

1

Introduction

The days are long gone when people flew for the very adventure of flying, when in-flight entertainment was looking out of the window and in-flight catering was the offer of a barley sugar sweet.

Lack of sound insulation, large rotary engines and no heating provided a noisy and vibrating environment with only blankets providing some form of comfort. In the armed forces the crew spent many long and miserable hours in terrible conditions, comforted only by glucose tablets.

This age of adventurous flying ushered in travel sweets, still on sale today for the intrepid car user. A.L. Simpkin's advertising made no mistake about their use in flying:

- 'Proven to increase energy and relieve the effects of air sickness';
- '... used by RAF personnel for high altitude flying during sorties in WW2';
- '... recommended as a great way to reduce inner ear pressure during flying'.

The practice of giving sweets at take-off persisted even into the 1980s on some airlines. The theory was probably that sucking the sweet or chewing stimulated the nasal passages and ear canal to relieve any build-up of pressure. A technique known as the Valsalva manoeuvre can be used to great effect, which entails closing the mouth and pinching the nose while attempting to exhale. This counteracts the effects of water pressure in the Eustachian tubes to eliminate problems in the middle ear.

1.1 Factors Affecting Health

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 as a result of prolonged or habitual exposure, and which cannot be alleviated by sucking a boiled sweet. These factors 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 relates to the operation of a high-speed machine and to the environment in which it operates.

This machine can be considered as the workplace, for aircrew, 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 aircraft 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 suffer the consequences.

Passengers are also affected by the environment; they are after all in the same vehicle as the crew. A major difference is that their exposure is transient and irregular.

The conditions that arise from exposure to these factors may lead to problems with health either short term or, in severe cases, chronic ill health. From time to time the press covers some of the health issues of passengers or crew, especially if there is a new outbreak of ill health. The internet also carries articles on the subject and there is serious academic research being carried out to explore some issues. However, on inspection the information and the research appear to be uncoordinated – with issues discussed separately, with no single integrated viewpoint. In this book we will endeavour to bring all aspects of air travel and ill health together in one place and try to draw some conclusions.

1.2 The System of Interest

Figure 1.1 illustrates the system which is the subject of this book, showing the subsystems and their interactions.

1.2.1 *The Operating Environment*

The operating environment is where the aircraft spends its life – on the ground and in the air. It consists of the natural environment and the aircraft

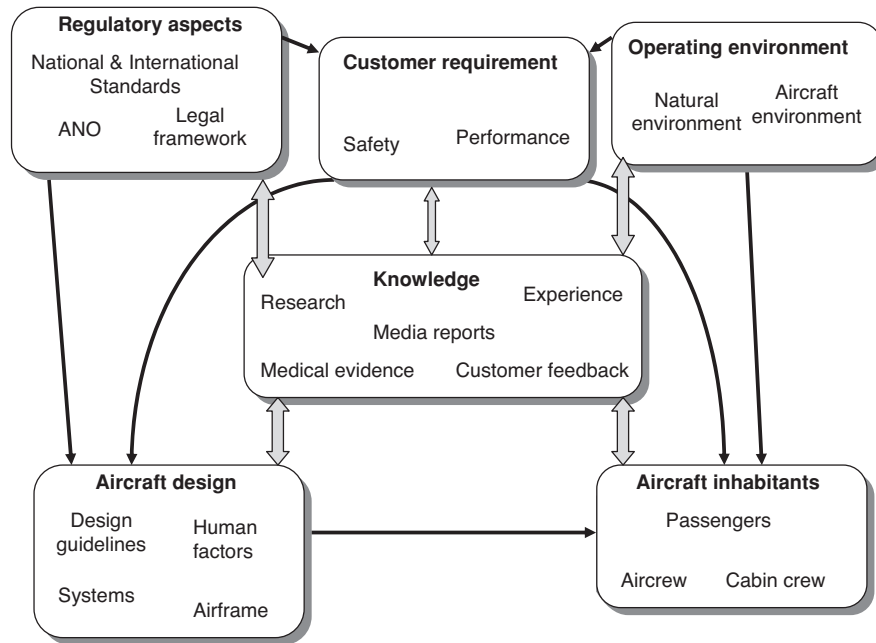


Figure 1.1 The system of interest.

