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Introduction

1.1 General

In three companion books in the Aerospace Series – *Aircraft Systems*, *Civil Avionic Systems*, and *Military Avionics* (Moir and Seabridge 2006, 2008, 2013) – 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 described the technical aspects of various systems, for example fuel systems (Langton et al. 2009) and display systems (Jukes 2004). However, we did not dwell on the mechanism by which such systems are designed and developed, although the process of systems development is a most important aspect that contributes to the consistency, quality, and robustness of design.

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

The second edition continued in this vein, widening its scope a little to offer subjects to people in the same industries who did not specialise in engineering but needed to have some knowledge of how engineers worked, for example procurement, contracts, and support.

This third edition has been produced to continue this 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

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

- 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 equipment engineering at high school, university undergraduate or postgraduate level. It is also suitable for short courses intended 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 system 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

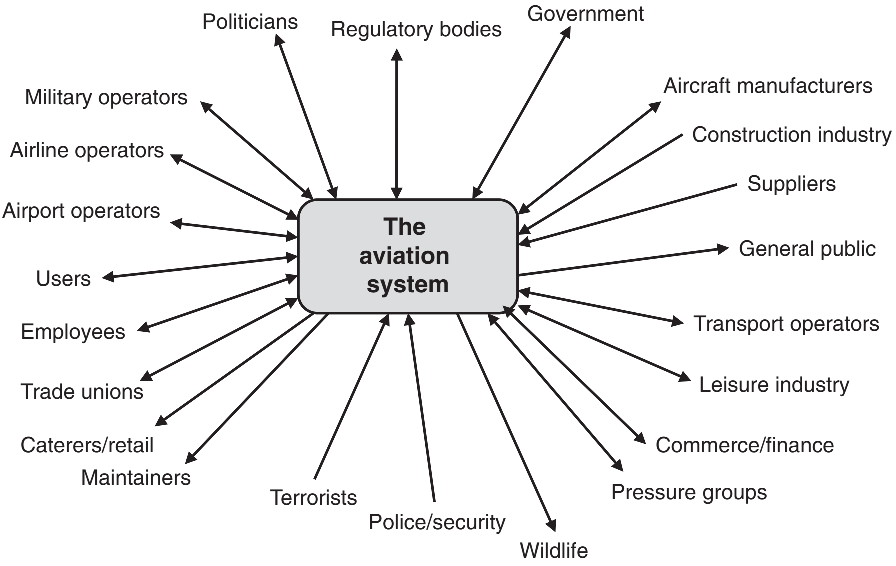

Figure 1.1 Stakeholders in the aviation system.

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 (IPTs). The system supplier is now typically responsible for system-level and component-level performance; in many cases the supplier 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 (Langton et al. 1999).

The principles established are equally applicable to other platforms, such as surface and sub-surface 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 comprising 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 lifecycles, often in excess of 25 years, usually with long gestation and development time-scales, and the need for operator and maintenance training and full-life in-service support. Such time-scales 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 author believes 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 a 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. (Checkland 1972; Lockett and Spear 1983).

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 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 extended 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, accountants, engineers, and manufacturing and support staff to critically examine and develop their own particular requirements (Burge 2019).

Another important property of systems is that they can be broken down into subsystems, 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

