CHAPTER 1
FUNDAMENTAL HUMAN FACTORS CONCEPTS

INTRODUCTION

Human performance is cited as a causal factor in the majority of aircraft accidents. If the accident rate is to be decreased, Human Factors issues in aviation must be better understood and Human Factors knowledge more broadly and proactively applied. By proaction it is meant that Human Factors knowledge should be applied and integrated during the systems design and certification stages, as well as during the operational personnel certification process, before the systems and the people become operational. The expansion of Human Factors awareness presents the international aviation community with the single most significant opportunity to make aviation both safer and more efficient. The purpose of this chapter is to present an overview of the various components which constitute Human Factors and to clarify its meaning.

Ever since humans began to make tools, thousands of years ago, the application of elementary ergonomics has improved work efficiency. But it is only during the last hundred years that the modern evolution of ergonomics towards Human Factors has begun.

The need during the First World War to optimize factory production and to assign thousands of recruits more effectively to military duties, and the fact that during the Second World War sophisticated equipment was surpassing human capability to operate it with maximum effectiveness provided further stimulus to Human Factors progress. Selection and training of staff, too, began to be approached more scientifically. However, it might be argued that the renewed interest in Human Factors contribution to aviation safety was a reactive response to technological limitations prevailing at the time. Therefore, human capabilities were extended to their maximum through the application of Human Factors knowledge, sometimes at the cost of overlooking human limitations.

The institutionalization of Human Factors occurred with the founding of several organizations such as the Ergonomics Research Society in 1949, the Human Factors Society (now Human Factors and Ergonomics Society) in 1957 and the International Ergonomics Association (IEA) in 1959.

The recognition that basic Human Factors education was needed throughout the industry led to various approaches to formal training in different countries. This recognition, tragically emphasized by the investigation of a number of accidents resulting almost entirely from deficiencies in the application of Human Factors, led ICAO to implement Human Factors training requirements into the training and licensing requirements included in Annex 1 (1989) and Annex 6 (1995), as well as into the process of accident investigations included in Annex 13 (1994).

The 1976 agreement between the United States Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) to establish a voluntary, non-punitive, confidential Aviation Safety Reporting System (ASRS) constituted official recognition that adequate information for analysis of human behaviour and errors in human performance is best obtained by eliminating the threat of punitive action against the person making the report. Similar schemes were later set up in the United Kingdom (CHIRP), Canada (CASRP) and Australia (CAIR).

This chapter outlines:

1. the meaning and definition of Human Factors, a conceptual model of it, and clarification of common misconceptions;
2. the industry need for Human Factors; and
3. a brief overview of the application of Human Factors in flight operations.

Incidents and Accidents - A Breakdown in Human Factors

In all of the examples above, the accident or incident was preventable and could have been avoided if any one of a number of things had been done differently. In some cases, a number of individuals were involved and the outcome could have been modified if any one of them had reacted or queried a particular action. In each situation however, the individuals failed to recognise or react to signs of potential hazards, did not react as expected of them, or allowed themselves to be diverted from giving their attention to the task in hand, leaving themselves open to the likelihood of committing an error.

As with many incidents and accidents, all the examples above involved a series of human factors problems which formed an error chain (see Figure below). If any one of the links in this 'chain' had been broken by building in measures which may have prevented a problem at one or more of these stages, these incidents may have been prevented.

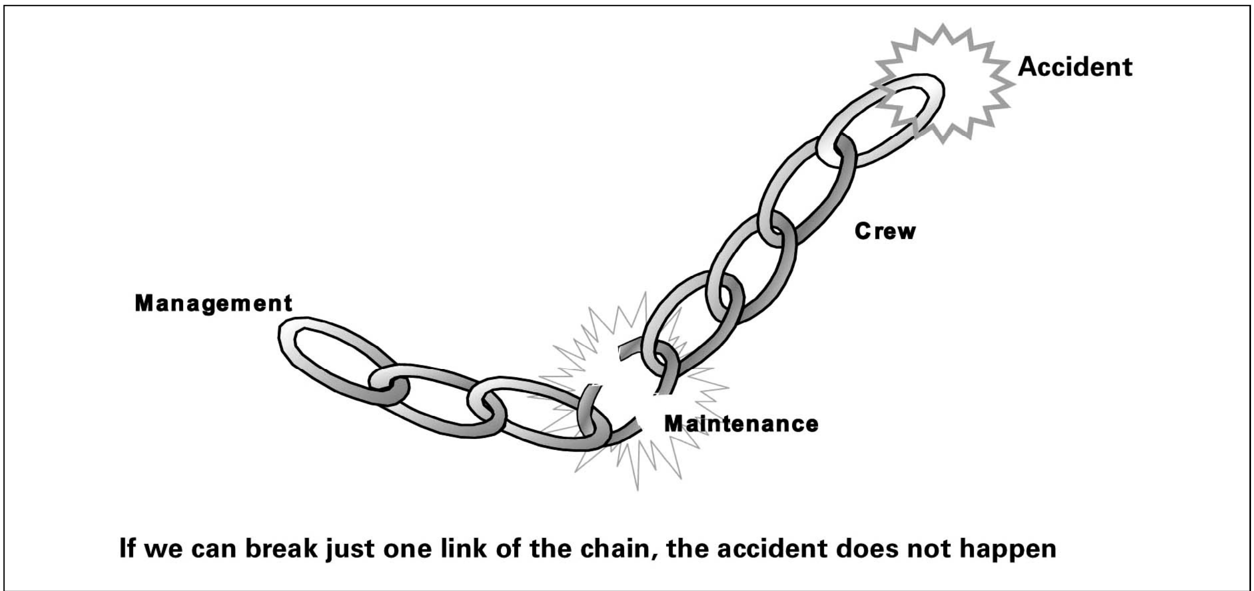


Fig. The Error Chain.Source: Boing[1]

MURPHY'S LAW

There is a tendency among human beings towards complacency. The belief that an accident will never happen to "me" or to "my Company" can be a major problem when attempting to convince individuals or organisations of the need to look at human factors issues, recognise risks and to implement improvements, rather than merely to pay 'lip-service' to human factors.

[1]Boeing (1993) Accident Prevention Strategies: Commercial Jet Accidents World Wide Operations 1982-1991.

> "Murphy's Law" can be regarded as the notion: "If something can go wrong, it will."

If everyone could be persuaded to acknowledge Murphy's Law, this might help overcome the "it will never happen to me" belief that many people hold. It is not true that accidents only happen to people who are irresponsible or 'sloppy'. The incidents and accidents described in above. show that errors can be made by experienced, well-respected individuals and accidents can occur in organisations previously thought to be "safe".

THE MEANING OF HUMAN FACTORS

Human Factors as a term has to be clearly defined because when these words are used in the vernacular they are often applied to any factor related to humans. The human element is the most flexible, adaptable and valuable part of the aviation system, but it is also the most vulnerable to influences which can adversely affect its performance. Throughout the years, some three out of four accidents have resulted from less than optimum human performance. This has commonly been classified as human error.

The term "human error" is of no help in accident prevention because although it may indicate WHERE in the system a breakdown occurs, it provides no guidance as to WHY it occurs. An error attributed to humans in the system may have been design-induced or stimulated by inadequate training, badly designed procedures or the poor concept or layout of checklists or manuals. Further, the term "human error" allows concealment of the underlying factors which must be brought to the fore if accidents are to be prevented. In fact, contemporary safety-thinking argues that human error should be the starting point rather than the stop-rule in accident investigation and prevention.

An understanding of the predictable human capabilities and limitations and the application of this understanding are the primary concerns of Human Factors. Human Factors has been progressively developed, refined and institutionalized since the end of the last century, and is now backed by a vast store of knowledge which can be used by those concerned with enhancing the safety of the complex system which is today's civil aviation. Throughout this manual capital initial letters are used for the term "Human Factors". The terms "human aspects" and "human elements" in common usage are helpful alternatives to avoid ambiguity and aid comprehension.

The disciplines of Human Factors

Many of the early concerns in aviation were related to the effects on people of noise, vibration, heat, cold and acceleration forces. Usually, the person nearest at hand with a knowledge of physiology was a physician; this may have generated one of the more persistent misconceptions about Human Factors, the belief that it is somehow a branch of medicine. Yet half a century ago work was expanding on the more cognitive aspects of aviation tasks and this trend has continued and is outside the scope of medicine. Optimizing the role of people in this complex working environment involves all aspects of human performance: decision-making and other cognitive processes; the design of displays and controls and flight deck and cabin layout; communication and computer software; maps and charts; and the field of documentation such as aircraft operating manuals, checklists, etc. Human Factors knowledge is also increasingly used in staff selection, training and checking and in accident prevention and investigation.

Human Factors is multidisciplinary in nature. For example, information is drawn from psychology to understand how people process information and make decisions. From psychology and physiology comes an understanding of sensory processes as the means of detecting and transmitting information on the world about us. The measures and movements workplace characteristics of the flight deck and cabin — call upon anthropometry and biomechanics. Biology and its increasingly important sub-discipline, chronobiology, are needed to understand the nature of the body's rhythms and sleep, and their effects in night flying and time-zone changes. No proper analysis or presentation of data from surveys or studies is possible without some basic understanding of statistics. While utilizing these academic sources of knowledge, Human Factors is essentially concerned with solving practical problems in the real world. Human Factors is practical in nature; it is problem-oriented rather than discipline-centred.

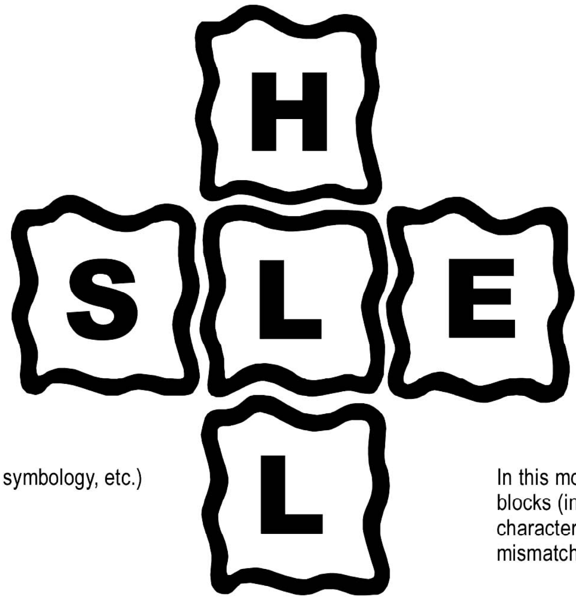
Human Factors is about people in their living and working situations; about their relationship with machines, with procedures and with the environment about them; and also about their relationships with other people. One definition of Human Factors, as proposed by Professor Edwards, declares that "Human Factors is concerned to optimize the relationship between people and their activities, by the systematic application of human sciences, integrated within the framework of systems engineering". Its objectives can be seen as effectiveness of the system, which includes safety and efficiency, and the well-being of the individual. Professor Edwards further elaborates that "activities" indicates an interest in communication between individuals and in the behaviour of individuals and groups. Lately, this has been expanded upon to include the interactions among individuals and groups and the organizations to which they belong, and to the interactions among the organizations that constitute the aviation system. The human sciences study the structure and nature of human beings, their capabilities and limitations, and their behaviours both singly and in groups. The notion of integration within systems engineering refers to the Human Factors practitioner's attempts to understand the goals and methods as well as the difficulties and constraints under which people working in interrelated areas of engineering must make decisions. Human Factors uses this information based on its relevance to practical problems.