environment. The natural environment is a complex interaction of chemicals and electro-magnetic radiation which forms the Earth's atmosphere. An excellent description of the atmosphere and the history of the discovery of its constituents can be found in *An Ocean of Air* (Walker, 2007). Only a small portion of the atmosphere is used by aircraft – up to about 40 000 ft (12 000 m) – although some specialised military aircraft operate above this altitude, as shown in Figure 1.2. The recent space-tourist vehicle revealed by Richard Branson is designed to operate up to 360 000 ft.

1.2.2 The Atmosphere

The atmosphere up to these altitudes is hostile to humans and the aircraft must provide some protection. The atmosphere directly affects all humans in the system – aircrew, cabin crew and passengers – but it is modified by the systems of the aircraft to provide a subtly different set of conditions. For example, the cabin conditioning system uses air from the engines to provide a comfortable cabin atmosphere for the inhabitants at the right temperature,

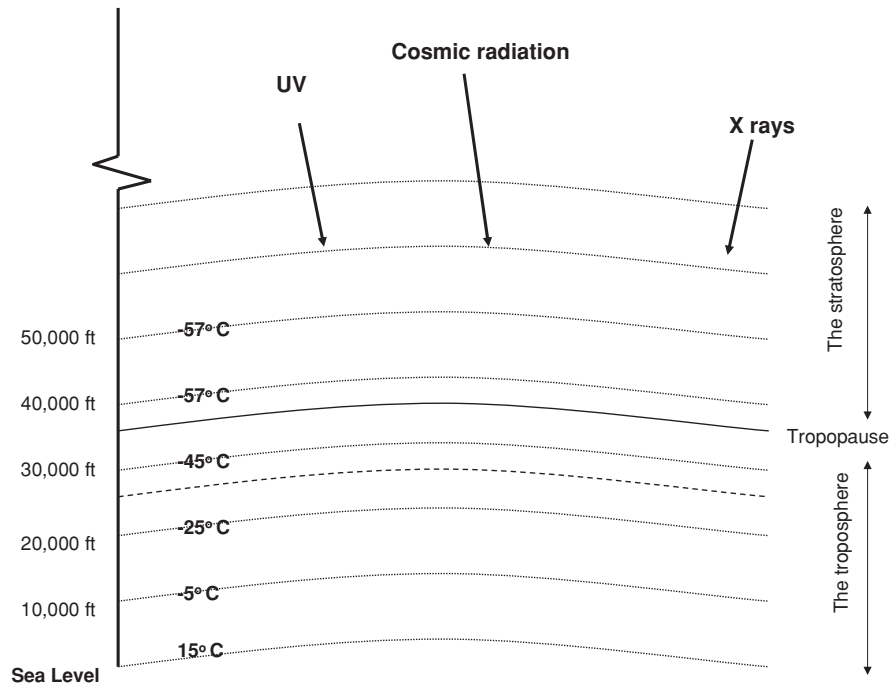


Figure 1.2 The atmosphere relevant to air travel.

pressure and humidity, whilst the engines themselves contribute to the noise and vibration experienced by the structure and the people inside.

1.2.3 The Aircraft Inhabitants

The aircraft inhabitants are taken into account in the design of the airframe and the aircraft systems. Human factors are a major element in the design of the flight deck and cabin to provide an environment that is comfortable, safe and easy to use for both crew and passengers. Guidelines developed by aircraft designers or mandated by customers are used to provide a framework for design. The aircraft design is also very much influenced by the requirements of the customer, whose specification or requirements statement will balance safety against performance, including cost and timescales. Major inputs to design are regulatory aspects such as national and international standards, legal aspects of safety, health and safety and product liability, as well as safety implications embodied in the air navigation order (ANO).