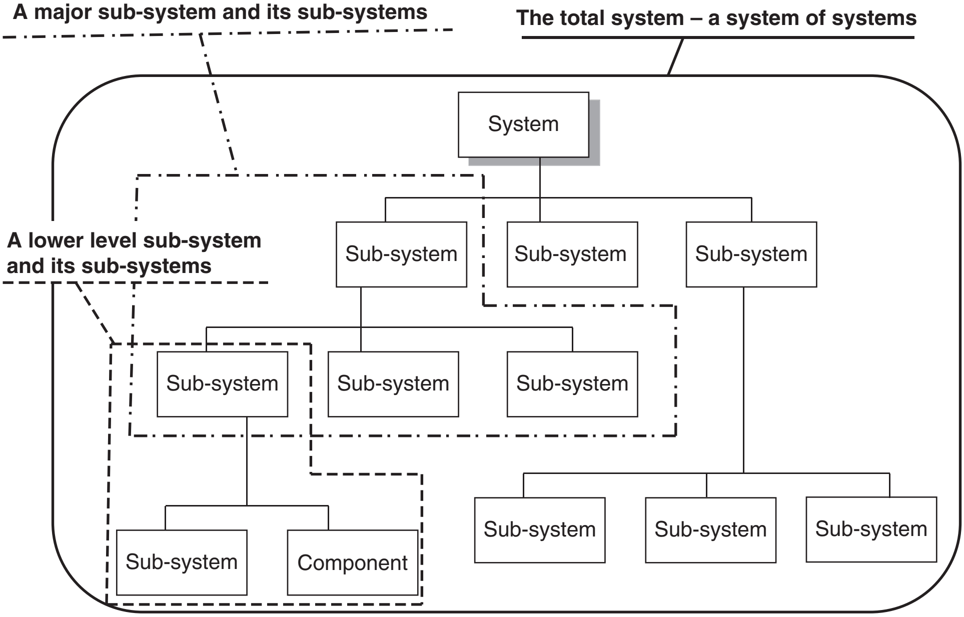

Figure 1.2 A hierarchy of systems, sub-systems, and components.

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 the 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, etc., 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, maybe as a single item of equipment.

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 that is fed back to its own input as feedback. Feedback loops are not confined to one stage of a system as 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 extending 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 the 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 practiced 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 Figure 1.3 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

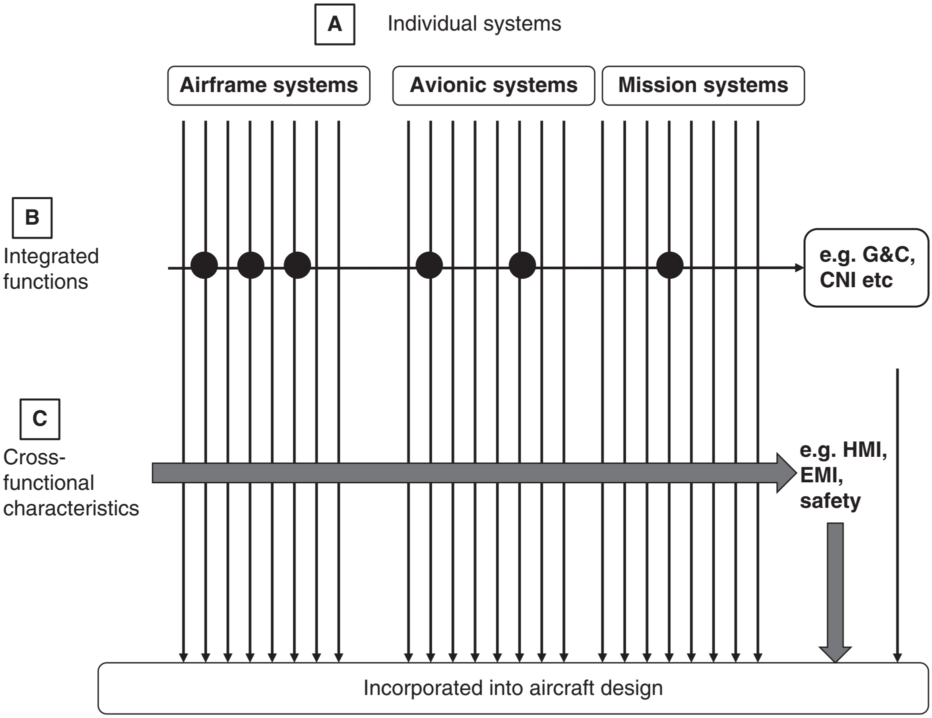

Figure 1.3 Some aspects of integration.

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 the 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 Figure 1.3 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), and 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, 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 of 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 (1972) and is based on a methodology defined by Hall (1962). Despite the age of this methodology its roots can be seen in many methods in use today. The methodology 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
- system selection – the selection of the most promising alternative
- system development – up to the prototype stage
- current engineering – system realisation beyond the prototype stage and including monitoring, modifying, and feeding back information to design.

For consistency across different projects it is usual for organisations to use a 'formal' process, either one defined by an industry standard or by their own developed process. Figure 1.4 shows two examples of how a process can be deployed in the design and development environment.

