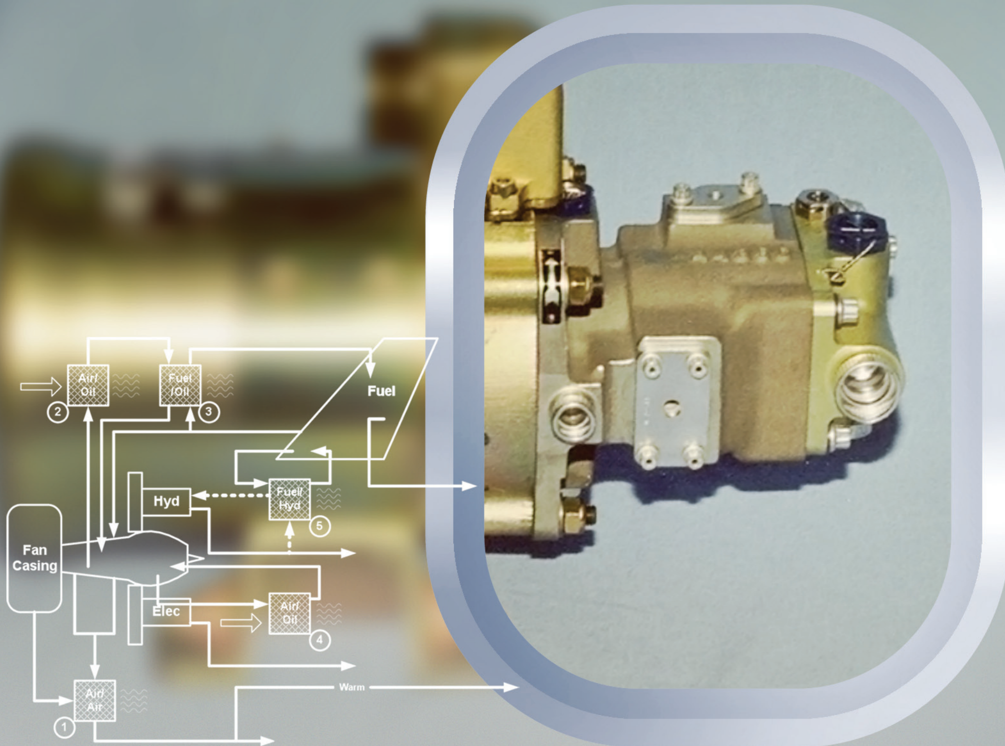


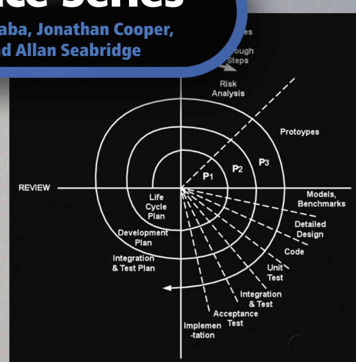
Ian Moir and Allan Seabridge

Design and Development of Aircraft Systems

Second Edition

Aerospace Series

Editors Peter Belobaba, Jonathan Cooper, Roy Langton and Allan Seabridge



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DESIGN AND DEVELOPMENT OF AIRCRAFT SYSTEMS

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DESIGN AND DEVELOPMENT OF AIRCRAFT SYSTEMS

SECOND EDITION

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WILEY
A John Wiley & Sons, Ltd., Publication

This edition first published 2013

Registered office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

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Library of Congress Cataloging-in-Publication Data

Moir, I. (Ian)
[Design and development of aircraft systems]
An introduction to aircraft systems design & development / Ian Moir, Allan Seabridge. – Second Edition
pages cm
Includes bibliographical references and index.
ISBN 978-1-119-94119-4 (cloth)
1. Airplanes–Design and construction. 2. Aeronautics–Systems engineering. I. Seabridge, A. G. (Allan G.) II. Title.
TL671.2.S39 2013
629.134′1–dc23

2012031458

A catalogue record for this book is available from the British Library and the Library of Congress.

ISBN: 978-1-119-94119-4

Typeset in 10/12pt Times by Aptara Inc., New Delhi, India

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About the Authors

Ian Moir after 20 years in the Royal Air Force as an engineering officer, went on to Smiths Industries in the UK where he was involved in a number of advanced projects. Since retiring from Smiths [now GE Aviation] he is now in demand as a highly respected consultant. Ian has a broad and detailed experience working in aircraft avionics systems in both military and civil aircraft. From the RAF Tornado and Army Apache helicopter to the Boeing 777 Electrical Load Management System [ELMS], Ian's work has kept him at the forefront of new system developments and integrated systems in the areas of more-electric technology and system implementations. He has a special interest in fostering training and education and further professional development in aerospace engineering. Ian now has over 50 years of experience in Aerospace.