Much of the design input is influenced by knowledge emanating from research, technological advances and hands-on experience from previous projects. Medical evidence from crew health checks is used to influence procedures or design, particularly if chronic effects can be proven. At all times the media – both popular and scientific – are prepared to relate anecdotal and research-based information to the public. The internet is a fruitful source of information.

1.2.4 Sources of Environmental Stimuli

A summary of the potential sources of environmental stimuli that may lead to damage to health is illustrated in Figure 1.3.

Inside the dashed oval are the sources that are internal to the aircraft. They are generated by the aircraft or its systems or they exist as a result of the aircraft and the inhabitants. Outside the dashed oval are external sources, over which the designers and operators of aircraft have no control; these sources are natural occurrences or circumstances which must be taken into account in the design or operation of any aircraft.

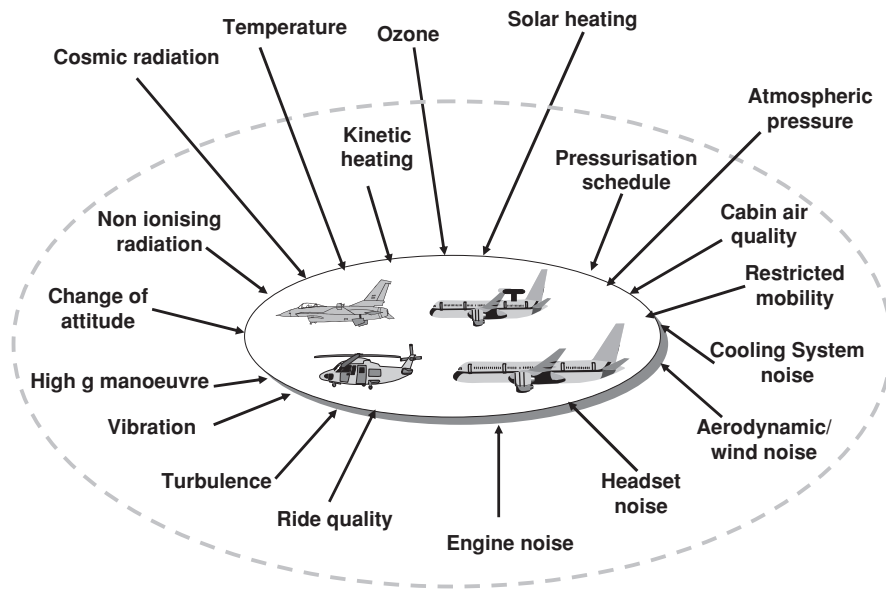


Figure 1.3 Sources of conditions that may be injurious to health.

1.3 The Aircraft

For design purposes the interior volume of an aircraft is often considered as two separate environments:

1. The airborne uninhabited environment is the space in the fuselage reserved for the installation of equipment such as avionics, for the stowage of cargo and baggage, and for the carriage of weapons or stores. This space may be ventilated, may receive warm air exhausted from the cabin, and may or may not be pressurised.
2. The airborne inhabited environment is the space reserved for occupants who require some form of life support. The space is provided with breathable air, a pressurised environment, heating and/or cooling, a means of preparing food, and suitable toilet and washing facilities.

The occupants are the subject of this book and in order to establish their position in the aircraft this section will describe who they are, where they sit and what their accommodation looks like.

1.3.1 *Military Aircraft*

Modern military aircraft are designed to perform in harsh conditions and operate to demanding operational performance criteria. For most of their life, though, even in an uncertain world, they rarely achieve the limits of their capability in peace-time operations. Nevertheless, the conditions encountered in flight expose the aircrew to hazards that the office worker would consider to be dangerous to health.

Military aircraft may be considered as two distinctly different types:

1. Fixed-wing or rotary-wing, highly manoeuvrable types which can exert stresses on aircrew for relatively short-duration missions.
2. Fixed-wing or rotary-wing logistic or surveillance types which may have more benign operational conditions, but fly long-duration missions and may expose crews to the same extent as commercial aircraft.

The airborne inhabited environment of some example military types is shown in Figure 1.4, together with the locations of the inhabitants.