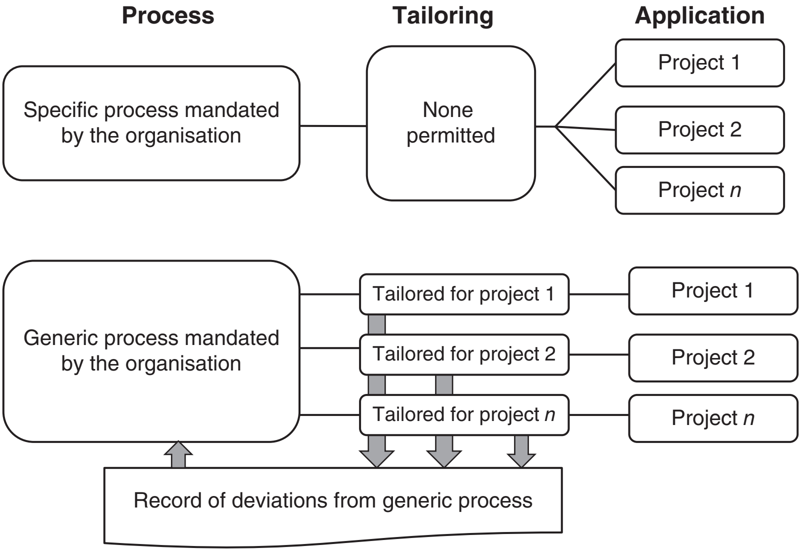

Figure 1.4 Process deployment examples.

Some organisations will mandate a project across all of their projects and will not tolerate any deviations at all. Other organisations will tolerate deviations or ‘tailoring’ of the process provided there is a sound reason for so doing. Such reasons include consideration of industrial partners in a joint project, taking account of their customer’s preferences or tailoring the project to suit a project technology.

This book will aim to show how the process works for aircraft systems by taking a generic view of the process and providing specific examples. The intention is to promote a holistic view of systems in a world of increasing complexity.

1.3 Skills

No matter how good the systems engineering process, it can only succeed by the application of the skills of individuals and teams, and successful interactions between multi-disciplinary organisations. People are an essential element of the system, whether in its design and implementation or as its operators and users. Many skills are applied in the design, development, and manufacture of a successful system. It is important to recognise the need for skills and experience as well as the need for training to develop and maintain the skill base. This will ensure that skills do not become ‘stale’, and that individuals and teams are continuously aware of emerging techniques, technologies, methods, and tools that may enable or promote effective new systems, as well as ensuring that legacy skills are maintained to support products with long in-service lives.

Within a particular project the people or stakeholders in the organisation will differ from those shown in Figure 1.1, more likely being similar to those shown in Figure 1.5.

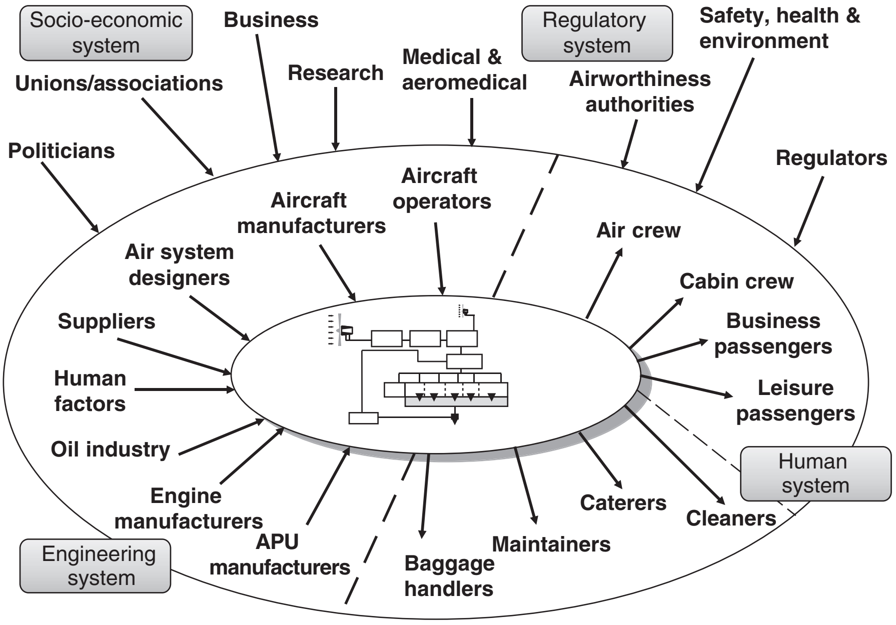

Figure 1.5 Typical stakeholders in a project.

Each chapter of this book will include a brief description of the typical skills that are particularly relevant to that part of the process being described. It must be recognised that skills can be taught but that experience can only be gained by working in the field and achieving levels of attainment. A particular skill that is difficult to describe, and that is usually acquired only with experience, is that of engineering judgement.