Allan Seabridge was until 2006 the Chief Flight Systems Engineer at BAE Systems at Warton in Lancashire in the UK. In over 45 years in the aerospace industry his work has included the opportunity to work on a wide range of BAE Systems projects including Canberra, Jaguar, Tornado, EAP, Typhoon, Nimrod and an opportunity for act as reviewer for Hawk, Typhoon and Joint Strike Fighter, as well being involved in project management, R&D and business development. In addition, Allan has been involved in the development of a range of flight and avionics systems on a wide range of fast jets, training aircraft and ground and maritime surveillance projects. From experience in BAE Systems with Systems Engineering education he is keen to encourage a further understanding of integrated engineering systems. An interest in engineering education continues since retirement with the design and delivery of systems and engineering courses at a number of UK universities at undergraduate and postgraduate level. Allan has been involved at Cranfield University for many years and has recently started a three year period as External Examiner for the M.Sc course in Aerospace Vehicle Design.

Between them the authors have been actively involved in undergraduate, postgraduate and continuing professional development courses and supervisory duties in aerospace at the Universities of Bristol, City, Cranfield, Lancaster, Loughborough, London Imperial, Manchester, and the University of the West of England.

Series Preface

Since the first publication of this book in 2004 there have been significant changes in the aerospace industry. Very large aircraft such as the A380 are in service and the Boeing 787 will introduce radical new technological solutions to improve its ‘green’ credentials. Long range, transpolar operations are common place and there is growing pressure from the environmentalist lobby to reduce emissions. Meanwhile passengers are faced with increasing fares and taxes that could threaten the viability of the aviation industry.

The supply industry has changed, partly as a result of mergers and acquisitions and partly from a desire of suppliers to acquire a greater share of the business available, altering the traditional prime contractor/subcontractor relationships. Another factor driving amalgamation is increased competitiveness in both commercial and military sectors and the aspirations of the aerospace sectors in the emerging nations such as Brazil, India and China. The dominance of domestic consumer markets has reduced the power of the aerospace industry to demand bespoke products in small volumes – a situation which is unlikely to be reversed. Emerging as a great challenge are unmanned air vehicles, used successfully in military theatres today but ultimately expected to appear in commercial applications. It is essential to move from development of vehicles towards developing total systems – the vehicle and the supporting ground systems – and their certification issues if unmanned air systems are to become as ubiquitous as manned aircraft are today.

These factors place great emphasis on an understanding of the customer’s requirements and the implementation of development process that provides a product with technical excellence whilst meeting cost and schedule targets. This demands a measure of discipline in the design process to ensure that the requirements are analysed with competence, the design proceeds in an orderly and consistent fashion towards production and that the product is tested and certificated as fit for purpose. Of major importance is that the product includes all aspects of the total system in which it is operated.

The aim of this book is to provide a familiarity with a generic process that can be tailored to meet the needs of individual projects and to introduce project engineers to the complex interactions that need to be understood and managed in contemporary projects. The intention, as with the first edition, is to provide a text that will be of use to practitioners but is also aimed at students and engineers wishing to enter the aerospace industry, whilst providing those professionals in allied disciplines an understanding of the process of developing a complex system.

Acknowledgements

> *There is no invention that does not possess a history, none that does not build on, or learn from or owe a debt to the work of others.*
>
> Joseph Swan, 1828–1914.

From ‘Swan, 1924’ by Sean O’Brien, ‘Litmus: Short Stories from Modern Science’ Ed Ra Page, Comma Press, 2011.

This work is the culmination of many years of work by both authors in the field of military and civil aircraft systems engineering. Our work experiences have been enriched by the opportunity to work with a number of universities at undergraduate and postgraduate level to develop and add to degree courses, where the delegates unwittingly became critics and guinea pigs for our subject matter. Discussions during the courses with the academics and the students have broadened our knowledge considerably. In particular we would like to mention the Universities of Manchester, Loughborough, Cranfield, Bristol, University of the West of England and Lancaster for their M.Sc and short courses attended by students and engineers from industry. At Cranfield special thanks must go to Dr Craig Lawson and Dr Huamin Jia for inviting us to participate in their MSc modules and short courses in Aircraft Systems Design and Avionics. Their students from the UK, Europe and China have been most attentive and have made significant contributions to our knowledge. Dr Craig Lawson has also contributed an important section in Chapter 12 on the estimation of fuel penalties as part of the trade-off process.