The occupants will mostly be armed forces personnel, although there are some roles that may be provided by outsourcing to trusted civilian

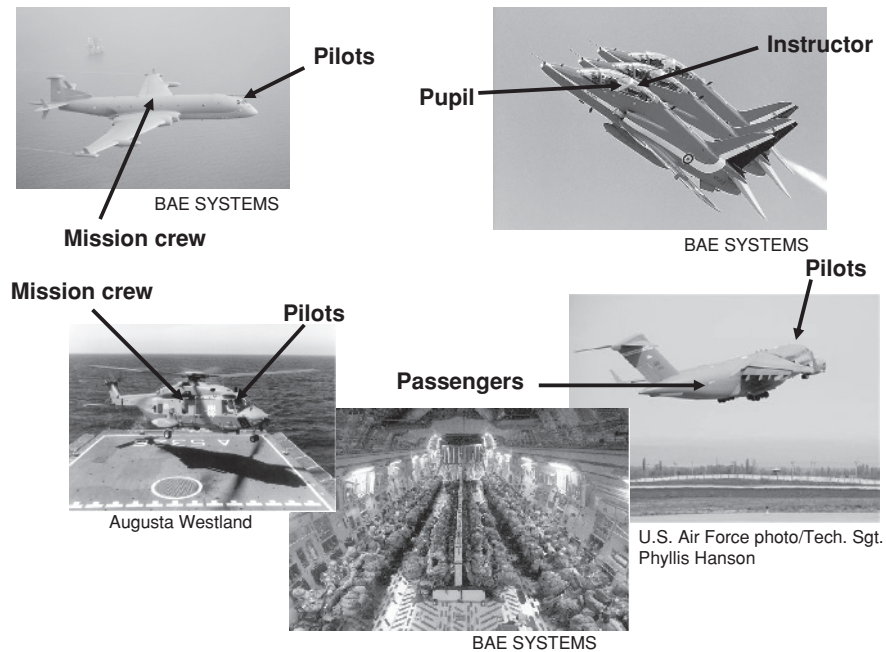


Figure 1.4 The airborne inhabited environment of example military types. Reproduced with permission from 1. BAe Systems, 2. AugustaWestland, 3. U.S. Air Force photo/Tech. Sgt. Phyllis Hanson.

agencies or government agencies such as the police, coastguard and customs and excise:

- **Pilot** – the pilot occupies the cockpit of single-seat fast jets, usually alone or in the front seat of two-seat types. Long-duration surveillance or transport types may have a first pilot and second pilot who will exchange pilot and navigator roles at regular intervals.
- **Navigator/weapons officer** – the navigator occupies the rear seat of fast jet types and doubles up as the systems and weapons officer.
- **Flight engineer** – some long-range aircraft have a flight engineer, although this role is diminishing with modern flight decks. For example, in the Nimrod MR2 the flight engineer sits behind the two pilots and monitors the performance of the aircraft systems.
- **Mission crew** – the mission crew usually occupy the cabin of surveillance aircraft, each with a role to perform and usually with a workstation.