Skill and experience are an essential part of the capability of a systems engineering team and, together with the process and support tools, form the basis of sound systems engineering. The cognitive and personality characteristics of systems engineers (Frank 2000) must be appreciated by managers in order for them to build successful teams for the present and maintain capability for the future (Goodlass and Seabridge 2003).

1.4 Human Aspects

1.4.1 Introduction

One inescapable fact about aircraft is that they are normally designed to accommodate one or more humans and Figure 1.5 shows that the stakeholder population includes a number of such people. Whilst much of this book is concerned with the design and development of hardware to operate in a particular environment, the occupants of the aircraft necessarily occupy the same environment, although they are offered some protection by the airframe and the systems. These occupants must be taken into account in the design of the aircraft and those systems that affect them in some way.

It is worth examining the atmosphere in which various types of aircraft operate: the atmospheric environment on the ground and in the air, and the environment which the aircraft generates in its pressure cabin. The natural environment is a complex interaction of chemicals and electro-magnetic radiation. Only a portion of this atmosphere is used by aircraft, commonly to around 40 000 ft, although the ever-closer presence of the space-tourist industry will extend that beyond 360 000 ft. The most usual zones occupied by aircraft of various types are shown in Figure 1.6; also noted is FL260 (26 000 ft) which has been taken as a reference point for ozone reduction systems to start up and also as a point at which cosmic radiation monitoring should begin.

There are a number of factors originating in the environment of an aircraft that can have an impact on the long-term health of aircrew, cabin crew, and passengers as a result of prolonged or habitual exposure. They may arise as a result of poor design, but more often than not they are a fact of life, a result of the physics that arises from the operation of a high-speed machine and of the environment in which it operates. The machine can be considered as the workplace for aircrew and cabin crew, in which long-term exposure and damage to health may be inevitable unless action is taken to reduce the exposure to specific hazards. In considering the machine in this way – as the 'office' or workplace – it is no different to the ground-based office or factory in which many humans go to work on a daily basis. Legislation exists to protect them and their employers must respect the law or pay the consequences.

The occupants of a commercial aircraft are confined in a relatively small volume. Occupants include pilots, flight engineer, relief pilot, cabin crew, and passengers. Some of

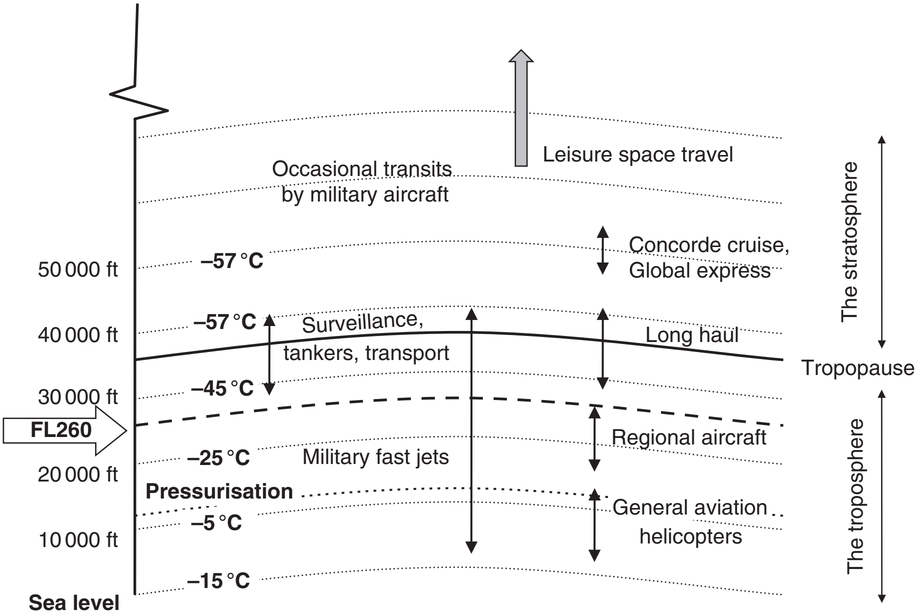

Figure 1.6 The atmosphere and air travel.

them may be anxious about flying; many may suffer from poor health or be predisposed to certain kinds of ailment from their genetic make-up or from recent illness. They breath re-circulated air obtained from the aircraft engines, they are exposed to noise, vibration, and motion for long periods of time, and at the same time the environment is subjecting the aircraft to solar and cosmic radiation. Under these circumstances it is not surprising that a few of the many millions of passengers complain about feeling unwell after flying or that frequent flyers claim to suffer from some kind of occupational effect.