Similarly at Bristol University and the University of the West of England where students from BAE Systems, Airbus, Rolls-Royce, Augusta Westland and European companies also have provided valuable inputs.

Cranfield University also gave us access to their group design project models, and our appreciation to Barry White for his model making skills.

The reviewers are to be congratulated for their diligence and for their constructive comments and criticism and our colleagues Malcolm Jukes, Roy Langton, Leon Skorczewski for their unstinting advice and encouragement.

We have received considerable help from the staff at Wiley especially Debbie Cox, Anne Hunt, Eric Willner and Liz Wingett as well as their proof readers, copy editors and publishing staff.

Ian Moir and Allan Seabridge
April 2012

Glossary

A4A	Airlines for America
ABS	Automatic braking system
AC	Alternating current
AC	Airworthiness Circular – document offering advice on specific aircraft operations
ACMP	AC driven motor pump
ADC	Air data computer
ADF	Automatic direction finding
ADM	Air data module
ADR	Accident data recording
AFDX	Avionics fast switched ethernet
AHARS	Attitude heading and reference system
AIMS	Aircraft information management system (Boeing)
Al	Aluminium
ALU	Arithmetic logic unit
AMP	Air motor driven pump
APC	Auxiliary power contactor
APU	Auxiliary power unit
ARINC	Air Radio INC (US)
ARINC 400 Series	Series of ARINC specifications providing a design foundation for avionic equipment
ARINC 404	Early ARINC standard relating to the packaging of avionic equipment
ARINC 429	Widely used civil aviation data bus standard
ARINC 500 Series	Series of ARINC specifications relating to the design of analogue avionic equipment
ARINC 578	ARINC standard relating to the design of VHF omni-range (VOR)
ARINC 579	ARINC standard relating to the design of instrument landing systems (ILS)
ARINC 600 Series	Series of ARINC specifications relating to Enabling technologies for avionic equipment
ARINC 600	Later ARINC standard relating to the packaging of avionic equipment
ARINC 629	ARINC standard relating to a 2Mbit/s digital data bus
ARINC 700 Series	Series of ARINC specifications relating to the design of digital avionic equipment
ARINC 708	ARINC standard relating to the design of weather radar

ARINC 755	ARINC standard relating to the design of multi-mode receivers (MMR)
ARP	Aerospace recommended practice (SAE)
ASIC	Application specific integrated circuit
ATA	Air Transport Association
ATC	Air Traffic Control
ATI	Air transport instrument – a means of specifying the size of aircraft instruments
AWG	American wire gauge
Backwards	The ability of systems to be compatible with earlier developments/ Compatibility configurations
BC	Bus controller (MIL-STD-1553B data bus)
BCAR	British civil airworthiness requirement
BIT	Built-in test
BMS	Business management system
BPCU	Bus power control unit
BTB	Bus tie breaker
CAD	Computer aided design
CADMID	UK MoD procurement process
CAIV	Cost as an independent variable
CANbus	Automotive data bus
CB	Circuit breaker
CDR	Critical design review
CFC	Chloro-fluoro-carbon compounds
CG, cg	Centre of gravity
CNI	Communications, navigation, identification
Cold Soak	Prolonged exposure to cold temperatures
Com	Command channel
COTS	Commercial-off-the-shelf
CPIOM	Common processor input/output module
CPM	Common processing module
CPU	Central processing unit
CSG	Computer symbol generator
Cu	Copper
DC	Direct current
DCMP	DC motor driven pump
Def Stan	Defence standard
DME	Distance measuring equipment
DMC	Display management computer
DoD	Department of Defense (US)
DOORS	A requirements management tool
Downey Cycle	Procurement model used in the UK MoD
DVI	Direct voice input
EASA	European Aviation Safety Administration
ECAM	Electronic check-out and maintenance (Airbus)
ECS	Environmental control system
EDP	Engine driven pump