The term "ergonomics" derives from the Greek words "ergon" (work) and "nomos" (natural law). It is defined as "the study of the efficiency of persons in their working environment". In some States, the term ergonomics is used strictly to refer to the study of human-machine system design issues.

A conceptual model of Human Factors

It is helpful to use a model to aid in the understanding of Human Factors, as this allows a gradual approach to comprehension. One practical diagram to illustrate this conceptual model uses blocks to represent the different components of Human Factors. The model can then be built up one block at a time, with a pictorial impression being given of the need for matching the components. The SHEL concept (the name being derived from the initial letters of its components, Software, Hardware, Environment, Liveware) was first developed by Edwards in 1972, with a modified diagram to illustrate the model developed by Hawkins in 1975. The following interpretations are suggested: liveware (human), hardware (machine), software (procedures, symbology, etc.), and environment (the situation in which the L-H-S system must function). This building block diagram does not cover the interfaces which are outside Human Factors (hardware-hardware; hardware-environment; software-hardware) and is only intended as a basic aid to understanding Human Factors.

Liveware. In the centre of the model is a person, the most critical as well as the most flexible component in the system. Yet people are subject to considerable variations in performance and suffer many limitations, most of which are now predictable in general terms. The edges of this block are not simple and straight, and so the other components of the system must be carefully matched to them if stress in the system and eventual breakdown are to be avoided.



The SHEL model as modified by Hawkins

In order to achieve this matching, an understanding of the characteristics of this central component is essential. Some of the more important characteristics are the following:

a. ***Physical size and shape.*** In the design of any workplace and most equipment, a vital role is played by body measurements and movements, which will vary according to age and ethnic and gender groups. Decisions must be made at an early stage in the design process, and the data for these decisions are available from anthropometry and biomechanics.

b. ***Physical needs.*** People's requirements for food, water and oxygen are available from physiology and biology.

c. ***Input characteristics.*** Humans have been provided with a sensory system for collecting information from the world around them, enabling them to respond to external events and to carry out the required task. But all senses are subject to degradation for one reason or another, and the sources of knowledge here are physiology, psychology and biology.

d. ***Information processing.*** These human capabilities have severe limitations. Poor instrument and warning system design has frequently resulted from a failure to take into account the capabilities and limitations of the human information processing system. Short- and long-term memory are involved, as well as motivation and stress. Psychology is the source of background knowledge here.

e. ***Output characteristics.*** Once information is sensed and processed, messages are sent to the muscles to initiate the desired response, whether it be a physical control movement or the initiation of some form of communication. Acceptable control forces and direction of movement have to be known, and biomechanics, physiology and psychology provide such knowledge.

f. ***Environmental tolerances.*** Temperature, pressure, humidity, noise, time of day, light and darkness can all be reflected in performance and also in well-being. Heights, enclosed spaces and a boring or stressful working environment can also be expected to influence performance. Information is provided here by physiology, biology and psychology.

The Liveware is the hub of the SHEL model of Human Factors. The remaining components must be adapted and matched to this central component.

Liveware-Hardware. This interface is the one most commonly considered when speaking of human-machine systems: design of seats to fit the sitting characteristics of the human body, of displays to match the sensory and information processing characteristics of the user, of controls with proper movement, coding and location. The user may never be aware of an L-H deficiency, even where it finally leads to disaster, because the natural human characteristic of adapting to L-H mismatches will mask such a deficiency, but will not remove its existence. This constitutes a potential hazard to which designers should be alert. With the introduction of computers and advanced automated systems, this interface has repositioned itself at the forefront of Human Factors endeavours.

Liveware-Software. This encompasses humans and the non-physical aspects of the system such as procedures, manual and checklist layout, symbology and computer programmes. Liveware-software problems are conspicuous in accident reports, but they are often difficult to observe and are consequently more difficult to resolve (for example, misinterpretation of checklists or symbology, non-compliance with procedures, etc.).

Liveware-Environment. The human-environment interface was one of the earliest recognized in flying. Initially, the measures taken all aimed at adapting the human to the environment (helmets, flying suits, oxygen masks, anti-G suits). Later, the trend was to reverse this process by adapting the environment to match human requirements (pressurization and air-conditioning systems, soundproofing). Today, new challenges have arisen, notably ozone concentrations and radiation hazards at high flight levels and the problems associated with disturbed biological rhythms and related sleep disturbance and deprivation as a consequence of the increased speed of transmeridian travel. Since illusions and disorientation are at the root of many aviation accidents the L-E interface must consider perceptual errors induced by environmental conditions, for example, illusions during approach and landing phases. The aviation system also operates within the context of broad political and economical constraints, and those aspects of the environment will interact in this interface. Although the possibility of modifying these influences is sometimes beyond Human Factors practitioners, their incidence is central and should be properly considered and addressed by those in management with the possibility to do so.

Liveware-Liveware. This is the interface between people. Training and proficiency testing have traditionally been done on an individual basis. If each individual team member was proficient, then it was assumed that the team consisting of these individuals would also be proficient and effective. This is not always the case, however, and for many years attention has increasingly turned to the breakdown of teamwork. Flight crews, air traffic controllers, maintenance technicians and other operational personnel function as groups and group influences play a role in determining behaviour and performance. In this interface, we are concerned with leadership, crew co-operation, teamwork and personality interactions. Staff/ management relationships are also within the scope of this interface, as corporate culture, corporate climate and company operating pressures can significantly affect human performance.

THE INDUSTRY NEED FOR HUMAN FACTORS

Admiral Donald Engen, the former Administrator of the United States Federal Aviation Administration, has been quoted as saying (1986): "We spent over fifty years on the hardware, which is now pretty reliable. Now it's time to work with people." This declaration somehow sets the foundation upon which the industry need for Human Factors can be assessed. Curiously enough, we retain a lawyer for advice about a legal problem, or hire an architect to build a house, or consult a physician when trying to establish the diagnosis of a medical problem, but when it comes to solving Human Factors problems, we have adopted an intuitive and in many cases perfunctory approach, even though many lives may depend on the outcome. A background of many years of industry experience or thousands of flying hours may have little or no significance when looking for the resolution of problems which only a thorough understanding of Human Factors can provide.

This is of special significance because, as already mentioned, it has long been known that some three out of four accidents result from performance errors made by apparently healthy and properly certificated individuals. The sources of some of these errors may be traced to poor equipment or procedure design or to inadequate training or operating instructions. But whatever the origin, the question of human performance capabilities and limitations and human behaviour is central to the technology of Human Factors. The cost, both in human and financial terms, of less than optimum human performance has become so great that a makeshift or intuitive approach to Human Factors is no longer appropriate. Safety being the ultimate objective of all those involved in aviation, its logical follow-up is to ensure a proper level of Human Factors knowledge throughout the industry.

The industry need for Human Factors is based on its impact on two broad areas, which interrelate so closely that in many cases their influences overlap and factors affecting one may also affect the other. These areas are:

- Effectiveness of the system
  - — safety
  - — efficiency
- Well-being of operational personnel.

Effectiveness of the system

Safety

The best way to illustrate the effect of Human Factors issues on aviation safety is through the example of accidents. A few accidents in which aspects of Human Factors triggered the attention of the aviation community and paved the way to the proliferation of Human Factors endeavours in aviation are described here as examples.

1. In the same month — December 1972 — an L1011 crashed in the Florida Everglades (NTSB/AAR 73-14) and a B-737 crashed at Midway Airport in Chicago (NTSB/AAR 73-16). In the first case, duties were not properly allocated and the whole flight crew became preoccupied with a landing gear indicator light bulb. In the second case, the captain — as

a leader — did not properly manage the resources which were available to him.

2. In 1974, a B-707 crashed during approach at Pago-Pago in Samoa, with a loss of 96 lives. A visual illusion related to the black-hole phenomenon was a cause factor (NTSB/AAR 74-15).
3. In 1974, a DC-10 crashed after take-off because a cargo door failed (it opened and blew out). The force applied by a cargo handler to close the cargo door, the door design and an incomplete application of a service bulletin were cited as factors (ICAO Circular 132-AN/93).
4. In 1974, a B-727 approaching Dulles Airport in Washington crashed into Mount Weather, with a loss of 92 lives. Lack of clarity and inadequacies in air traffic control procedures and regulations led to the accident. The absence of timely action of the regulatory body to resolve a known problem in air traffic terminology was also listed as a factor (NTSB/AAR 75-16).
5. In 1977, two B-747s collided while on the runway at Tenerife, with a loss of 583 lives. A breakdown in normal communication procedures and misinterpretation of verbal messages were considered factors (ICAO Circular 153-AN/98).
6. In 1979, a DC-10 crashed into Mount Erebus in Antarctica. Information transfer and data entry errors played a role in the accident (Accident Report No. 79/139, New Zealand).
7. In 1982, a B-737 crashed after take-off in icing conditions in Washington. Erroneous engine thrust readings (higher than actual), and the co-pilot's lack of assertiveness in communicating his concern and comments about aircraft performance during the take-off run were among the factors cited (NTSB/AAR 82-08).
8. The report of a 1983 A300 accident in Kuala Lumpur suggests that variations in panel layout amongst the aircraft in the fleet had adversely affected crew performance. (The aircraft was on a dry lease.) (Accident Report No. 2/83, Malaysia).
9. In 1984, a DC-10 overran the runway at John F. Kennedy Airport in New York. Excessive reliance on automation was noted in the accident report (NTSB/AAR 84-15). Excessive reliance on automation was also listed as a factor in a loss of control incident in 1985, in which a B-747 lost 20 000 feet in less than two minutes and sustained structural damage (NTSB/AAR 86-03).
10. In 1987 an MD-80 crashed on take-off in Detroit. The pilots had not set the flaps, thus violating standard operating procedures. Also, the take-off configuration warning did not sound, for undetermined reasons (NTSB/AAR 88-05).

Efficiency

The need for application of Human Factors is not limited to flight safety. Efficiency is also radically influenced by the application of, or the lack of, Human Factors knowledge. For instance, neglect of Human Factors in flight operations can be expected to cause less than optimum performance of tasks. The following paragraphs are intended as an overview of particular applications of Human Factors knowledge which relate to efficiency.

