & Design
OSA	Open System Architecture
RA	Radio Altimeter or Radar Altimeter
RAIM	Receiver Autonomous Integrity Monitoring
RLG	Ring Laser Gyros
RTOS	Real Time Operating Systems
RWR	Radar Warning Receiver

SAR	Synthetic Aperture Radar
SDR	Software Defined Radio
SE	System Engineering
STD	State Transition Diagram
TAWS	Terrain Awareness and Warning Systems
TCAS	Traffic Alert & Collision Avoidance System
TDMA	Time Division Multiplex Access
UML	Unified Modelling Language
USMS	Utility Services Management System
VNAV	Vertical Navigation
VOR	VHF Omni directional Range
WAAS	Wide Area Augmentation Systems

CHAPTER 1

Introduction

1.1 GENERAL INTRODUCTION TO AVIONICS SYSTEMS

1.1.1 Role of Avionics System in an Aircraft

Avionics system is the core of all aerospace platforms including civil commercial aircrafts, fighter aircrafts, Unmanned Aerial Vehicles (UAV) and airborne early warning and surveillance aircrafts. In manned aircraft both the civil and military aviators depend on avionics systems for most of the functionalities which include aviate, navigate and communicate for both civil and military aircrafts and additional functions like offensive, defensive and surveillance roles for military aircrafts. Unmanned aircrafts are totally dependent on avionics for their operations. In modern aircrafts 30 % to 50 % of the cost can be attributed to avionics. Most of the life extension of older aircrafts depend on modern avionics updates.

1.1.2 All Pervasive Integrated Avionics

Avionics stands for aviation electronics. As the electronics hardware cost, size and power consumption decreases and higher processing power and higher memory become available, the role of electronics in aircrafts has become more complex. If we look back at the evolution of avionics, the first manned flight by Wright Brothers in 1903 had no avionics. As the technologies of electronics and communications developed, the aircraft designers could add more functions based on these technologies. For example, the flight control functions were mechanical or electromechanical in earlier aircrafts. Modern aircrafts employ Digital fly by wire Flight Control System (FCS) with aircraft control law embedded in the FCS computer. The engine control and monitoring functions are digital with Full Authority Digital Engine Control System (FADEC). The mechanical systems such as environmental control system, fuel systems, hydraulic systems, and brake management and landing gear system have electronics hardware and software embedded for control and monitoring of these systems. In military aircraft all sensors (radar and electro-optics), electronic warfare systems, data fusion and weapon management computers are part of the integrated avionics system. Hence, avionics is now all pervasive in aircraft and is dissolving traditional boundaries between systems and integrating all functions in an aircraft.

1.1.3 Avionics in Maintenance

The proliferation of avionics among all the aircraft systems has an additional benefit. The condition, status, and health of systems–avionics, FCS and mechanical systems are monitored in real time resulting in higher safety of aircraft and improved maintenance, reducing the operating cost and increasing the availability of aircraft. In fact, avionics is the basis of modern cost effective technology of Integrated Vehicle Health Management System (IVHM) encompassing status monitoring, fault detection and analysis, diagnostics, and prognostics.

1.1.4 Pilot Vehicle Interface

Another area of major impact of modern avionics is the cockpit and pilot vehicle interface. In earlier aircrafts, there were a large number of mechanical and electromechanical instruments in the cockpit which were difficult to read which increased the pilot's workload. In modern avionics systems, information from all aircraft systems and sensors are available in real time. This has enabled the introduction of 'Glass Cockpit' with programmable large LCD multi function displays which provide the pilot with any information he needs at the touch of a button/icon. Electronic Flight Instrumentation System (EFIS) increases the situation awareness (both external and internal) of the pilot and reduces his workload. In fact integrated avionics system with glass cockpit and increased automation has enabled the reduction of crew in the cockpit of large long distance passenger aircrafts from four to two. Avionics enables extensive automation of many of the pilot's functions and improves the safety of the aircraft by giving early warning of faults in any system or navigation errors or adverse weather conditions. A typical glass cockpit of a civil aircraft (Boeing 777) is shown in Fig. 1.1.

Figure 1.1. Cockpit of Boeing 777.

1.2 INTEGRATED AVIONICS SYSTEMS

1.2.1 Federated Architecture

Avionics started in a modest scale with mechanical and electromechanical instruments providing the pilot with essential navigation, engine, and fuel indications. Next generation of avionics were individual Line Replaceable Units (LRUs) interconnected serially (ARINC429 Bus) or through Multiplexed Buses (MilStd1553B, ARINC629, etc.). This is called 'federated architecture' and proved useful until 1990s.