EDR	Engineering design requirements
EEC	Electronic engine controller
EFIS	Electronic flight instrument system
EICAS	Engine indication and crew alerting system
ELMS	Electrical load management system
EMC	Electromagnetic compatibility
EMH	Electromagnetic health
EMI	Electromagnetic interference
EPB	External power breaker
ESM	Electronic support measures
ETOPS	Extended Twin operations
EUROCAE	European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration (US)
FADEC	Full authority digital engine control
FAV	First article verification
FBW	Fly-by-wire
FCU	Flight control unit
FL	Flight level
FMECA	Failure mode and criticality analysis
FMQGC	Fuel management and quantity gauging computer
FMS	Flight management system
FOB	Fuel on board
Forwards	The ability of systems to be compatible with future developments/ Compatibility configurations
FRR	Final readiness review
Full duplex	A data bus that passes data in a bi-directional manner
G&C	Guidance and control
GCB	Generator control breaker
GCU	Generator control unit
GHz	10^9 Hertz (gigaHertz)
GPS	Global positioning system
GPWS	Ground proximity warning system- see also TAWS
GUI	Graphical user interface
gpm	Gallons per minute
Half duplex	A data bus that passes data in a unidirectional manner
HALT	Hardware accelerated life test
HF	High frequency
HIRF	High intensity radio frequency
HMI	Human machine interface
HOTAS	Hands on throttle and stick
Hot soak	Prolonged exposure to high temperatures
HP	Horse power
IAS	Indicated airspeed
IC	Integrated circuit
ICD	Interface control document
IDG	Integrated drive generator

IEEE 1498	High speed data bus
IFE	In-flight entertainment
ILS	Instrument landing system – an approach aid used for guiding the aircraft on a final approach to landing
IMA	Integrated modular architecture
INCOSE	International Council On Systems Engineering
INS	Inertial navigation system
I/O	Input/output
IPT	Integrated product team
IR	Infrared
IRS	Inertial reference system
ISIS	Integrated standby instrument system
IT	Information technology
JAA	Joint Aviation Authorities (Europe) See EASA
kbits	10^3 bits (kilobits)
LCD	Liquid crystal display
LED	Light emitting diode
LfE	Learning from experience
LRI	Line replaceable item
LRU	Line replaceable unit
LVDT	Linear variable differential transformer
Mach	The speed of an aircraft in relation to the speed of sound
MAD	Magnetic anomaly detector
MAU	Modular avionics unit
MBits	10^6 bits (megabits)
MCDU	Multifunction control and display unit
MCU	Modular concept unit
MEA	More electric aircraft
MHz	10^6 Hertz (megaHertz)
MIL-HBK	Military Handbook – A US military publication
MIL-STD-1553B	Widely used military data bus standard
MLS	Microwave landing system – an advanced approach aid used for guiding the aircraft on a final approach to landing
MMEL	Master minimum equipment list
MMR	Multimode receiver – a receiver containing GPS, ILS and MLS receivers
MoD	Ministry of Defence (UK)
Mode S	A communication system used to exchange flight data between adjacent aircraft and Air Traffic Control
Mon	Monitor channel
MPCDU	Multipurpose control and display unit
MPP	Master programme plan
NASA	National Aeronautics & Space Administration (US)
NATO	North Atlantic Treaty Organisation
ND	Navigation display
NDA	Non-disclosure agreement

NRC	Non-recurring costs
OAT	Outside air temperature
OOD	Object oriented design
PBS	Product breakdown structure
PC	Personal computer
PDR	Preliminary design review
PFD	Primary flight display
PHM	Prognostics and health management
PMA	Permanent magnet alternator
PoR	Point of regulation
PRR	Production readiness review
psi	Pounds per square inch
PTU	Power transfer unit
Quadrax	A four-wire full duplex data bus connection arrangement that enables data to be passed each way thereby effectively achieving bi-directional data transfers (favoured by Airbus)
QMS	Quality management system
RAM	Random access memory
RASP	Recognised air surface picture
RAT	Ram air turbine
R&D	Research and development
RF	Radio frequency
RFI	Request for information
RFP	Request for proposal
ROM	Read only memory
RT	Remote terminal (MIL-STD-1553B data bus)
RTCA	Radio Technical Committee Association (US)
RVDT	Rotary variable differential transformer
SAE	Society of Automotive Engineers (US)
SAHRS	Secondary attitude and heading reference system
SARS	Severe acute respiratory syndrome
SATCOM	Satellite communications
SBAC	Society of British Aerospace Companies (UK)
SDD	System design document
SDR	System design review
sfc	Specific fuel consumption
SIGINT	Signals intelligence
SOW	Statement of work
SPC	Statistical process control
SRR	System requirements review
SSA	System safety analysis
SSPC	Solid state power controller
SSR	Software specification review
Stanag	Standardisation agreement (NATO)
SysML	System modelling language