Motivation can be explained as reflecting the difference between what a person can and actually will do; motivated individuals perform with greater effectiveness than unmotivated individuals. Human error and its consequences in aviation can be controlled by Human Factors technology, thus improving effectiveness.

The proper layout of displays and controls in the flight deck promotes and enhances effectiveness. Properly trained and supervised crew members are likely to perform more efficiently. From the perspective of efficiency, standard operating procedures (SOPs), which are developed to provide the most effective methods of operations, should be regarded as a means of measuring the performance of crew members.

Application of group interaction principles enhances the managerial position of the captain, whose leadership role is essential to the integration of a team and thus to more effective performance. The relationship between cabin attendants and passengers is also important. Cabin crew members should have an understanding of passenger behaviour and the emotions they can expect to encounter on board, as well as how to manage emotional situations.

Well-being of operational personnel

Three of the many factors which may influence the well-being of operational personnel are fatigue, body rhythm disturbance, and sleep deprivation or disturbance. These are briefly explained below. Other factors affecting physiological or psychological well-being include temperature, noise, humidity, light, vibration, workstation design and seat comfort.

Fatigue

Fatigue may be considered to be a condition reflecting inadequate rest, as well as a collection of symptoms associated with displaced or disturbed biological rhythms. Acute fatigue is induced by long duty periods or by a string of particularly demanding tasks performed in a short term. Chronic fatigue is induced by the cumulative effects of fatigue over the longer term. Mental fatigue may result from emotional stress, even with normal physical rest. Like the disturbance of body rhythms, fatigue may lead to potentially unsafe situations and a deterioration in efficiency and well-being. Hypoxia and noise are contributing factors.

Body rhythm disturbance

The most commonly recognized of the body's rhythms is the circadian, or 24-hour rhythm, which is related to the earth's rotation time. This cycle is maintained by several agents: the most powerful are light and darkness, but meals and physical and social activities also have an influence on the body's systems. Safety, efficiency and well-being are affected by the disturbed pattern of biological rhythms typical of today's long-range flights. The impact of circadian dysrhythmia is relevant not only to long-distance transmeridian flying — short-haul operators (couriers and freight carriers, for instance) flying on irregular or night schedules can suffer from reduced performance produced by circadian dysrhythmia. Air traffic controllers and maintenance technicians with frequently changing shift schedules can suffer a similar deterioration in their performance.

Jet lag is the common term for disturbance or desynchronization of body rhythms, and refers to the lack of well-being experienced after long-distance transmeridian air travel. Symptoms include sleep disturbance and disruption of eating and elimination habits, as well as lassitude, anxiety, irritability and depression. Objective evidence shows slowed reaction and decision-making times, loss of or inaccurate memory of recent events, errors in computation and a tendency to accept lower standards of operational performance.

Sleep

The most common physical symptoms associated with long-range flying result from disturbance of the normal sleep pattern, which may in some cases involve an over-all sleep deprivation. Adults usually take sleep in one long period each day; where this pattern has been established it becomes a natural rhythm of the brain, even when prolonged waking is imposed. Wide differences are found amongst individuals in their ability to sleep out of phase with their biological rhythms. Tolerance to sleep disturbance varies between crew members and is mainly related to body chemistry and, in some cases, to emotional stress factors.

Insomnia defines a condition where a person has difficulty sleeping or when the quality of sleep is poor. When occurring under normal conditions and in phase with the body rhythms, it is called primary insomnia. Circadian rhythm sleep disorder refers to difficulty in sleeping in particular situations where biological rhythms are disturbed, and is the one we are concerned about in long-range transmeridian flying.

The use of drugs such as hypnotics, sedatives (including antihistamines with a sedative effect) and tranquilizers to induce sleep is usually inappropriate, as they have an adverse effect on performance when taken in therapeutic doses for up to 36 hours after administration. Alcohol is a depressant of the nervous system. It has a soporific effect, but it disturbs normal sleep patterns and entails poor quality of sleep. The effects persist after it has disappeared from the blood ("hangover"). Ingestion of hypnotics in combination with alcohol can have bizarre consequences. Caffeine in coffee, tea and various soft drinks increases alertness and normally reduces reaction times, but it is also likely to disturb sleep. Amphetamines, when used to maintain the level of performance during sleep deprivation, only postpone the effects of sleep loss.

Sleep has a restorative function, and is essential for mental performance. Sleep deprivation and disturbance can reduce alertness and attention. When this phenomenon is recognized, alertness and attention can at least be partly restored by the application of extra effort. The relevance of this phenomenon to safety is obvious.

The resolution of the problem of sleep disturbance or deprivation includes:
- scheduling crews with due consideration to circadian rhythms and fatigue resulting from sleep deprivation and disturbance;
- adapting the diet, understanding the importance of meal times, and adopting other measures in relation to light/darkness, rest/activity schedules and social interaction;
- recognizing the adverse long-term effect of drugs (including caffeine and alcohol);
- optimizing the sleeping environment; and
- learning relaxation techniques.

Health and performance

Certain pathological conditions — gastrointestinal disorders, heart attacks, etc. — have caused sudden pilot incapacitation and in rare cases have contributed to accidents. While total incapacitation is usually quickly detected by other crew members, a reduction in capacity or partial incapacitation — produced by fatigue, stress, sleep, rhythm disturbances, medication, certain mild pathological conditions may go undetected, even by the person affected.

Although no conclusive evidence is available, physical fitness may have a direct relationship to mental performance and health. Improved fitness reduces tension and anxiety and increases self-esteem. It has favourable effects on emotions, which affect motivation, and is believed to increase resistance to fatigue. Factors having a known influence on fitness include diet, exercise, stress levels and the use of tobacco, alcohol or drugs.

Stress

Stress can be found in many jobs, and the aviation environment is particularly rich in potential stressors. Of main interest is the effect of stress on performance. In the early days of aviation, stressors were created by the environment: noise, vibration, temperature, humidity, acceleration forces, etc., and were mainly physiological in nature. Today, some of these have been replaced by new sources of stress: irregular working and resting patterns and disturbed circadian rhythms associated with long-range, irregular or night-time flying.

Stress is also associated with life events, such as family separation, and with situations such as periodic medical and proficiency checks. Even positive life events, such as a wedding or the birth of a child, can induce stress in normal life. Likewise, in situations where mental workload becomes very high, such as during take-off, landing or an in-flight emergency, mental stress may appear.

Individuals differ in their responses to stress. For example, flight in a thunderstorm area may be challenging for one individual but stressful for another. The same stressor (the thunderstorm) produces different responses in different individuals, and any resulting damage should be attributed to the response rather than to the stressor itself.

HUMAN FACTORS APPLICATIONS IN AVIATION OPERATIONS

Control of Human Error

To contain and control human error, one must first understand its nature. There are basic concepts associated with the nature of human error: the origins of errors can be fundamentally different; and the consequences of similar errors can also be significantly different. While some errors are due to carelessness, negligence or poor judgement, others may be induced by poorly designed equipment or may result from a normal reaction of a person to a particular situation. The latter kind of error is likely to be repeated and its occurrence can be anticipated.

Errors at the model interfaces

Each of the interfaces in the SHEL model has a potential of error where there is a mismatch between its components. For example:

- The interface between Liveware and Hardware (human and machine) is a frequent source of error: knobs and levers which are poorly located or lack of proper coding create mismatches at this interface.
- In the Liveware-Software interface, delays and errors may occur while seeking vital information from confusing, misleading or excessively cluttered documentation and charts.
- Errors associated with the Liveware-Environment interface are caused by environmental factors (noise, heat, lighting and vibration) and by the disturbance of biological rhythms in long-range flying resulting from irregular working/sleeping patterns.
- In the Liveware-Liveware interface, the focus is on the interaction between people because this process affects crew effectiveness. This interaction also includes leadership and command, and shortcomings at this interface reduce operational efficiency and cause misunderstandings and errors.

Information processing

Before a person can react to information, it must first be sensed; there is a potential for error here, because the sensory systems function only within narrow ranges. Once information is sensed, it makes its way to the brain, where it is processed, and a conclusion is drawn about the nature and meaning of the message received. This interpretative activity is called perception and is a breeding ground for errors. Expectation, experience, attitude, motivation and arousal all have a definite influence on perception and are possible sources of errors.

After conclusions have been formed about the meaning of a message, decision-making begins. Many factors may lead to erroneous decisions: training or past experience; emotional or commercial considerations; fatigue, medication, motivation and physical or psychological disorders. Action (or inaction) follows decision. This is another stage with potential for error, because if equipment is designed in such a way that it can be operated wrongly, sooner or later it will be. Once action has been taken, a feedback mechanism starts to work. Deficiencies in this mechanism may also generate errors.

Controlling human error

The control of human error requires two different approaches. First, it is necessary to minimize the occurrence of errors by: ensuring high levels of staff competence; designing controls so that they match human characteristics; providing proper checklists, procedures, manuals, maps, charts, SOPs, etc.; and reducing noise, vibration, temperature extremes and other stressful conditions. Training programmes aimed at increasing the co-operation and communication between crew members will reduce the number of errors (the total elimination of human error is a difficult goal, since errors are a normal part of human behaviour). The second avenue to the control of human error is to reduce the consequences of the remaining errors by cross-monitoring and crew co-operation. Equipment design which makes errors reversible and equipment which can monitor or complement and support human performance also contribute to the limitation of errors or their consequences.

Training and evaluation

The purpose of this section is to illustrate how Human Factors applies to the design of methods of operational training.

Education and training are seen here as two different aspects of the teaching process. Education encompasses a broad-based set of knowledge, values, attitudes and skills required as a background upon which more specific job abilities can be acquired later. Training is a process aimed at developing specific skills, knowledge or attitudes for a job or a task. Proper and effective training cannot take place unless the foundations for the development of those skills, knowledge or attitudes have been laid by previous education.

PLAIN TALK

Because of the high cost of aviation gasoline, a private pilot once wrote to his aviation administration and asked if he could mix kerosene in his aircraft fuel. He received the following reply:

"Utilization of kerosene involves major uncertainties/probabilities respecting shaft output and

metal longevity where application pertains to aeronautical internal combustion power plants."

> The pilot sent the following cable:
>
> "Thanks for the information. Will start using kerosene next week."
>
> "Regrettably decision involves uncertainties. Kerosene utilization consequences questionable, with respect to metalloferrous components and power production."
>
> This prompted another cable from the pilot:
>
> "Thanks again. It will sure cut my fuel bill."
>
> The same day he finally received a clear message:
>
> "DON'T USE KEROSENE. IT COULD KILL THE ENGINE — AND YOU TOO!"