Typical conditions that may be experienced on an aircraft are shown in Figure 1.7. Those conditions within the dotted shape are part of the aircraft interior environment and can be controlled; those outside the dotted line exist in the environment and are beyond the control of the designer. Not all these conditions apply to all types of aircraft, nor do they have a significant impact on non-frequent flyers, but they may have an impact on crews who are subjected to the conditions in the course of their job. They are, however, worthy of research by systems engineers designing safe systems and these conditions should be recorded with an acknowledgement that they have been considered in the design.

1.4.2 Design Considerations

The engineering teams designing different types of aircraft aim to meet customer specifications for performance and logistic support under demanding environmental and operational conditions. Many of these conditions are also inflicted on the aircrew, together with other conditions of operation resulting from inhabiting and operating a complex military machine, most often in peace time. Aircrew, cabin crew, and passengers of commercial

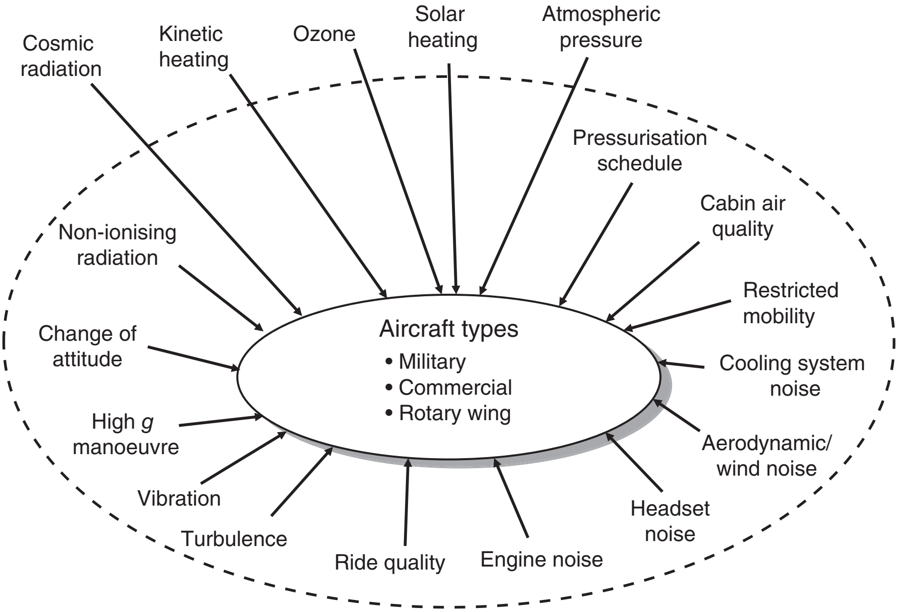

Figure 1.7 Sources of conditions that may be injurious to health.

aircraft also experience the same combination of conditions, albeit at less extreme limits. Singly, or in combination, these conditions can have an impact on the physical well-being of aircrew and passengers which may be apparent immediately or may only emerge after a long period of flying. In some cases, the effects may appear after flying employment has terminated for those whose career has been in aviation.

The good systems engineer needs to be mindful of these effects and the conditions most likely to cause them. This will enable the design of the aircraft to incorporate some alleviating aspects wherever possible, and most certainly to ensure that users of their products are aware of the risks and their duty of care to aircrew in their employment. At the same time organisations should be carrying out or supporting research to understand the issues and the risk that they pose.

The systems engineer must be sure to acquire knowledge and experience, and apply it in the engineering design of the aircraft and its systems:

- knowledge of legislation and its impact on design and operation
- awareness of research in the relevant field
- awareness of how to merge engineering and aero-medical or physiological aspects.

Mindful may not actually be the correct word. The designer and manufacturer of military aircraft has a responsibility, a duty of care to its own test pilots, and to its customers, to ensure that long-term use of the product does not pose a hazard to aircrew health. Similarly, the operator of commercial aircraft must take responsibility for the users of its aircraft, therefore there is a moral as well as a legal duty of care to users of the product. The operators of commercial aircraft have a similar duty of care to their aircrew, cabin crew, and passengers.