System of Systems	A system embracing a collection of other systems
TAS	True airspeed
TAWS	Terrain avoidance warning system
TCAS	Traffic collision avoidance system
TRR	Test readiness review
TRU	Transformer rectifier unit
TV	Television
Twinax	A two wire half duplex data bus connection that allows unidirectional data transfers (favoured by Boeing)
UAV	Unmanned air vehicle
UK	United Kingdom
UML	Unified modelling language
US, USA	United States (of America)
USMS	Utility systems management system
UTP	Unshielded twisted pair
UV	Ultraviolet
VHF	Very high frequency
VMS	Vehicle management system
VOR	VHF omni-range; a commonly used navigation beacon in civil aerospace
VSCF	Variable speed constant frequency
WBS	Work breakdown structure

1

Introduction

1.1 General

In three companion books in the Aerospace Series – Aircraft Systems [1], Civil Avionic Systems [2], and Military Avionics [3] the authors described the technical aspect of systems for military and commercial aircraft use – in essence the engineering of systems and system products. Other books in the Series have also described the technical aspects of various systems, for example, fuel systems [4], and display systems [5]. However, we did not dwell on the mechanism by which such systems are designed and developed, and yet the process of systems development is a very important aspect that contributes to the consistency, quality and robustness of design.

The first edition of this book tried to make amends and described the design and development process and the life cycle of typical aircraft systems. Since its initial publication the material in the book has been used in a number of postgraduate courses and industrial short courses for aerospace systems engineers and has been developed to suit the engineering audience in response to questions received and discussions held during the course delivery.

This second edition is intended to be an introduction to aircraft systems and the systems development process for students studying systems or aerospace subjects and wishing to enter the aircraft industry or related industries, and for organisations sponsoring these people. The content is intended to be of interest to people intending to join or already working in:

- Organisations directly involved in the design, development and manufacture of manned and unmanned, fixed-wing and rotary-wing aircraft – both military and commercial
- Systems and equipment supply companies involved in providing services, sub-systems, equipment and components to the manufacturers of aviation products
- Organisations involved in the repair, maintenance and overhaul of aircraft for their own use or on behalf of commercial or military operators
- Commercial airlines and armed forces operating their own or leased aircraft on a daily basis
- Organisations involved in the training of personnel to work on aircraft

The book is also aimed at educational establishments involved in the teaching of systems engineering, aerospace engineering or specialist branches of the topic such as avionics or

Design and Development of Aircraft Systems, Second Edition. Ian Moir and Allan Seabridge.

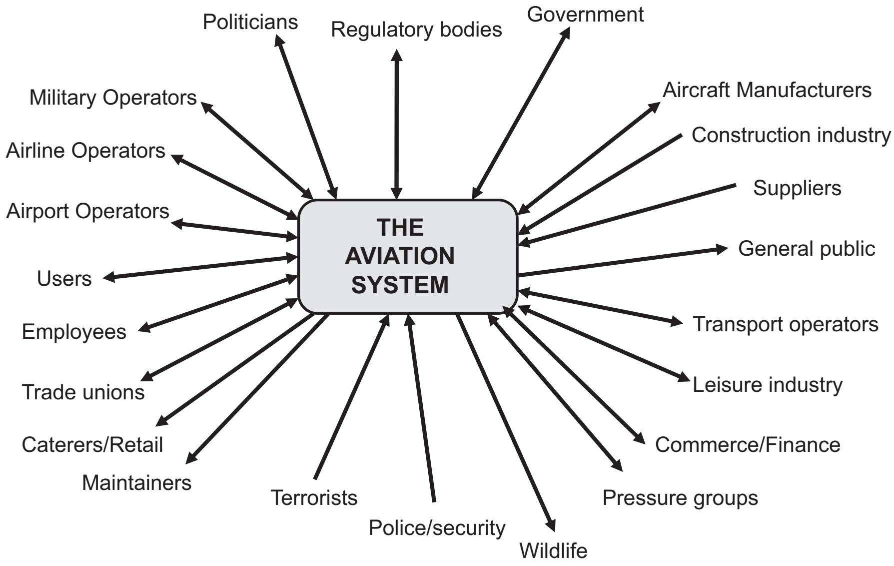

Figure 1.1 Stakeholders in the Aviation System.

equipment engineering at high school, university undergraduate or postgraduate level. It is also aimed at short courses suitable for the professional development of industry professionals and practitioners.