A skill is an organized and co-ordinated pattern of psychomotor, social, linguistic and intellectual activity. Teaching is a skill in its own right, and the possession of a skill in a particular activity does not necessarily indicate skill in teaching that activity to others. This is an important consideration in the selection of flight instructors, check pilots, or anyone connected with a teaching activity.

Skills, knowledge or attitudes gained in one situation can often be used in another. This is called positive transfer. Negative transfer occurs when previous learning interferes with new learning. It is important to identify the elements of training which can induce negative transfer since a return to earlier learned practices may occur in conditions of stress.

Learning is an internal process and training is the control of this process. The success or failure of training must be determined by the changes in performance or behaviour which the learning produces. Since learning is accomplished by the student and not by the teacher, the student must be an active rather than a passive participant. Memory is relevant to learning — short-term memory (STM) refers to the storage of information which will be stored and quickly forgotten, while long-term memory (LTM) allows the storage of information for extended periods of time. STM is limited to a few items of information during a few seconds. Through repetition, information is transferred into LTM. While there is a very large capacity in LTM and fewer storage problems, there are certainly retrieval problems, as exemplified by the problems of witness recollections of past events.

A number of factors can interfere with the success of a training programme — obvious ones like sickness, fatigue or discomfort as well as others like anxiety, low motivation, poor quality instruction, an unsuitable instructor, inadequate learning techniques or inadequate communication.

It is cost-effective to observe a systems approach to training. Its first step is to determine the training needs, possibly through job task analyses. The second step provides a clear job description and analysis. The objective of the training can then be formulated, and criteria can be established for the selection of the trainees. Next, the course content is determined, and the course implemented. Different methods include: lectures, lessons, discussions, tutorials, audio-visuals, programmed instruction, and computer-based training.

There are two major types of training devices: training aids (such as slides, videographs, blackboards, wall charts), which help the teacher present a subject and training equipment (such as the flight simulator), which provides for active participation and practice by the trainee. The development of simulators is based on the need to provide practical training in as realistic an environment as possible, at low cost and risk, and with a high degree of efficiency. To obtain approval from certifying authorities, the simulator's fidelity must be high enough to develop the proficiency and performance which are expected in real life situations.

It is often assumed that to achieve the best training results it is necessary to incorporate the highest degree of fidelity in the training situation. Fidelity is expensive, however, and it should be cost-effective. Motion, control loading, sound and visual systems, and specific equipment simulation (radar — built-in test equipment — flight management computers, etc.) involve considerable expenditure. At the upper limits of simulation, a very small increase in fidelity becomes very expensive — this is especially relevant since available evidence supports the fact that a good return of training transfer is often obtained from moderate levels of fidelity. It is the specialist's task to determine the degree of fidelity needed to meet specific training requirements for a particular situation. High fidelity is required in a training device when the student must learn to make discriminations when selecting switches or controls and where the responses required are difficult to make or critical to the operation. Low fidelity in the equipment is acceptable when procedures are first being learned, in order to avoid confusion and not overload the beginner. As the training progresses, increased fidelity is generally required for user acceptance.

Leadership

A leader is a person whose ideas and actions influence the thought and the behaviour of others. Through the use of example and persuasion, and an understanding of the goals and desires of the group, the leader becomes a means of change and influence.

It is important to establish the difference between leadership, which is acquired, and authority, which is assigned. An optimal situation exists when the two are combined. Leadership involves teamwork, and the quality of a leader depends on the success of the leader's relationship with the team. Leadership skills should be developed for all through proper training; such training is essential in aircraft operations where junior crew members are sometimes called upon to adopt a leadership role throughout the normal performance of their duties. This may occur when the co-pilot must take over from an absent or incapacitated captain, or when a junior flight attendant must control the passengers in a particular cabin section.

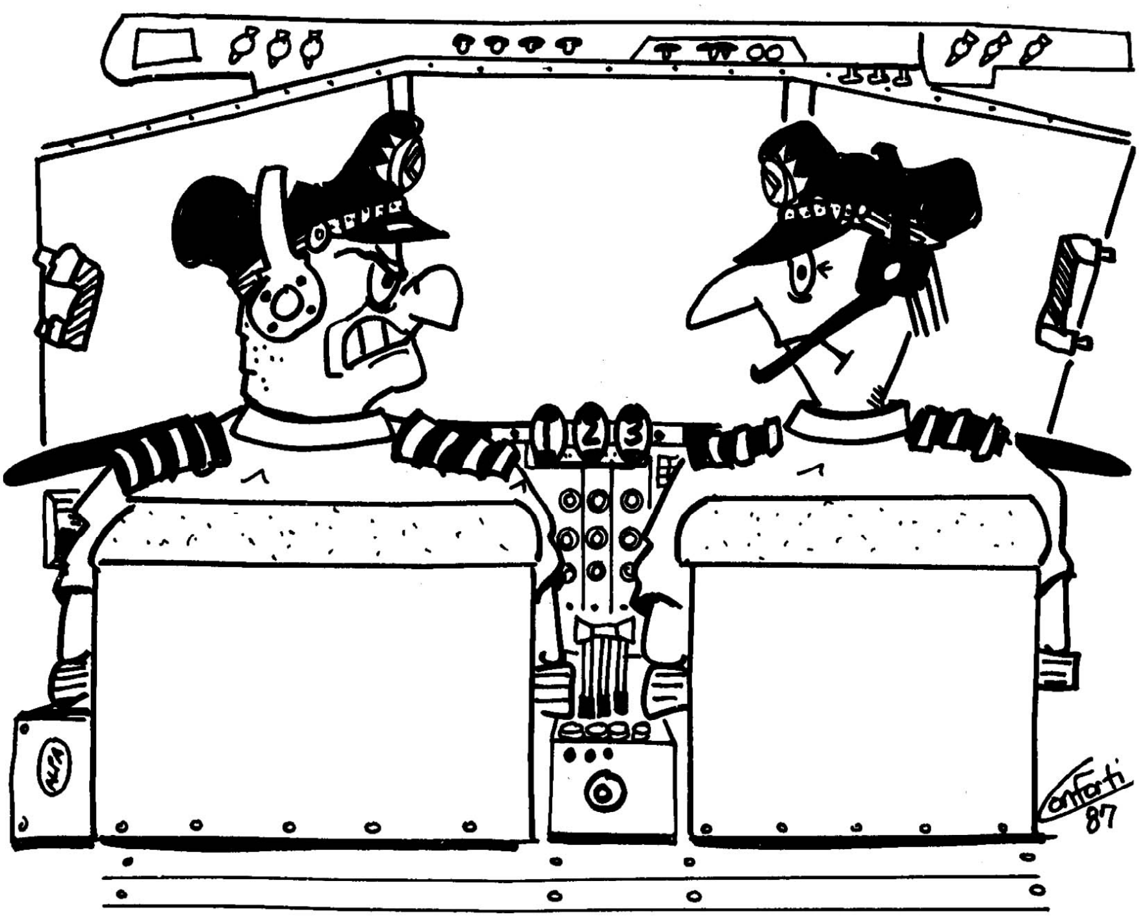
Skilled leadership may be needed to understand and handle various situations. For instance, personality and attitude clashes within a crew complicate the task of a leader and can influence both safety and efficiency. Aircraft accident and incident investigations have demonstrated that personality differences influence the behaviour and performance of crew members. Other situations requiring skilled leadership may be rooted in the frustrations of first officers over slow promotions, or of pilots who are employed as flight engineers.

Personality and attitudes

Personality traits and attitudes influence the way we conduct our lives at home and at work. Personality traits are innate or acquired at early stages of life. They are deep-rooted characteristics which define a person, and they are very stable and resistant to change. Traits such as aggression, ambition and dominance may be seen as reflections of personality.

Attitudes are learned and enduring tendencies or predispositions, more or less predictable, to respond favourably or unfavourably to people, organizations, decisions, etc. An attitude is a predisposition to respond in a certain way; the response is the behaviour itself. It is believed that our attitudes provide some sort of cognitive organization of the world in which we live, allowing us to make rapid decisions on what to do when facing certain situations.

Accidents have been caused by inadequate performance by people who had the capacity to perform effectively and yet failed to do so. Reports from the Confidential Human Factors Reporting Programme (CHIRP) and the Aviation Safety Reporting System (ASRS) support the view that attitudes and behaviour play a significant role in flight safety. This indicates the need for more research into desirable and undesirable personality characteristics in crew members, and the importance of an effective assessment of personality during crew selection. If personality or attitude differences on the flight deck have indeed been cited as the cause of accidents and incidents, then we should also look at the extent to which it may be possible to influence attitudes through training.



"Oh, I believe in resource management all right . . . you're the resource and I'm the management!"

The difference between personality and attitudes is relevant, because it is unrealistic to expect a change in personality through routine training, or captaincy or management training. The initial screening and selection process are the place and time to take appropriate action. On the other hand, attitudes are more susceptible to change through training. The effectiveness of the training depends on the strength of the attitude(s) which are to be modified. To this end, some States have demonstrated the safety benefits — particularly for single-pilot operations — of programmes for improving the pilot decision-making process by identifying hazardous thought patterns. Modifying attitudes or behaviour patterns through persuasion is also of direct relevance to safety and efficiency. Crew bulletins, staff notices and advertising are examples of persuasion.

Communication

Effective communication, which includes all transfer of information, is essential for the safe operation of flight. The message might be transferred by speech, by the written word, by a variety of symbols and displays (e.g. instruments, CRT, maps) or by non-verbal means such as gestures and body language. The quality and effectiveness of communication is determined by its intelligibility: the degree to which the intended message is understood by the receiver.

There are several hazards which reduce the quality of communications:

- failures during the transmitting process (e.g. the sending of unclear or ambiguous messages, language problems);
- difficulties caused by the medium of transmission (e.g. background noises or distortion of the information);
- failures during receiving (e.g. the expectation of another message, wrong interpretation of the arriving message or even its disregard);
- failures due to interference between the rational and emotional levels of communication (e.g. arguments);
- physical problems in listening or speaking (e.g. impaired hearing or wearing of the oxygen mask);
- use of English among native and non-native speakers; and
- encoding/decoding/noise.

It is the task of Human Factors training to prevent communication errors. This task includes the explanation of common communication problems as well as the reinforcement of a standard of language to ensure the error-free transmission of a message and its correct interpretation. Ambiguous, misleading, inappropriate or poorly constructed communication, combined with expectancy, have been listed as elements of many accidents, the most notorious one being the double B747 disaster in Tenerife (March 1977).

Crew co-ordination

Crew co-ordination is the advantage of teamwork over a collection of highly skilled individuals. Its prominent benefits are:

- an increase in safety by redundancy to detect and remedy individual errors; and
- an increase in efficiency by the organized use of all existing resources, which improves the in-flight management.