Legislation is continuously being revised to cope with differing workplace environments to protect workers. The responsible manufacturer of aircraft and responsible operators do their utmost to reduce the risk, but workplace legislation often advances faster than the design lifecycle of major aircraft products, which means that there is often a difference between in-service products and legislation.

Aircraft provide a dynamic environment that is the daily working environment – 'the office' – for aircrew and cabin crew. Some aspects of this environment are particularly harsh, especially for military aircrew. Prolonged exposure to these conditions may lead to long-term damage to health unless something is done to reduce the risk. This may be by design of the aircraft and its environment or by control of flying hours.

1.4.3 Legislation

Legislation exists to protect workers in their workplace. This is often interpreted as the protection of office and factory workers, and their working environment is well-regulated and governed. The workplace for aircrew is the cabin or cockpit of their aircraft and this is a dynamic environment that is less easy to regulate, but nevertheless contributes to their health.

The Health and Safety at Work Act 1974 in the UK outlines some general conditions that must be met by law to safeguard the health of people in their place of work. All employees have a statutory duty to observe the Act and to demonstrate that they do so. In addition, there are regulations that govern the exposure of workers to specific threats to their health, e.g. noise, vibration, ionising radiation, etc. All nations will have similar legislation in place.

The Act contains requirements that should be used as guidelines for any aircraft design. It puts the onus on product designers to undertake or promote the necessary research to discover and, so far as is reasonably practicable, to eliminate or minimise risks to health or safety to which the design or article may give rise. Furthermore, in the event of any legal action, the designer must prove that they have taken the necessary steps to eliminate risk, or that there was no practicable or viable alternative.

There is a possibility that aircraft operators may be subject to litigation by their aircrew claiming damage to health or impact on their career as a result of using manufactured products in their work. The customer may then claim that the aircraft manufacturer has made a contribution to this condition as a result of limitations in the design of the product.

1.4.4 Summary of Legal Threats

In the event that products supplied by an aircraft manufacturer are found to be unsafe or harmful to those operating them, there are several potential sanctions that may apply:

- Criminal prosecution is likely if it can be shown that the manufacturer is in breach of relevant legislation, particularly health and safety legislation but also a whole series of safety-related legislation. The penalties that the aircraft manufacturer would suffer will generally be fines, ranging from relatively small amounts to significant sums of money.

There is also the possibility of corporate manslaughter charges arising out of negligence leading to the death of individuals. Whilst at present this is unlikely, changes in the law have been mooted and could lead to prison sentences for company directors.

- Civil lawsuits are a possibility if individuals suffer injury as a result of the use of products and if that injury can be shown to have been caused by a defect within the product then aircraft manufacturers face the prospect of being sued by that individual for damages. The amount payable will depend upon the severity of the injury but in any event if held liable the aircraft manufacturer will be required to pay the legal costs of all parties involved. Customers may also take legal action against the manufacturer if the products that are supplied or maintained are defective. Again, the penalty for this will be damages and significant legal costs.
- Customer/public relations will suffer if the aircraft manufacturer receives a reputation for supplying products that are inherently unsafe and lead to users suffering harm; customers are less likely to purchase from them with the consequent effect on profits and shareholder value.
- Manufacturers need to ensure that the products they supply are as safe as possible given all the circumstances and that they continue to evaluate and minimise risk wherever possible. Failure to do this can have significant and far-reaching consequences.

1.4.5 Conclusions

It is clear that there are a number of different phenomena to which aircraft inhabitants are subject, knowingly if they are employed to operate the aircraft and un-knowingly if they are paying passengers. Operators are subject to these phenomena for long periods of time simply because they fly more often, whereas the leisure and business traveller will be only infrequently exposed. It is also clear that some inhabitants will be subjected to a number of these phenomena simultaneously, i.e. noise, vibration, g-manoeuvres, and hard landings all in the same flight. It is, however, common to see research reports and newspaper accounts applied to individual subjects. It is important to look at the integrated system – the machine, the human, and the combined effects of various phenomena.

The wise systems engineer will try to resolve this issue by taking into account all aspects of design of the vehicle. It should be noted, however, that organisations often divide their engineering teams into functional responsibilities and that makes it difficult to take an integrated viewpoint.

The staff of a company designing and releasing to service an aircraft need to be aware of the implications of the impact of their design on the inhabitants of the aircraft. All staff should be aware of legislation and should keep pace with any changes that occur. The company should publish procedures and processes that ensure that engineers are given guidance on where to look for standards, how to apply them, and how to deal with any deviations. Training should be made available to ensure that engineering staff are fully briefed on contemporary legislation.