These are the sort of people who will be found in the broad range of stakeholders in complex aerospace projects. Figure 1.1 gives an example of the Aviation System and some of the people and groups affected by the systems or directly affecting the system. This diagram has been developed to illustrate the stakeholders in the development of an aircraft solution to meet environmental considerations. A specific project will have its own specific set of stakeholders.

Each of these stakeholders will have a different perspective of the design and development process and each is capable of exerting an influence on the process. For those directly involved it is vital that the design process is visible to all parties so that they can coordinate their contributions for maximum benefit to the project. A clear and well documented process is essential to allow the stakeholders to visualise the design and development path as a framework in which to discuss their different perspectives. This can be used to establish boundaries, to air differences of opinion and to arbitrate on differences of technical, commercial or legal understanding.

It is worth noting that since the first edition of this book there have been significant changes in business practice in the aerospace industry. Previously, the development of aircraft had been mainly in the hands of Prime Contractors appointed by the customer, with a supply chain competing for individual equipment and components. In modern aircraft development the first tier suppliers compete at the system level and in many cases the supplier teams work on-site at the prime contractor's base. In many cases of international collaboration this usually means a number of prime contractor partner bases in different countries. In this situation the supplier and the prime engineering teams develop equipment and component specifications together as integrated product teams (IPT). The system supplier is now typically responsible for system level and component level performance; and in many cases also responsible for direct maintenance costs associated with their system. This change in business practices demands that the supplier base becomes ‘systems smart’ and this book should provide a valuable insight for the business community to fulfil this need effectively [6].

The principles established are equally applicable to other platforms, such as surface and subsurface naval vessels, commercial marine vessels and land vehicles. The aerospace industry is almost unique, given the nature of an aircraft, in having to address high integrity and availability, weight, volume, power consumption, cost and performance issues. The conflict of competing system drivers often makes trade-offs more acute when attempting to achieve the optimum balance of meeting the customer’s requirements and achieving an affordable product. There are also differences between commercial and military solutions that may demand a subtly different interpretation of the process and the standards that apply. The emergence of Unmanned Air Vehicles broadens the system concept to incorporate ground stations for remotely piloted vehicles. The striving for autonomous unmanned vehicles will lead to more innovative approaches to design and will require more rigour in the certification of systems. Nevertheless, the process described in this book should be applicable, albeit with suitable tailoring.

Although the text is formed around examples that are mainly aeronautical platform based the reader may also apply them to other high value systems such as ground-based radar, communications, security systems, maritime and space vehicle based systems, or even manufacturing or industrial applications.

What makes all these platforms and systems similar is that they are all complex, high value products comprised of many interacting sub-systems, and they are intended to be used by a human operator. They also share a common characteristic of having long operational life cycles, often in excess of 25 years, usually with long gestation and development time-scales, the need for operator and maintenance training and full-life in-service support. Such timescales demand a rigorous, controlled and consistent development process that can be used to maintain an understanding of the standard or configuration of the platform throughout its life, in order to support repair, maintenance and update programmes.

1.2 Systems Development

There are many valuable lessons to be learned from the field of Systems Engineering. The authors believe that much of the theory and practice of Systems Engineering can be applied to the engineering of hardware and software based systems for use in aircraft. It is a broad field of practice that covers the behaviour of systems across wide range of subjects including organisational, operational, political, commercial, economic, human and educational systems. The concept of Systems and Systems Engineering operates at many different levels in many different types of organisation. Much of the early analysis of systems behaviour was concerned with organisational or management issues – the so-called ‘soft’ systems. This work led to an understanding of the interactions of communications, people, processes and flows of information within complex organisations [7, 8].

An important outcome from this work was the emergence of ‘systems thinking’. This term encompasses the ability to take a holistic or a total systems view of the development or analysis of any system. The key to this activity is the ability to take into account all influences or factors