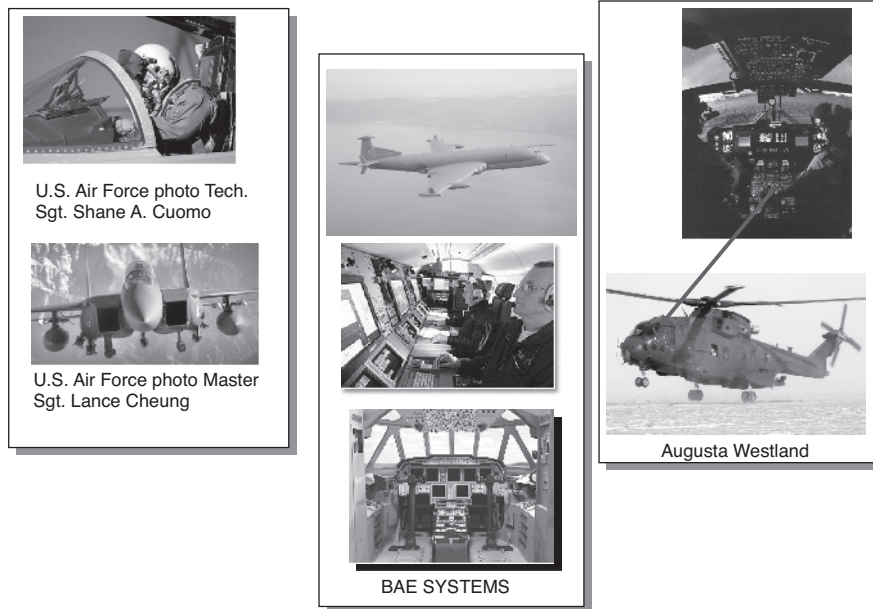


Figure 1.5 The inhabited sections of military aircraft types. Reproduced with permission from 1. BAE Systems, 2. AugustaWestland, 3. U.S. Air Force photo/Tech. Sgt. Shane A. Cuomo, 4. U.S. Air Force photo/Master Sgt. Lance Cheung.

- **Instructor** – in training aircraft tandem types the pilot instructor will sit in the rear seat, in a slightly elevated position.
- **Pupil/student** – the student pilot occupies the front seat of trainer types so that the view from the cockpit is that of the types to which the student is converting.

Examples of the interiors or inhabited sections of these types are illustrated in Figure 1.5.

1.3.2 Commercial Aircraft

Commercial aircraft generally operate in benign conditions with predictable flight envelopes and fly from large airports with facilities for servicing the aircraft and managing the passengers. For the aircrew and cabin crew the aircraft is their place of work and they may spend many hours in the cabin environment. Passengers, even frequent flyers, are not exposed to the

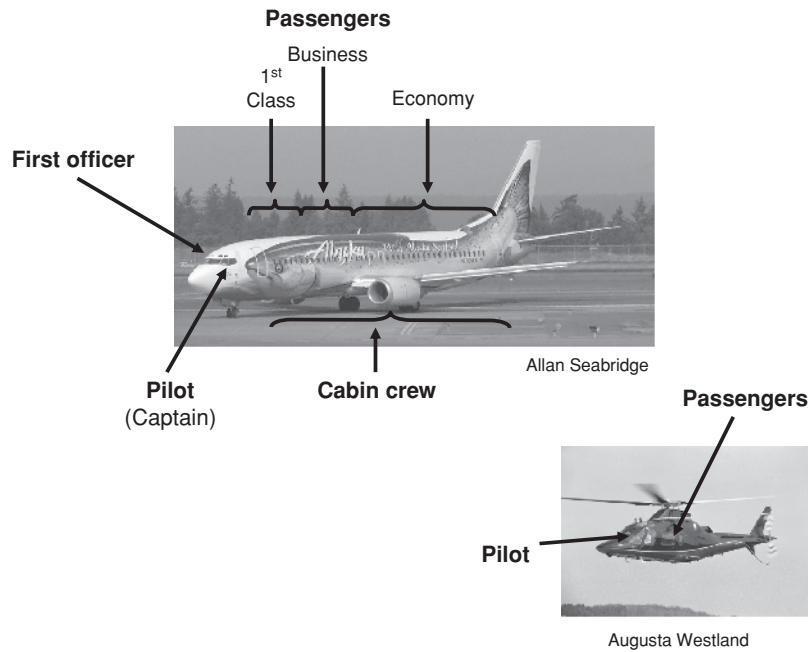


Figure 1.6 The airborne inhabited environment of example commercial types. Reproduced with permission from 1. Allan Seabridge, 2. AugustaWestland.

environment to the same extent as the crew. A description of a typical commercial airliner and crew actions is given in Midkiff, Hansman and Reynolds (2009).

The airborne inhabited environment of some example commercial types is shown in Figure 1.6, together with the locations of the inhabitants.