Tracking and understanding legislation is an essential task for all aircraft companies. The requirements of the immediate customer and prospective customers must be included in the design standards. The requirements of certification agencies and government agencies mandating on health and safety must also be understood. Figure 1.8 illustrates an example

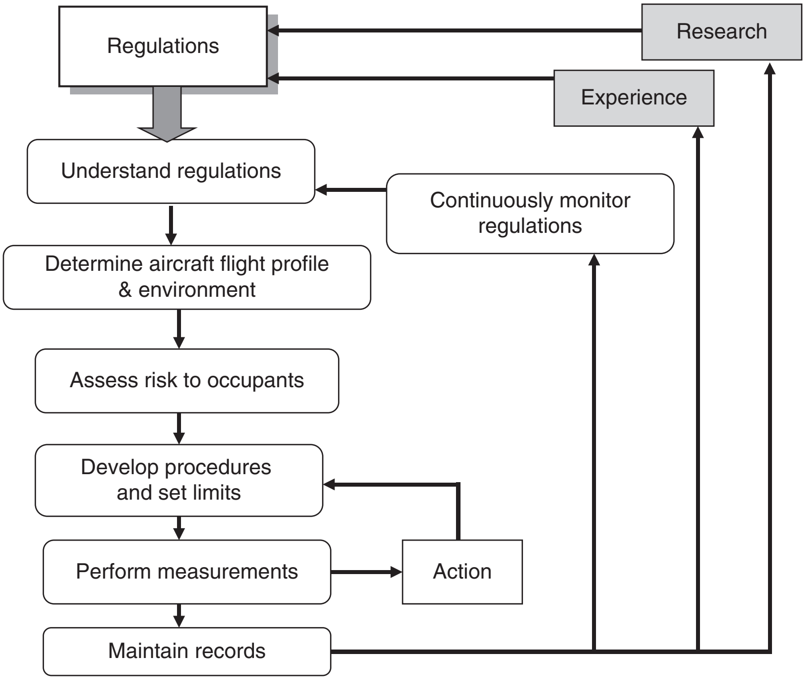

Figure 1.8 An example process for monitoring and applying legislation.

process for monitoring and applying legislation, and making a contribution to a body of knowledge that can be used for future updates of regulations.

1.5 Overview

The intention of this book is to provide a basic understanding of the principles of practical systems engineering, not to justify or recommend specific processes or tools. Examples will be used to illustrate the principles, but it is important to note that there is not one single ‘right’ approach to an engineering process, nor need there be. As long as there is consistency of approach in the partners in a project, and as long as the process works, then that is the correct approach for that project. This understanding will be particularly useful to engineers designing systems or equipment, and will provide essential background information for engineers or technicians using or maintaining the systems.

What this book aspires to do is to create an open-minded approach, so that systems engineers feel comfortable that the process they have chosen will produce a safe and successful result. It will also serve to introduce people to the language, jargon, and terms used in industry.

Exercises have been included at the end of most chapters to encourage readers to develop their reading of the chapter. There are no answers given; in many cases there are no ‘right answers’, but doing the work, alone or in groups, will help to develop the skills of understanding a system and developing it to a firm solution. Many references and suggestions for further reading have been provided to assist in this process, and the internet serves as a source of further information.

Chapter 2 addresses the general nature of an aircraft system and leads to a definition of such systems in the context of a physical application. Some characteristics of systems and their environments are introduced to encourage the reader to adopt a behavioural skill of broad systems thinking when addressing the analysis and design of systems. This description includes the associated ground systems, such as those required for support and logistics organisations to analyse fault and prognostic information, as well as the systems required to operate and analyse the information collected by unmanned air systems for real-time operations.

Chapter 3 examines a typical product lifecycle and describes example processes used in each phase of the lifecycle from concept through to retirement of the product. A view of people skills is also given to illustrate that the process of developing a successful product is a combination of processes and people. Consideration is also given to the extended development and operational lifecycle common to many aviation projects and the conflicts with rapidly moving technology in other sectors.

Chapter 4 describes how the influences of design drivers or factors in the system environment are exerted on the design process and how they affect the technical and economic feasibility of systems solutions. This illustrates the multi-disciplinary nature of systems engineering. These drivers will have a different influences in different industries, and may even change between projects or phases of a project. There is a need, therefore, to constantly examine the design drivers and prioritise them to ensure an appropriate response.