The basic variables determining the extent of crew co-ordination are the attitudes, motivation and training of the team members. Especially under stress (physical, emotional or managerial), there is a high risk that crew co-ordination will break down. The results are a decrease in communication (marginal or no exchange of information), an increase in errors (e.g. wrong decisions) and a lower probability of correcting deviations either from standard operating procedures or the desired flight path. Additionally, emotional conflicts in the cockpit may result.

The high risks associated with a breakdown of crew co-ordination show the urgent need for Crew Resource Management training, discussed in Part 2 of the manual. This kind of training ensures that:

– the pilot has the maximum capacity for the primary task of flying the aircraft and making decisions;
– the workload is equally distributed among the crew members, so that excessive workload for any individual is avoided; and
– a co-ordinated co-operation — including the exchange of information, the support of fellow crew members and the monitoring of each other's performance — will be maintained under both normal and abnormal conditions.

Motivation

Motivation reflects the difference between what a person can do and actually will do, and is what drives or induces a person to behave in a particular fashion. Clearly, people are different and driven by different motivational forces. Even when selection, training and checking ensure capability to perform, it is motivation that determines whether a person will do so in a given situation.

There is a relationship between expectancy and reward as motivators, since the utility of a reward and the subjective probability of its achievement determine the level of effort which will be applied to obtain the reward. This effort must be accompanied by the proper skills. It is important for high performers to see that they are in a better position than poor performers to achieve a reward, otherwise motivation may decline. Job satisfaction motivates people to higher performance.

Modifying behaviour and performance through rewards is called positive reinforcement; discouraging undesirable behaviour by use of penalties or punishment is called negative reinforcement. Even though positive reinforcement can be more effective in improving performance, both must be available to management. Different responses are to be expected from different individuals in relation to positive and negative reinforcers. Care should be taken not to generate an effect which is opposite from that which is intended.

Documentation

Inadequacies in aviation documentation have a twofold impact: there is a monetary aspect associated with increased time or the impossibility of performing a particular task and there is also a safety aspect. With reference to documentation — including electronic flight documentation displayed on screen — some basic aspects require Human Factors optimization:

a. written language, which involves not only vocabulary and grammar, but also the manner in which they are used;
b. typography, including the form of letters and printing and the layout, has a significant impact on the comprehension of the written material;
c. the use of photograph diagrams, charts or tables replacing long descriptive text is advantageous to help comprehension and maintain interest. The use of colour in illustrations reduces the discrimination workload and has a motivational effect;

d. the working environment in which the document is going to be used has to be considered when print and page size are determined (for example, an airport chart which is too small may induce error during taxiing).

Workstation design

For design purposes, the flight deck should be considered as a system, as opposed to a collection of particular aspects or systems such as hydraulic, electrical or pressurization. Expertise should be applied towards matching the characteristics of these systems to those of humans, with due consideration to the job to be performed. Proper matching of working areas to human dimensions and characteristics is important — for instance, size, shape and movements of the body provide data used to ensure adequate visibility in the flight deck, location and design of controls and displays, and seat design.

The importance of the standardization of panel layout relates to safety, since there are numerous reports of errors arising from inconsistent panel layouts, involving inadvertent reversion to an operating practice appropriate to an aircraft flown previously. Seat design considerations include seat controls, headrests, seat cushion and fabric, lumbar support, thigh support, etc.

A display is any means of presenting information directly to the operator. Displays use the visual, aural or tactile senses. The transfer of information from a display to the brain requires that information is filtered, stored and processed, a requirement which can cause problems. This is a major consideration in the design of flight deck displays. The information should be presented in such a way as to assist the processing task, not only under normal circumstances, but also when performance is impaired by stress or fatigue.

A fundamental consideration in display design is to determine how, in what circumstances, and by whom the display is going to be used. Other considerations include the characteristics of visual displays and aural signals; light requirements; the selection of analogue or digital alternatives; the applicability of LEDs (light-emitting diodes), LCDs (liquid-crystal displays) and CRTs (cathode-ray tubes); the angle at which the display is to be viewed and its related parallax; viewing distance, and possible ambiguity of the information.

Three fundamental operational objectives apply to the design of warning, alerting and advisory systems: they should alert the crew and draw their attention, report the nature of the condition, and, when possible, guide them to the appropriate corrective action. System reliability is vital, since credibility will be lost if false warnings proliferate, as was the case with earlier generations of ground proximity warning systems. In the event of a technical failure of the display system, the user should not be presented with unreliable information. Such information must be removed from sight or clearly flagged. For example, unreliable flight director command bars should disappear. Invalid guidance information which remained on display has been a factor in accidents.

A control is a means of transmitting discrete or continuous information or energy from the operator to some device or system. Control devices include push buttons, toggle or rotary switches, detented levers, rotary knobs, thumbs wheels, small levers or cranks and keypads. The type of device to be used depends on functional requirements and the manipulation force required. Several design features apply to controls:

a. location;
b. control-display ratio (control movement related to that of the moving element of the associated display);
c. direction of movement of the control relative to the display;
d. control resistance;
e. control coding, by means of shape, size, colour, labelling and location; and
f. protection against inadvertent actuation.

The application of automation to flight deck displays and controls may breed complacency and over-reliance on the automated system, which have been suggested as factors in accidents and incidents. If the Human Factors-related issues (e.g. the limited performance of the human as monitor and effects on motivation) are properly addressed, there may be a justification for automation. It may contribute to improved aircraft and system performance and over-all efficiency of the operation. It may relieve the crew of certain tasks so as to reduce workload in phases of flight where it reaches the limit of operational acceptability.

Cabin design

Human Factors considerations for the cabin include aspects of workspace and layout as well as information on human behaviour and performance.

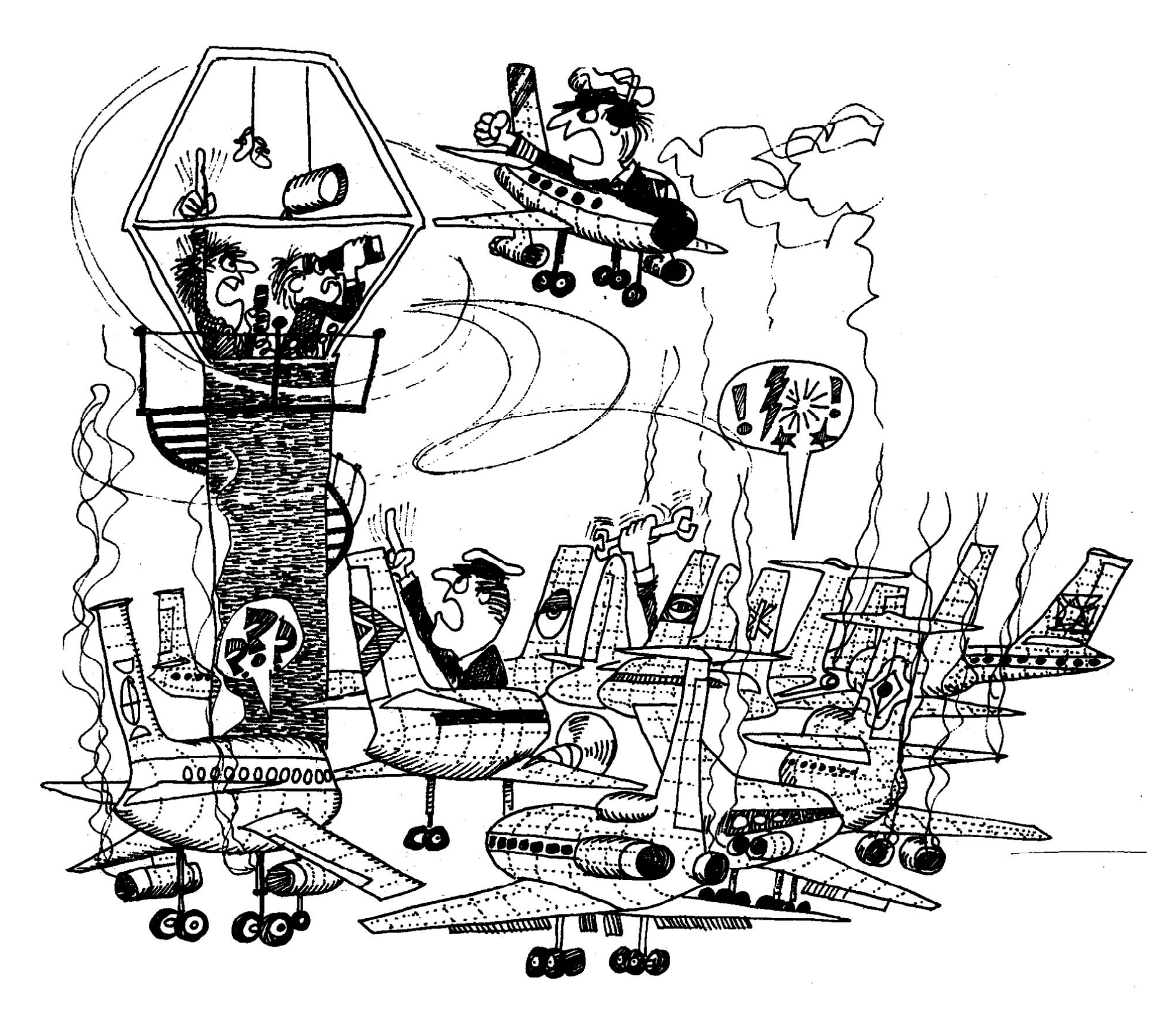
Human size and shape are relevant in the design of cabin equipment (toilets, galleys, meal carts and overhead bins); emergency equipment design (life-jackets, life-rafts, emergency exits, oxygen masks); seats and furnishings (including in-flight entertainment); jump seats and rear-facing seats. Knowledge of the user’s height and reach determines location of equipment and controls. Proper access and room to work must be provided in cargo compartments. The estimation of human forces required to operate doors, hatches and cargo equipment have to be realistic. Anthropometry (the study of human dimensions) and biomechanics (study of the movement of parts of the body and the forces which they can apply) are the sources of the required information for those purposes.

Due consideration has to be given to handling special passengers: the physically handicapped, the intoxicated, and the fearful. Passenger behaviour, including group influences, and expected human behaviour when facing a crisis are of relevance here.

Recent accidents and incidents have documented the need for Human Factors information for those involved in ground operations, such as maintenance and inspection managers, flight line supervisors and others. Similarly, persons involved in the design of aircraft systems should recognize human limits in maintaining, inspecting and servicing aircraft. Such factors as training, work environment, communication methods, physiological limitations and human engineering of equipment should be considered.

Visual performance and collision avoidance

A proper understanding of how the visual system works helps in the determination of optimum working conditions. The characteristics and measurement of light, the perception of colour, the physiology of the eyes and the way the visual system works are relevant in this area. Also important are factors involved in the ability to detect other aircraft at a distance, either in daytime or at night, or to identify outside objects in the presence of rain or other contamination on the windscreen.