The occupants will mostly be a mixture of crew and passengers:

- **Pilot** – the pilot occupies the left hand seat of the flight deck and is the captain of the aircraft.
- **First officer** – the first officer occupies the right hand seat as a fully qualified pilot. The flying task is shared between the first officer and the captain.
- **Relief/check pilot** – on long-haul flights a relief pilot will be carried, who will rest and sleep in the business or first-class cabin. A jump seat between the two pilots is carried in the event that a check pilot is carried for certain mandatory pilot inspections.
- **Flight engineer** – if a flight engineer is carried, they will occupy a seat behind the two pilots.

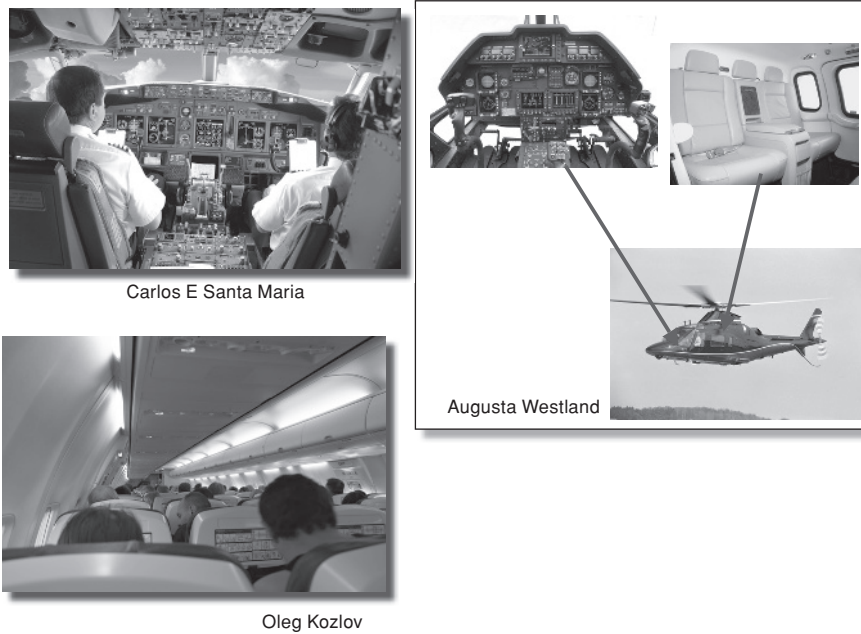


Figure 1.7 The inhabited sections of commercial aircraft types. Reproduced with permission from 1. Carlos E Santa Maria. 2. Oleg Kozlov. 3. AugustaWestland.

- **Cabin crew** – the cabin crew usually occupy the cabin with their own designated seats. Apart from providing meals and service to the passengers, the primary role of the cabin crew is to assist the passengers in the event of an evacuation or in-flight incident.
- **Passengers** – passengers are housed in cabins that are designed and equipped to a standard determined by the class of travel.

Figure 1.7 illustrates the cabin and flight deck of commercial types.

1.4 Design Considerations

The engineering teams designing these types are aiming 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. Singly or in combination, these conditions can have an impact on the physical well-being of aircrew 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.

A good systems engineer needs to be mindful of these effects and the conditions most likely to cause them. This will enable the designers 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 the aircrew.

'Mindful' in this case includes acquiring knowledge and experience and applying 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 have a responsibility, a duty of care to their own test pilots and to their customers, to ensure that long-term use of the product does not jeopardise aircrew health. 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. This book describes the aircraft environment and identifies the sources of factors that can damage aircrew health and relates these to legislation – treating the aircraft as the workplace of the aircrew. Responsible manufacturers 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.

Each of the factors that can affect health in some way is discussed in terms of its impact on aircrew and consequently on working life and chronic ill health. The impact of legislation on legacy and new designs is discussed, together with mechanisms for reducing risk. Human beings are notoriously variable in their response to external factors affecting health, and many individuals do not fly for sufficiently long periods for them to represent a statistically significant sample. Nevertheless, it is worth looking for trends in aircrew and passenger comments and observations to see if there are any underlying causes.

The initial viewpoint will be that of the systems engineer, whose responsibility is to design the product to be safe to operate. This view will be complemented by a medical and human physiological viewpoint. The combination should provide guidance for engineers and contracts managers in aerospace in forming a view of the safe operation of their products and their release to service.