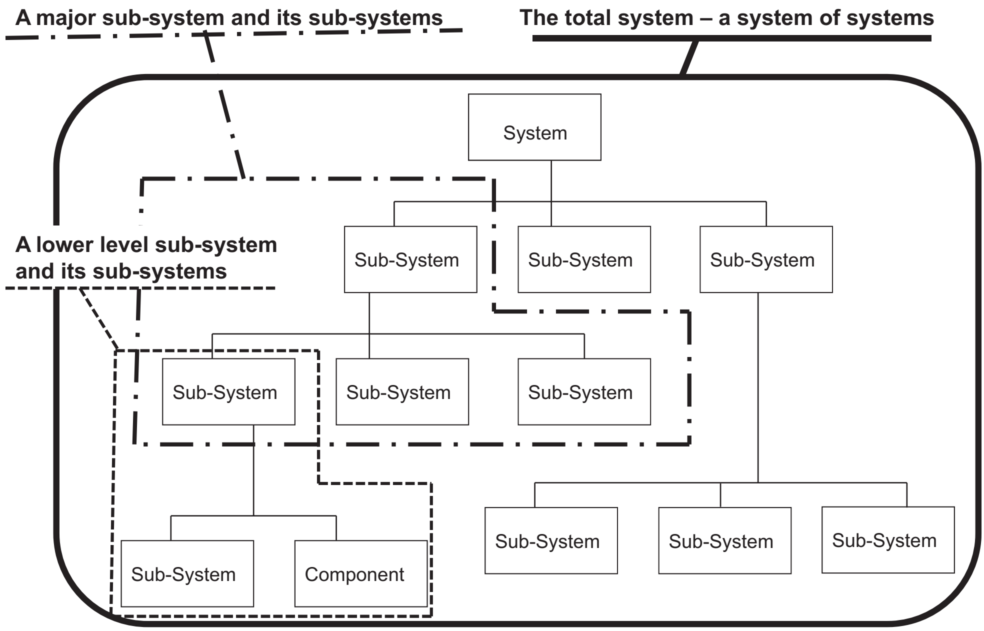

Figure 1.2 A hierarchy of systems, sub-systems and components.

which may affect the behaviour of a system. This is accomplished by viewing the system as existing in an environment in which certain factors of importance to the understanding of the system are present. In this book the concept of a single environment has been extend to encompass layers or shells of environments that allow people in an organisation to take their own viewpoint, and to examine aspects of prime importance to themselves. In this way it is possible to examine a system from the top down and to allow individuals such as politicians, marketing personnel, accountants, engineers, manufacturing and support staff to critically examine and develop their own particular requirements.

Another important property of systems is that they can be broken down into sub-systems, almost indefinitely. Thus Figure 1.2 shows how a system can be considered as a system of systems which is a grouping of several sub-systems, which may not require detailed definition at the level at which the system is being examined. The owners of the sub-systems, however, will regard their sub-system as being the system of prime importance and may choose to break it down into further sub-systems. This top down sub-division, or decomposition, can take place from an abstract concept of a system, right down to its hardware and software components. This hierarchy of systems, in which the top level systems are important and exert an influence on lower level systems, is the manner in which most complex systems are analysed and implemented. It is a way in which the key systems and systems architectural principles stated at the highest levels of system definition are preserved throughout the implementation and into the product.

For aircraft systems the ultimate and most elemental building blocks for a system are the components – physical components such as pumps, valves, sensors, effectors, and so on that determine the hardware characteristics of the system, or alternatively the software applications or modules that contribute to the overall system performance. The human, in the form of the pilot, crew member, passenger or maintainer is also a vital part of the system.

The decision on how far to keep decomposing a system into sub-systems depends on the complexity of the system and the ability to view the functions and interfaces as a whole. At some stage it may become necessary to construct a boundary around a system in order to specify it to an external supplier for further analysis and design. An example of this is the definition of a sensor sub-system that will be more effectively developed and manufactured by a specialist supplier.

Such a breakdown of systems into sub-systems, and yet further sub-systems and components reinforces another important aspect of systems and their interconnections. The outputs from a system can form inputs to other systems. Indeed a system may produce an output, which is fed back to its own input as feedback. Feedback loops are not confined to one stage of a system, feedback may occur over several concatenated or interconnected systems in order to produce system condition status or stability. Feedback may also be implemented using a data bus and multiplexed processing units, which means that data latency must be taken into account. To enable this to happen effectively in a hard system, the system interfaces must be defined to ensure compatibility – that a system output is accepted and understood as an input so that it can be acted upon. This requires that interfaces are well defined and rigorously controlled throughout the development of the system.

It should also be noted that there have been significant changes in the aircraft supplier industry resulting in mergers and acquisitions leading to large organisations with aspirations to extend their business to tender for larger systems contracts. The mergers have increased the capability of suppliers to the extent that this is a feasible and sensible proposition. At the same time some major prime contractors have focussed their sights on major system of system management contracts, concentrating their capabilities on management of design, design of specialist integration tasks, final assembly and qualification of the product.