Visual illusions and disorientation in flight operations may be directly related to safety. During all phases of flight, but in particular during approach and landing, visual illusions are believed to have played a significant role in accidents for which it is difficult to find any other explanation. Factors of specific consideration here include sloping terrain, runway width, lighting intensity, the “black hole” phenomenon and lack of runway texture. An effective step in reducing the risks associated with visual illusions in flight operations is the recognition through training that visual illusions are a natural phenomenon. Training should also help in understanding that the circumstances in which they occur are often predictable. The use of additional information sources to supplement visual cues (radar, attitude displays, radio altimeters, VASIs, DMEs, etc.) is the most effective protective measure against disorientation and illusions. To some extent the risk from visual illusions may be alleviated by design features such as high optical quality windshield glass, adequate visibility, eye position guidance, effective windshield rain and ice protection, etc.

■■■

CHAPTER 2
HUMAN PERFORMANCE AND LIMITATIONS

The intention of this chapter is to provide an overview of those key physical and mental human performance characteristics which are likely to affect an aircraft maintenance engineer in his working environment, such as his vision, hearing, information processing, attention and perception, memory, judgement and decision making.

HUMAN PERFORMANCE AS PART OF THE MAINTENANCE ENGINEERING SYSTEM

Just as certain mechanical components used in aircraft maintenance engineering have limitations, engineers themselves have certain capabilities and limitations that must be considered when looking at the maintenance engineering 'system'. For instance, rivets used to attach aluminium skin to a fuselage can withstand forces that act to pull them apart. It is clear that that these rivets will eventually fail if enough force is applied to them. While the precise range of human capabilities and limitations might not be as well-defined as the performance range of mechanical or electrical components, the same principles apply in that human performance is likely to degrade and eventually 'fail' under certain conditions (e.g. stress).

Mechanical components in aircraft can, on occasion, suffer catastrophic failures. Man, can also fail to function properly in certain situations. Physically, humans become fatigued, are affected by the cold, can break bones in workplace accidents, etc. Mentally, humans can make errors, have limited perceptual powers, can exhibit poor judgement due to lack of skills and knowledge, etc. In addition, unlike mechanical components, human performance is also affected by social and emotional factors. Therefore failure by aircraft maintenance engineers can also be to the detriment of aircraft safety.

The aircraft engineer is the central part of the aircraft maintenance system. It is therefore very useful to have an understanding of how various parts of his body and mental processes function and how performance limitations can influence his effectiveness at work.

VISION

The Basic Function of the Eye

In order to understand vision, it is useful first to know a little about the anatomy of the eye (see Figure below). The basic structure of the eye is similar to a simple camera with an aperture (the iris), a lens, and a light sensitive surface (the retina). Light enters the eye through the cornea, then passes through the iris and the lens and falls on the retina. Here the light stimulates the light-sensitive cells on the retina (rods and cones) and these pass small electrical impulses by way of the optic nerve to the visual cortex in the brain. Here, the electrical impulses are interpreted and an image is perceived.

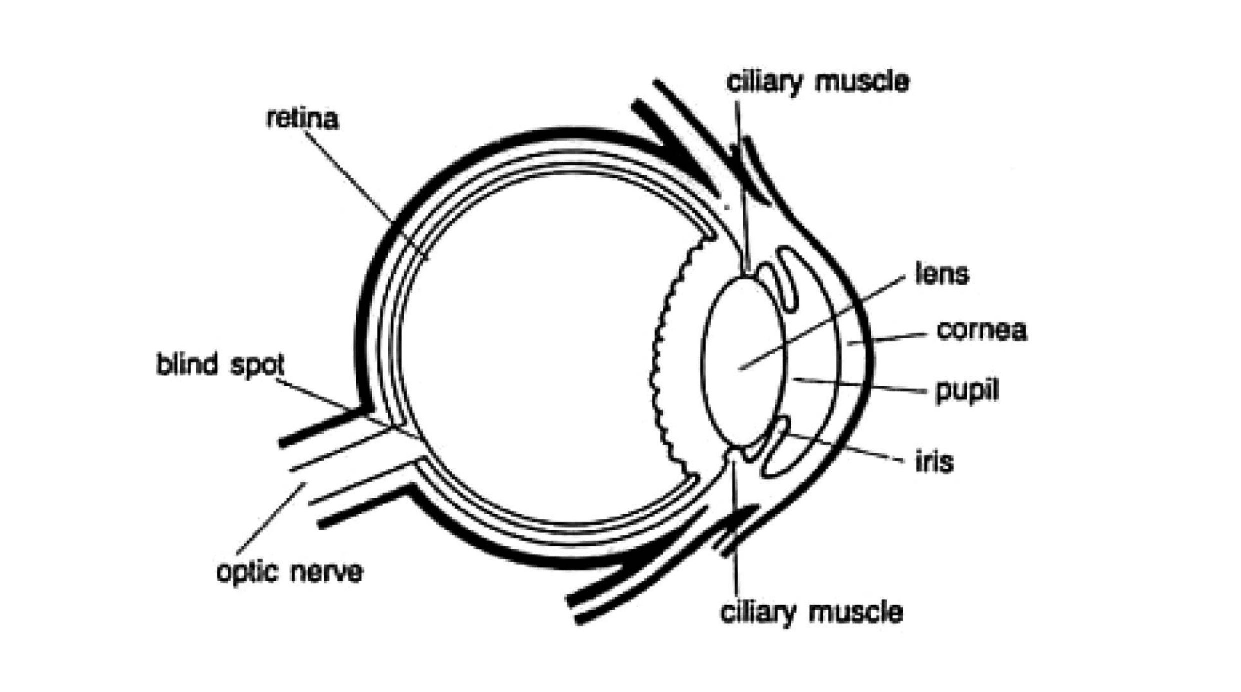


Fig. The human eye

The Cornea

The cornea is a clear 'window' at the very front of the eye. The cornea acts as a fixed focusing device. The focusing is achieved by the shape of the cornea bending the incoming light rays. The cornea is responsible for between 70% and 80% of the total focusing ability (refraction) of the eye.

The Iris and Pupil

The iris (the coloured part of the eye) controls the amount of light that is allowed to enter the eye. It does this by varying the size of the pupil (the dark area in the centre of the iris). The size of the pupil can be changed very rapidly to cater for changing light levels. The amount of light can be adjusted by a factor of 5:1.

The Lens

After passing through the pupil, the light passes through the lens. Its shape is changed by the muscles (cillary muscles) surrounding it which results in the final focusing adjustment to place a sharp image onto the retina. The change of shape of the lens is called accommodation. In order to focus clearly on a near object, the lens is thickened. To focus on a distant point, the lens is flattened. The degree of accommodation can be affected by factors such as fatigue or the ageing process.

> When a person is tired accommodation is reduced, resulting in less sharp vision (sharpness of vision is known as visual acuity).

The Retina

The retina is located on the rear wall of the eyeball. It is made up of a complex layer of nerve cells connected to the optic nerve. Two types of light sensitive cells are found in the retina - rods and cones. The central area of the retina is known as the fovea and the receptors in this area are all cones. It is here that the visual image is typically focused. Moving outwards, the cones become less dense and are progressively replaced by rods, so that in the periphery of the retina, there are only rods.

Cones function in good light and are capable of detecting fine detail and are colour sensitive. This means the human eye can distinguish about 1000 different shades of colour.

Rods cannot detect colour. They are poor at distinguishing fine detail, but good at detecting movement in the edge of the visual field (peripheral vision). They are much more sensitive at lower light levels. As light decreases, the sensing task is passed from the cones to the rods. This means in poor light levels we see only in black and white and shades of grey.

At the point at which the optic nerve joins the back of the eye, a 'blind spot' occurs. This is not evident when viewing things with both eyes (binocular vision), since it is not possible for the image of an object to fall on the blind spots of both eyes at the same time. Even when viewing with one eye (monocular vision), the constant rapid movement of the eye (saccades) means that the image will not fall on the blind spot all the time. It is only when viewing a stimulus that appears very fleetingly (e.g. a light flashing), that the blind spot may result in something not being seen. In maintenance engineering, tasks such as close visual inspection or crack detection should not cause such problems, as the eye or eyes move across and around the area of interest (visual scanning).

Factors Affecting Clarity of Sight

The eye is very sensitive in the right conditions (e.g. clear air, good light, etc.). In fact, the eye has approximately 1.2 million nerve cells leading from the retinas to the area of the brain responsible for vision, while there are only about 50,000 from the inner ears - making the eye about 24 times more sensitive than the ear.

Before considering factors that can influence and limit the performance of the eye, it is necessary to describe visual acuity.

Visual acuity is the ability of the eye to discriminate sharp detail at varying distances.

An individual with an acuity of 20/20 vision should be able to see at 20 feet that which the so-called 'normal' person is capable of seeing at this range. It may be expressed in metres as 6/6 vision. The figures 20/40 mean that the observer can read at 20 feet what a 'normal' person can read at 40 feet.

Various factors can affect and limit the visual acuity of the eye. These include:

- Physical factors such as:
  - physical imperfections in one or both eyes (short sightedness, long sightedness),
  - age.
- The influence of ingested foreign substances such as:
  - drugs,
  - medication,
  - alcohol,
  - cigarettes.

- Environmental factors such as:
  - amount of light available,
  - clarity of the air (e.g. dust, mist, rain, etc.).
- Factors associated with object being viewed such as:
  - size and contours of the object,
  - contrast of the object with its surroundings,
  - relative motion of the object,
  - distance of the object from the viewer,
  - the angle of the object from the viewer.

Each of these factors will now be examined in some detail.

Physical Factors

Long sight - known as Hypermetropia - is caused by a shorter than normal eyeball which means that the image is formed behind the retina (Figure). If the cornea and the lens cannot use their combined focusing ability to compensate for this, blurred vision will result when looking at close objects.

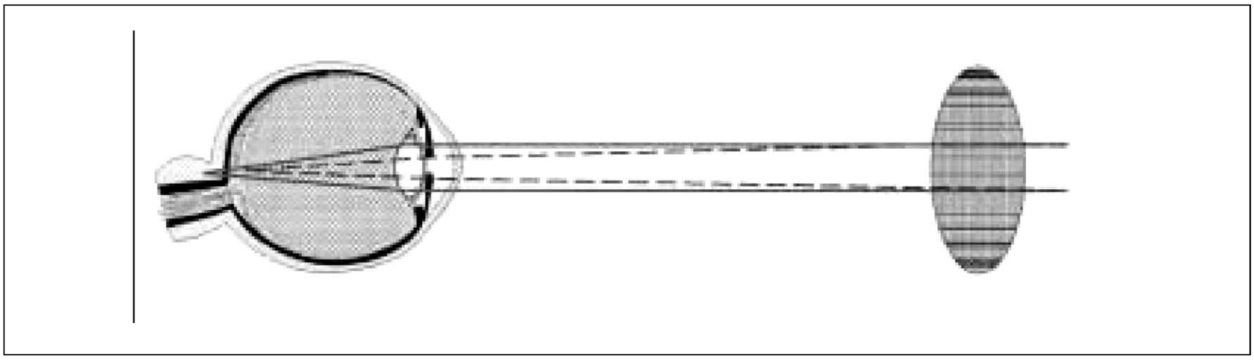


Fig. A convex lens will overcome long sightedness by bending light inwards before it reaches the cornea.