The book will consider the difference between commercial aircraft and military aircraft where both the operating regimes and the impact of the environmental issues are significantly different. The interpretation of legislation by commercial and military operators will also be discussed. It must be said that the commercial aircraft field has produced the main body of knowledge in the public domain, partly because of the many millions of person-flight-hours logged, partly because of the many millions of passengers, some of whom feel free to make their views known, and partly because of a lack of security which may restrict the circulation of military aircraft experience.

Aircraft provide a dynamic environment which is the daily working environment – ‘the office’ – for aircrew. 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. This chapter will discuss the aspects of aircraft design and operations that lead to exposure to risk, and will compare these aspects with those of the ground-based office or factory worker. It will also set the scene by describing the aircraft types and the roles that lead to the emergence of risk factors.

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

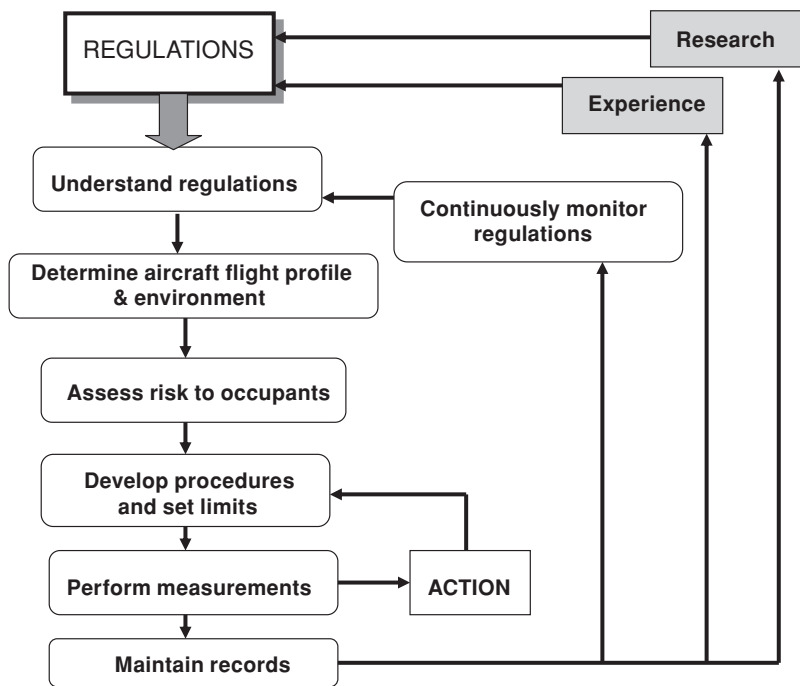


Figure 1.8 An example process for monitoring and applying legislation.

1.5 Summary

So it seems that short-term discomfort is almost inevitable. What one does not expect is long-term or even chronic illness. Yet there is evidence that some aircrew, cabin crew and passengers do suffer. Those who do fly for work should expect their employers to make some provision for reducing the risk, in response to various health and safety legislation. Operators have a duty of care to passengers to reduce their risk.

The following chapters will present a picture of the potential hazards to health that are posed, together with mitigating action that can be provided by aircraft design by the application of suitable operating procedures.

We also examine the issues and their effects upon aircraft inhabitants and explore the current body of research, debate and anecdotal evidence. It is important that aircraft and system designers are aware of the facts, in order to ensure that their design takes into account the real issues of their customers. We also discuss how the aircraft systems contribute to the issues, how they can be designed to reduce any negative impact and warn the crew of the presence of detrimental effects, and how alleviation can be achieved by design, by operational and procedural limitations, or by creating and improving public awareness.

Chapter 2 looks at some ailments that affect many people who fly. Although referred to as 'minor' ailments in this chapter, this is not meant to trivialise the issue. They may not lead to long-term physiological damage, but they are of real concern to those who suffer and for whom the very thought of flying causes great concern.