Chapter 5 looks briefly at system architectures and block diagrams to give a high-level view of systems design. This high-level view is used to show how simple block architectures can be used to gain an understanding of complex systems and their behaviours. Such simple architectures are used as a stimulus for communication between stakeholders. There is also a discussion of the complexity of modern architectures with functions and data in the system being shared and transmitted by various data bus systems and relayed to the crew on multifunction displays. The levels of complexity being encountered cast some doubt on the reality of exhaustively testing systems and on the understanding of systems status by the crew in major failure conditions.

Chapter 6 addresses systems integration as the discipline of combining systems in terms of functions performed, data produced, data used, systems interactions, and the HMI, leading to the production of a system that is fit for purpose. Integration is a most important topic as there is an increasing trend towards ‘tighter’ integration, especially as technology offers greater computing and storage power. There is a risk that the introduction of non-deterministic techniques in software languages and in data bus scheduling may lead to non-linear systems tending to behaviours that are unexpected and maybe even chaotic.

Chapter 7 describes methods of modelling used in the product lifecycle. Modelling a system is a quantitative description of the behaviour of a system to predict performance over a range of operating conditions at all phases of the lifecycle. At little cost modelling enables the system to be analysed under differing conditions that would be extremely time-consuming, sometimes impossible, to emulate in hardware. Modelling is used in various ways throughout the product lifecycle to perform trade-offs of different solutions. It is a quick and effective way of examining complex solutions before committing to design. Models can also be used to examine system performance for prediction and qualification, providing evidence to support qualification of the product long before the functional product is available.

Chapter 8 introduces some practical considerations based on experience in the industry in the areas of communication and criticism, both essential aspects of the open-minded systems approach. The considerations are not simply technical, but also address people and communication issues on the basis that complex projects undertaken by complex organisations demand clear and unambiguous communications in order to be successful.

Chapter 9 outlines the issues associated with the subject of configuration control and shows how the key system attributes must be maintained in a compatible manner. In this way forward and backward compatibility may be maintained between successive system or product development iterations, easing development and support costs. This control is essential in a product where many sub-systems will develop at different rates and it is inevitable that differing design standards will co-exist in the lifecycle. Also included is a discussion on control of information in the information age where ownership of multiple devices and access to many ways of creating and exchanging information may compromise information integrity.

Chapter 10 addresses an example of aircraft systems, showing how key aircraft systems all contribute to the total aircraft functionality and also interact with one another. Specific system examples are given.

Chapter 11 examines some issues of integration and complexity, and their potential impact on flight safety. Developments leading to increased integration, automation, and complexity in modern aircraft are described followed by a study of literature and reports of some unexplained events that may be due to complexity in modern systems. The issue of complexity in modern architectures that leads to decreasing visibility of design and functional performance and the difficulty, maybe of impossibility, of exhaustive testing of complex systems are discussed. A view is taken of the potential impact of all this on flight safety. Finally, the chapter looks at the possibility of complex systems integrated with an expanding air transport management system and with aircraft systems remaining powered up continuously for many days, which may lead to chaotic behaviour.

Chapter 12 presents the key characteristics of all aircraft systems in an abbreviated tabular form. The intention is to provide a brief summary of what each system is and to provide references to source material for further detailed descriptions.

A section provides a short process to assist engineers who need to examine their system further for the purpose of quantifying aspects of mass, power demand, dissipation, and fuel penalties. The tables contain an entry to enable students to identify the key components that need to be considered to do this. This is often done to provide a model of individual systems, or even a whole project, to enable trade-off studies to be conducted to evaluate different proposals.

Chapter 13 summarises the content of the book and provides a table of the systems covered in the book along with key integration and interfacing aspects. Also included are references to textbooks providing more detailed system descriptions. Each systems description in the tables contains information to enable students to ‘size’ a system for project work, for which typical parameters are mass, power demand, dissipation, and installation factors.

Exercises

1 Re-draw Figure 1.1 from the perspective of your own sector of the aviation system. Now take a personal view of the stakeholders and identify them by name to form a personal contact list for your sector.

2 Carry out this process using Figure 1.5 and apply it to the project on which you work.

3 Consider Figure 1.3. From your own experience can you think of an example of a project composed of a number of technical strands in the line management that would benefit from a cross-functional or integrating viewpoint? What benefits would result from this?

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