Short sight - known as Myopia - is where the eyeball is longer than normal, causing the image to be formed in front of the retina (Figure). If the accommodation of the lens cannot counteract this then distant objects are blurred.

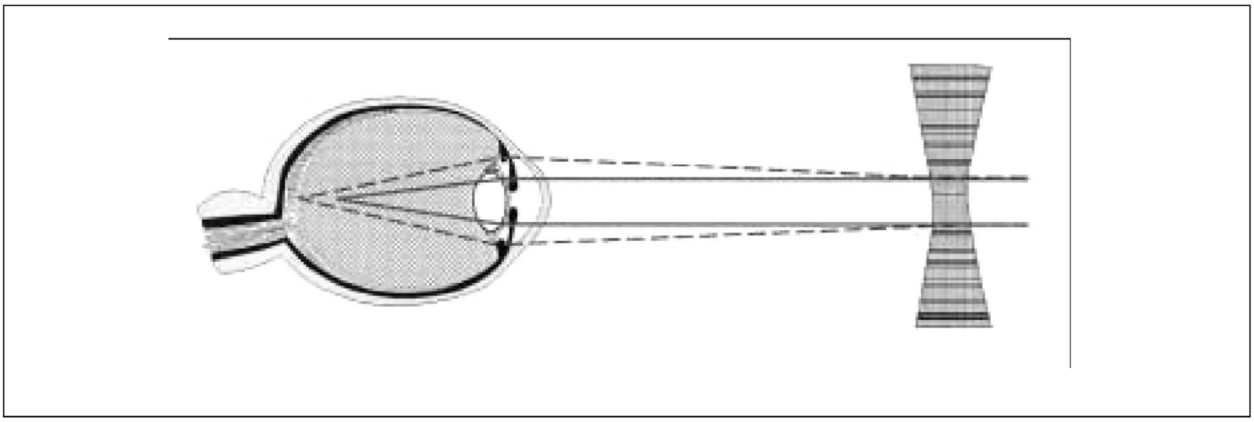


Fig. A concave lens will overcomeshort sightedness by bending light outwards before it reaches the cornea.

Other visual problems include:
- cataracts - clouding of the lens usually associated with ageing;
- astigmatism - a misshapen cornea causing objects to appear irregularly shaped;
- glaucoma - a build up in pressure of the fluid within the eye which can cause damage to the optic nerve and even blindness;
- migraine - severe headaches that can cause visual disturbances.

Finally as a person grows older, the lens becomes less flexible meaning that it is unable to accommodate sufficiently. This is known as presbyopia and is a form of long sightedness. Consequently, after the age of 40, spectacles may be required for near vision, especially in poor light conditions. Fatigue can also temporarily affect accommodation, causing blurred vision for close work.

Foreign Substances

Vision can be adversely affected by the use of certain drugs and medications, alcohol, and smoking cigarettes. With smoking, carbon monoxide which builds up in the bloodstream allows less oxygen to be carried in the blood to the eyes. This is known as hypoxia and can impair rapidly the sensitivity of the rods. Alcohol can have similar effects, even hours after the last drink.

Environmental Factors

Vision can be improved by increasing the lighting level, but only up to a point, as the law of diminishing returns operates. Also, increased illumination could result in increased glare. Older people are more affected by the glare of reflected light than younger people. Moving from an extremely bright environment to a dimmer one has the effect of vision being severely reduced until the eyes get used to less light being available. This is because the eyes have become light adapted. If an engineer works in a very dark environment for a long time, his eyes gradually become dark adapted allowing better visual acuity. This can take about 7 minutes for the cones and 30 minutes for the rods. As a consequence, moving between a bright hanger (or the inside of an aircraft) to a dark apron area at night can mean that the maintenance engineer must wait for his eyes to adjust (adapt). In low light conditions, it is easier to focus if you look slightly to one side of an object. This allows the image to fall outside the fovea and onto the part of the retina which has many rods.

Any airborne particles such as dust, rain or mist can interfere with the transmission of light through the air, distorting what is seen. This can be even worse when spectacles are worn, as they are susceptible to getting dirty, wet, misted up or scratched. Engineers who wear contact lenses (especially hard or gas-permeable types) should take into account the advice from their optician associated with the maximum wear time - usually 8 to 12 hours - and consider the effects which extended wear may have on the eyes, such as drying out and irritation. This is particularly important if they are working in an environment which is excessively dry or dusty, as airborne particles may also affect contact lens wear. Goggles should be worn where necessary.

The Nature of the Object Being Viewed

Many factors associated with the object being viewed can also influence vision. We use information from the objects we are looking at to help distinguish what we are seeing. These are known as visual cues. Visual cues often refer to the comparison of objects of known size to unknown objects. An example of this is that we associate small objects with being further away. Similarly, if an object does not stand out well from its background (i.e. it has poor contrast with its surroundings), it is harder to distinguish its edges and hence its shape. Movement and relative motion of an object, as well as distance and angle of the object from the viewer, can all increase visual demands.

Colour Vision

Although not directly affecting visual acuity, inability to see particular colours can be a problem for the aircraft maintenance engineer. Amongst other things, good colour vision for maintenance engineers is important for:

- Recognising components;
- Distinguishing between wires;
- Using various diagnostic tools;
- Recognising various lights on the airfield (e.g. warning lights).

Colour defective vision is usually hereditary, although may also occur as a temporary condition after a serious illness.

> Colour-defective vision (normally referred to incorrectly as colour blindness) affects about 8% of men but only 0.5% of women. The most common type is difficulty in distinguishing between red and green. More rarely, it is possible to confuse blues and yellows.

There are degrees of colour defective vision, some people suffering more than others. Individuals may be able to distinguish between red and green in a well-lit situation but not in low light conditions. Colour defective people typically see the colours they have problems with as shades of neutral grey.

Ageing also causes changes in colour vision. This is a result of progressive yellowing of the lens, resulting in a reduction in colour discrimination in the blue-yellow range. Colour defective vision and its implications can be a complex area and care should be taken not to stop an engineer from performing certain tasks merely because he suffers from some degree of colour deficient vision. It may be that the type and degree of colour deficiency is not relevant in their particular job. However, if absolutely accurate colour discrimination is critical for a job, it is important that appropriate testing and screening be put in place.

Vision and the Aircraft Maintenance Engineer

It is important for an engineer, particularly one who is involved in inspection tasks, to have adequate vision to meet the task requirements. As discussed previously, age and problems developing in the eye itself can gradually affect vision. Without regular vision testing, aircraft maintenance engineers may not notice that their vision is deteriorating.

In the UK, the CAA have produced guidance[1] which states:

"A reasonable standard of eyesight is needed for any aircraft engineer to perform his duties to an acceptable degree. Many maintenance tasks require a combination of both distance and near vision. In particular, such consideration must be made where there is a need for the close visual inspection of structures or work related to small or miniature components. The

---

[1]CAA (1999) CAP455: Airworthiness Notices. AWN47. UK Civil Aviation Authority, paragraph 3.4.

use of glasses or contact lenses to correct any vision problems is perfectly acceptable and indeed they must be worn as prescribed. Frequent checks should be made to ensure the continued adequacy of any glasses or contact lenses. In addition, colour discrimination may be necessary for an individual to drive in areas where aircraft manoeuvre or where colour coding is used, e.g. in aircraft wiring. Organisations should identify any specific eyesight requirement and put in place suitable procedures to address these issues."
Often, airline companies or airports will set the eyesight standards for reasons other than aircraft maintenance safety, e.g. for insurance purposes, or for driving on the airfield.

Ultimately, what is important is for the individual to recognise when his vision is adversely affected, either temporarily or permanently, and to consider carefully the possible consequences should they continue to work if the task requires good vision.

HEARING

The Basic Function of the Ear

The ear performs two quite different functions. It is used to detect sounds by receiving vibrations in the air, and secondly, it is responsible for balance and sensing acceleration. Of these two, the hearing aspect is more pertinent to the maintenance engineer, and thus it is necessary to have a basic appreciation of how the ear works.

As can be seen in Figure, the ear has three divisions: outer ear, middle ear and inner ear. These act to receive vibrations from the air and turn these signals into nerve impulses that the brain can recognise as sounds.

Outer Ear

The outer part of the ear directs sounds down the auditory canal, and on to the eardrum. The sound waves will cause the eardrum to vibrate.

Middle Ear

Beyond the eardrum is the middle ear which transmits vibrations from the eardrum by way of three small bones known as the ossicles, to the fluid of the inner ear. The middle ear also contains two muscles which help to protect the ear from sounds above 80 dB by means of the

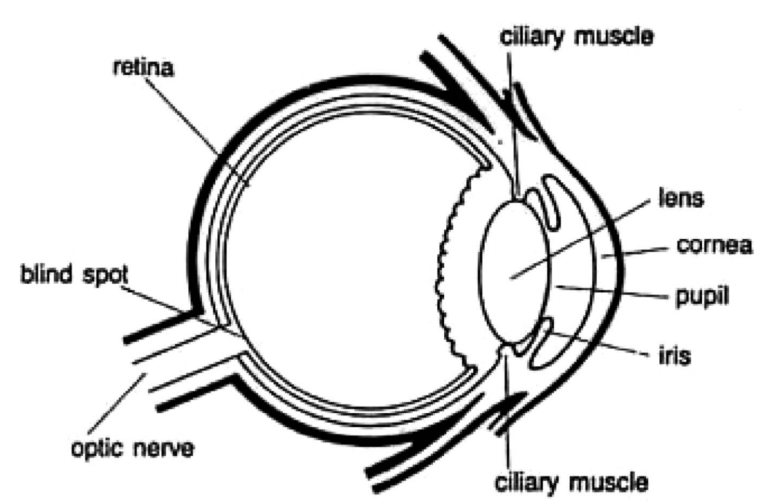


Fig. The human ear

acoustic or aural reflex, reducing the noise level by up to 20 dB. However, this protection can only be provided for a maximum of about 15 minutes, and does not provide protection against sudden impulse noise such as gunfire. It does explain why a person is temporarily ‘deafened’ for a few seconds after a sudden loud noise. The middle ear is usually filled with air which is refreshed by way of the eustachian tube which connects this part of the ear with the back of the nose and mouth. However, this tube can allow mucus to travel to the middle ear which can build up, interfering with normal hearing.