Chapter 3 examines the quality of air provided to fast-jet military pilots as oxygen-enriched pressurised air, and the air in a pressure cabin of large military types and commercial aircraft with pressurised cabins. Generally air is extracted from the engine and conditioned to make a comfortable environment for passengers. There have been reports of contamination from the bleed air causing discomfort and even long-term damage to health. This chapter will examine the symptoms and some potential technical solutions including one new and innovative piece of technology.

Chapter 4 looks at deep vein thrombosis (DVT), which is a controversial subject affecting both crew and passengers. Although there is no proven link to air travel, the subject does enjoy a wide press and many in-flight magazines include a section on exercises to perform during flight to reduce the risk of potential damage. The chapter examines aircraft cabin arrangements and seating to look for causes and solutions.

Chapter 5 considers the sources and effects of noise and vibration – separately and combined. Comparisons are drawn with other workplaces in which noise and vibration are major issues.

Chapter 6 deals with exposure to cosmic radiation as well as non-ionising radiation from radio frequency sources such as radar transmitters. Ionising radiation from cosmic rays is a fact of life, made slightly more of a threat to humans by long exposure at high altitude.

Chapter 7 considers the occurrence of circumstances which can lead to back and neck injury, excluding direct impact such as use of an ejection seat. There are aspects of seating for normal use that can lead to chronic back pain.

Chapter 8 examines some issues specific to military fast-jet crews. This includes the effects of acceleration as an issue for military crews, particularly those on fast jets. The impact of sustained high-g manoeuvres on immediate performance and on long-term health will be examined, as well as the impact of heavier helmets and the possibility of neck/vertebra damage. Heat stress is another issue – the military pilot is exposed to a wide range of temperatures, including direct solar radiation in high-flying fast jets. In many cases the pilot wears clothing to ensure survival in the event of an accident and also rubber garments designed to reduce the impact of high-g manoeuvres. Combined with a high metabolic rate in a stressful combat or training scenario, this may lead to heat stress. Pressure oxygen breathing is used by military fast-jet crews and there is potential for hypoxia as a result of loss of oxygen or reduced oxygen concentration caused by cabin pressurisation failures.

Chapter 9 examines the situation where aircrew are expected to use a workstation to perform their task throughout the mission. This may be aircrew who make use of cockpit displays and controls throughout the flight to control the aircraft and its route, or it may be mission crew on military surveillance aircraft who must analyse sensor data for long periods of time using screens and keyboards in the cabin.

Chapter 10 looks at legislation in the UK and Europe that is aimed at health and safety in the workplace as it exists at the time of writing. Legislation is continually being reviewed and revised and readers are expected to familiarise themselves with the latest situation.

Chapter 11 describes a generic process that is used by aircraft designers to ensure there is a rigorous process for including in the aircraft design those requirements that determine the performance and safety of the product and ensuring that all aspects of legislation are considered. This process continues throughout the in-service life of the aircraft to ensure that comments received during operations with the public and with users are suitably recognised.

Chapter 12 will examine the information in the previous chapters and try to establish some common causes and solutions that are known. The impact of the effect of one or more of the issues will be discussed as an integrated system view.

Each chapters ends with a view of what can be done in the system to provide some form of alleviation. This includes not only engineering solutions in the aircraft systems, but also solutions in the wider system of interest illustrated in Figure 1.1. The solutions may be technical, such as the introduction of control of the systems or the introduction of warnings, or may be procedural and influence the manner in which the aircraft is operated or the crew deployed.

References

- Midkiff, A.H., Hansman, R.J. and Reynolds, T.G. (2009) Airline flight operations, in *The Global Airline Industry* (eds P. Belobaba, A. Odoni and C. Barnhart), John Wiley & Sons, Ltd.
- Walker, G. (2007) *An Ocean of Air: A Natural History of the Atmosphere*, Bloomsbury.

Further Reading

- Belobaba, P., Odoni, A. and Barnhart, C. (eds) (2009) *The Global Airline Industry*, John Wiley & Sons, Ltd.

Useful Web Sites

publications.parliament.uk/pa/ld200708/ldselect/ldsctech