1.2.2 Increased Functionalities and Evolution of Integrated Modular Architecture

With the increased functionalities and with the evolution of satellite-based navigation and introduction of new systems and sensors like weather radar to detect adverse weather conditions like rain, turbulence and wind shear, Terrain Avoidance and Warning System (TAWS), Traffic Alert and Collision Avoidance System (TCAS), Automatic Dependent Surveillance Broadcast (ADS-B) system, synthetic vision and enhanced vision using infrared sensors, information processing capabilities of the avionics systems has increased many times. Enormous processing is required in order to process information from sensors and status and health information from all systems including flight critical system such as digital flight control system, propulsion system and brake management System[1].

In addition to this, in a fighter aircraft, more information has been to be processed using Multi Sensor Data Fusion Systems (MSDF) to present the pilot on cockpit displays fused information on external threats obtained from multi mode radar, radar warning receiver, and electro-optic sensors. The increased processing power from modern multi core processors helps in meeting these requirements. Data storage requirements including 3D terrain data have also increased requiring higher memory capabilities. Display processors using powerful graphics processors enable presentation of pilot-friendly pages on multiple displays including head up displays. To meet these multiple requirements the older federated architecture proved to be inadequate.

The integrated avionics systems evolved in 1990s using the concept Integrated Modular Architecture (IMA) and open architecture using commercial backplanes like VME and VPX. This has resulted in decreased cost (due to use of commercial off the shelf ruggedised cards) decreased size, weight and power (SWAP). An example the integrated modular avionics system of Indian LCA (Tejas fighter aircraft) is given in Fig. 1.2. Glass cockpit of LCA (Tejas) is shown in Fig. 1.3.

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About the Book

This monograph deals with the subject of avionics systems of both fighter aircraft and civil aircraft. Modern integrated avionics systems implement various complex functionalities of the aircraft. and have interfaces with all the other systems on board the aircraft. This makes the design and development of avionics systems a complex process. This monograph covers all these aspects in detail. Subjects covered include: Avionics System Functionalities, Subsystems, System Design, Speciality Engineering topics like QA, Reliability and EMI/EMC, Development, Safety, Integration, Testing and Certification of Avionics Systems. It also covers lessons learnt in most of the topics based on the experience of the author in the Indian Light Combat Aircraft (LCA)-Tejas Program.

Design for Safety which requires adoption of Fault Tolerant features–both in hardware and software, modern software engineering processes and tools are also dealt in detail. Pilot Vehicle Interface (PVI) and Human Factors (HF) are important topics covered as part of the cockpit design, automation and safety design. Certification aspects for both fighter and civil aircrafts are covered. Multi Mode Radar (including AESA), EW systems and EM and IR sensors including reconnaissance pods are covered. Modern techniques and future trends in avionics are also elaborated.

This book will be of interest to avionics engineers, technicians, operators, maintenance engineers and all those who have interest in avionics systems.

About the Author

Shri P.N.A.P. Rao obtained his BTech (Hons) Degree in Electronics and Communication Engineering from IIT, Kharagpur in 1963 and MS Degree from JNT University, Hyderabad in 1984. He is a Graduate of National Defence College, New Delhi.

He worked at Defence Electronics Research Laboratory from 1964 to 1989 in the areas of EW Systems, Communications Systems, and EMI/EMC. He was with Aeronautical Development Agency (ADA) as Project Director (System) during 1989 to 2002, leading the National Team on the Design & Development of Avionics & Weapon Systems for Indian Light Combat Aircraft (LCA-Tejas) which has been inducted into service with Indian Air Force. He held the post of Outstanding Scientist during 2001-2002 and Emeritus Scientist in 2002-2003 at ADA. He also worked as a Specialist Consultant at NAL working on the National Civil Aircraft Development Program (NCAD) from April 2010 to March 2013. He has more than 80 papers in journals, conferences & books to his credit.

He was conferred the Dr VM Ghatge Award by Aeronautical Society of India in 2001, Award by the Society of EMC Engineers (India) in 2001 and IETE-B V Baliga Memorial Award-2016 for his outstanding contributions to the development, integration and flight testing of avionics system of Indian LCA and for pioneering contributions towards development and growth in the fields of Avionics, Electronic Warfare and EMI/EMC.

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