The 'top down' development of individual systems as practised in many line management organisations is shown in Figure 1.3 at point A.

This is the development path with which most engineers are familiar for all aircraft systems, avionics systems and mission systems treated as individual systems. However, there is often a need for something more than this straightforward development route. Point B on the figure illustrates a case where certain systems are interconnected to form a synergistic integrated function – in other words a function is performed that is more than the sum of the individual system functions. An example of such a function is that of guidance and control (G&C) as an integration of functions of flight control, hydraulics, automatic flight control and fuel systems, (See Chapter 6 for more detail). Also shown in this diagram is the integration of communications, navigation and identification (CNI) systems.

Point C in the figure illustrates an alternative view of integration – that of a design aspect that applies equally to all systems as a common discipline. Examples of this are safety, the human/machine interface (HMI), electromagnetic health (EMH) or maintainability. These disciplines are governed centrally, usually by the Chief Engineer's office, and their impact on the individual systems will be gathered together to form a statement of design for the complete product.

The systems concepts described above can be used in aircraft systems engineering. They can be used to develop, from an understanding of a customer's top level system requirements, a particular type of aircraft to perform a specific role and, after several successive analyses,

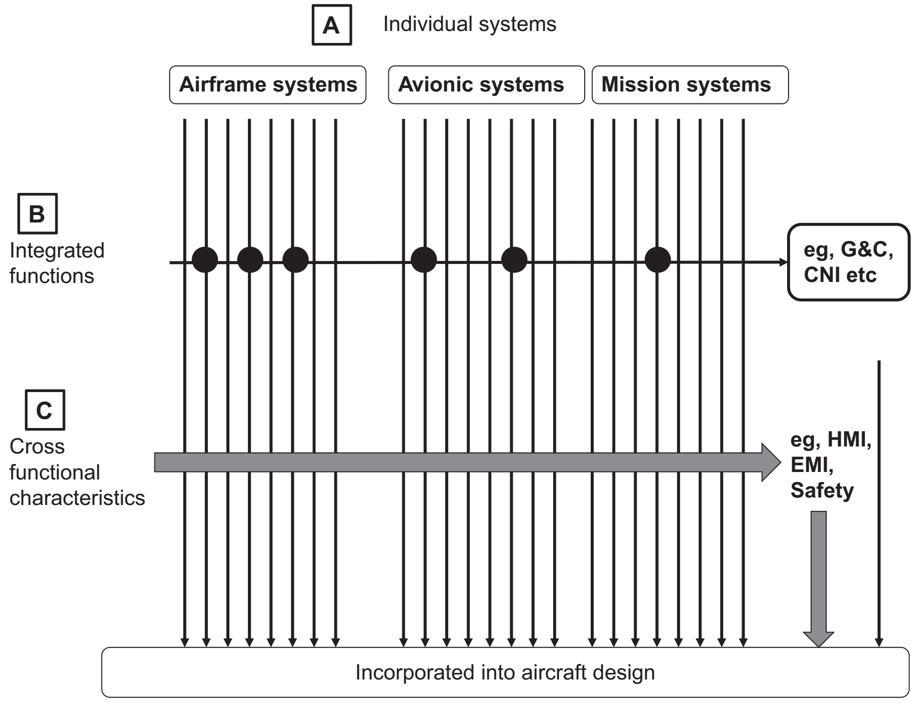

Figure 1.3 Some aspects of integration.

or decompositions, can lead to an implementation of a product. The top level system may be related to a need for National Defence or for a transportation system which can be expressed in terms of people, communication and processes, and eventually is expressed as a combination of various hardware products.

Such a top level system is one that is conceived by many customers as representing their highest level operational need. The role of systems engineering and systems integration is to ensure that the resulting combination of products can be shown to meet the overall requirements posed from this top level. The requirements set at the top level must flow down to the lowest level of product in a clearly traceable and testable manner, so that the integrity – or fitness for purpose – of the product can be demonstrated to the customer and to regulatory bodies governing adherence to mandatory national and international regulations.

Systems thinking encompasses a process for the development of a system. This has been defined by Checkland [7] and is based on a methodology defined by Hall [9] in 1962. Despite the age of this methodology its roots can be seen in many methods in use today. It is:

- **Problem definition** – essentially the definition of a need
- **Choice of objectives** – a definition of physical needs and of the value system within which they must be met
- **Systems synthesis** – the creation of possible alternative systems
- **Systems analysis** – analysis of the hypothetical systems in the light of different interpretations of the objectives