Inner Ear

Unlike the middle ear, the inner ear is filled with fluid. The last of the ossicles in the middle ear is connected to the cochlea. This contains a fine membrane (the basilar membrane) covered in hair-like cells which are sensitive to movement in the fluid. Any vibrations they detect cause neural impulses to be transmitted to the brain via the auditory nerve.

> The amount of vibration detected in the cochlea depends on the volume and pitch of the original sound.

Performance and Limitations of the Ear

The performance of the ear is associated with the range of sounds that can be heard - both in terms of the pitch (frequency) and the volume of the sound.

> The audible frequency range that a young person can hear is typically between 20 and 20,000 cycles per second (or Hertz), with greatest sensitivity at about 3000 Hz.

Volume (or intensity) of sound is measured in decibels (dB). Table 1 shows intensity levels for various sounds and activities.

Table 1 : Typical sound levels for various activities

Activity	Approximate Intensity level (Decibels)
Rustling of leaves / Whisper	20
Conversation at 2m	50
Typewriter at 1m	65
Car at 15m	70
Lorry at 15m	75
Power Mower at 2m	90
Propellor aircraft at 300m	100
Jet aircraft at 300m	10
Standing near a propellor aircraft	120
Threshold of pain	140
Immediate hearing damage results	150

Impact of Noise on Performance

Noise can have various negative effects in the workplace. It can:

- be annoying (e.g. sudden sounds, constant loud sound, etc.);
- interfere with verbal communication between individuals in the workplace;
- cause accidents by masking warning signals or messages;
- be fatiguing and affect concentration, decision making, etc.;
- damage workers' hearing (either temporarily or permanently).

Intermittent and sudden noise are generally considered to be more disruptive than continuous noise at the same level. In addition, high frequency noise generally has a more adverse affect on performance than lower frequency. Noise tends to increase errors and variability, rather than directly affect work rate. This subject also latter in this book.

VOICE AND SPEECH MECHANISM

The vocal and auditory systems

The vocal system generates speech, which is the result of the interaction of several of its components. Different voices utilize different ranges of pitch and frequency, and although there are many ways in which speech can be deformed, so long as the pattern of frequency remains intact, the speech will remain intelligible. The auditory system senses audio signals and speech, and conveys them to the brain for processing. The external ear comprises the pinna, auditory canal, and eardrum. The middle ear has three small bones called ossicles, which transmit sound from the outside to the inner ear. The middle ear is connected to the nose and throat; through swallowing, yawning or sneezing, pressure within the middle ear is equalized with that of the outside. The inner ear houses the vestibular apparatus which has functions such as maintaining balance and providing the brain with information related to acceleration and changes of position.

Hearing Impairment

Hearing loss can result from exposure to even relatively short duration noise. The degree of impairment is influenced mainly by the intensity of the noise. Such damage is known as Noise Induced Hearing Loss (NIHL). The hearing loss can be temporary - lasting from a few seconds to a few days - or permanent. Temporary hearing loss may be caused by relatively short exposure to very loud sound, as the hair-like cells on the basilar membrane take time to 'recover'. With additional exposure, the amount or recovery gradually decreases and hearing loss becomes permanent. Thus, regular exposure to high levels of noise over a long period may permanently damage the hair- like cells in the cochlea, leading to irreversible hearing impairment.

The UK 'Noise at Work' regulations (1989) impose requirements upon employers. They stipulate three levels of noise at which an employer must act:

a. 85 decibels (if normal speech cannot be heard clearly at 2 metres), employer must;
   - assess the risk to employees' hearing,
   - tell the employees about the risks and what precautions are proposed,
   - provide their employees with personal ear protectors and explain their use.

b. 90 decibels (if normal speech cannot be heard clearly at 1 metre) employer must;
   - do all that is possible to reduce exposure to the noise by means other than by providing hearing protection,

- mark zones where noise reaches the second level and provide recognised signs to restrict entry.

c. 140 decibels (noise causes pain).

The combination of duration and intensity of noise can be described as noise dose. Exposure to any sound over 80 dB constitutes a noise dose, and can be measured over the day as an 8 hour Time Weighted Average sound level (TWA).

For example, a person subjected to 95 decibels for 3.5 hours, then 105 decibels for 0.5 hours, then 85 decibels for 4 hours, results in a TWA of 93.5 which exceeds the recommended maximum TWA of 90 decibels.

Permanent hearing loss may occur if the TWA is above the recommended maximum.

It is normally accepted that a TWA noise level exceeding 85 dB for 8 hours is hazardous and potentially damaging to the inner ear. Exposure to noise in excess of 115 decibels without ear protection, even for a short duration, is not recommended.

Hearing Protection

Hearing protection is available, to a certain extent, by using ear plugs or ear defenders.

Noise levels can be reduced (attenuated) by up to 20 decibels using ear plugs and 40 decibels using ear muffs. However, using ear protection will tend to adversely interfere with verbal communication. Despite this, it must be used consistently and as instructed to be effective.

It is good practice to reduce noise levels at source, or move noise away from workers. Often this is not a practical option in the aviation maintenance environment. Hearing protection should always be used for noise, of any duration, above 115 dB. Referring again to Table 1, this means that the aviation maintenance engineer will almost always need to use some form of hearing protection when in reasonably close proximity (about 200 - 300m) to aircraft whose engines are running.

Presbycusis

Hearing deteriorates naturally as one grows older. This is known as presbycusis. This affects ability to hear high pitch sounds first, and may occur gradually from the 30's onwards. When this natural decline is exacerbated by Noise Induced Hearing Loss, it can obviously occur rather sooner.

Hearing and the Aircraft Maintenance Engineer

The UK CAA[1] makes the following recommendations regarding hearing:

> "The ability to hear an average conversational voice in a quiet room at a distance of 2 metres (6 feet) from the examiner is recommended as a routine test. Failure of this test would require an audiogram to be carried out to provide an objective assessment. If necessary, a hearing aid may be worn but consideration should be given to the practicalities of wearing the aid during routine tasks demanded of the individual."

It is very important that the aircraft maintenance engineer understands the limited ability of the ears to protect themselves from damage due to excessive noise. Even though engineers should be given appropriate hearing protection and trained in its use, it is up to individuals to ensure that they actually put this to good use. It is a misconception that the ears get used to constant noise: if this noise is too loud, it will damage the ears gradually and insidiously.

INFORMATION PROCESSING

The previous sections have described the basic functions and limitations of two of the senses used by aircraft maintenance engineers in the course of their work. This section examines the way the information gathered by the senses is processed by the brain. The limitations of the human information processing system are also considered.

Information processing is the process of receiving information through the senses, analysing it and making it meaningful.

An Information Processing Model

Information processing can be represented as a model. This captures the main elements of the process, from receipt of information via the senses, to outputs such as decision making and actions. One such model is shown in Figure below.

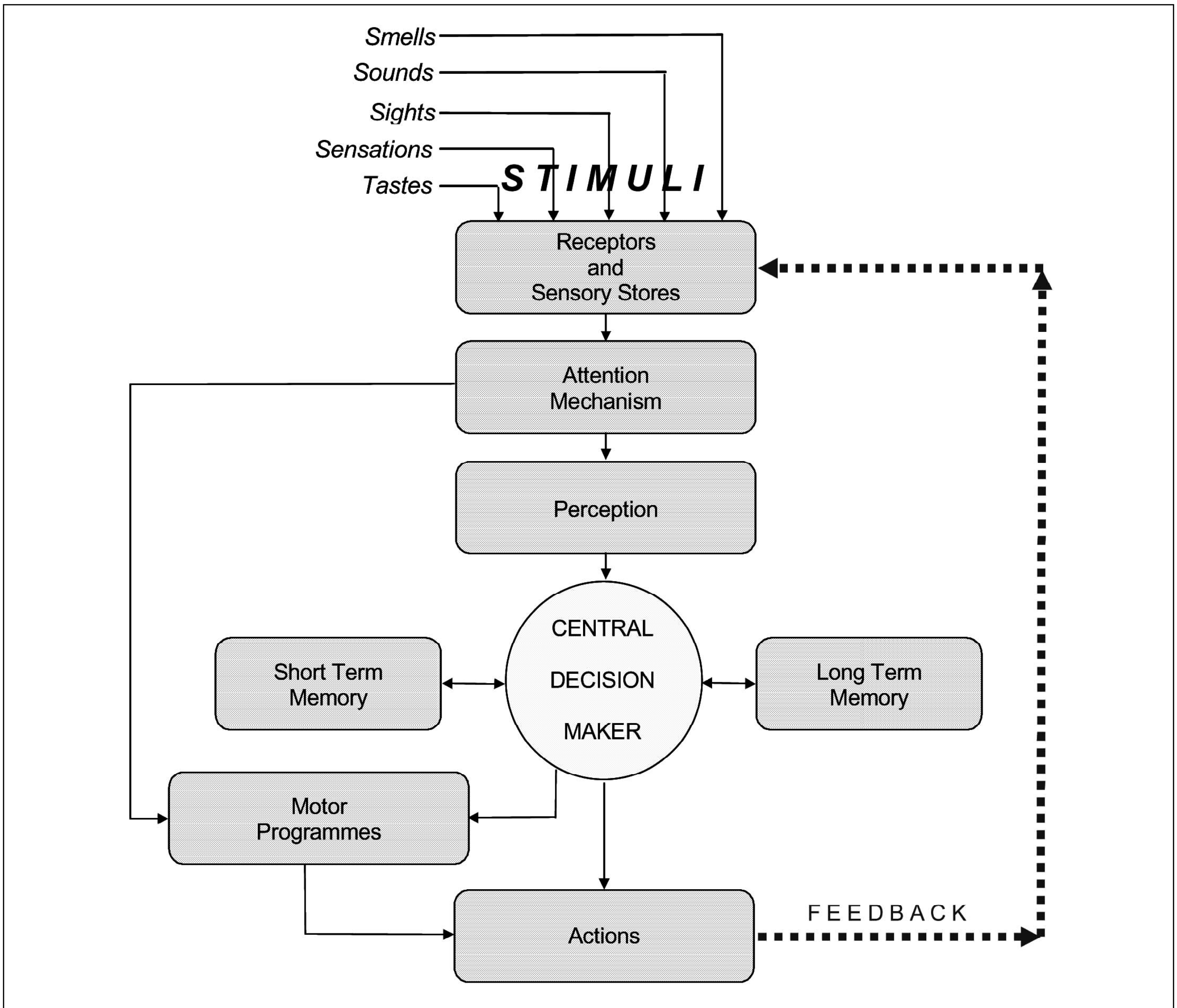


Fig. A functional model of human information processing

Sensory Receptors and Sensory Stores

Physical stimuli are received via the sensory receptors (eyes, ears, etc.) and stored for a very brief period of time in sensory stores (sensory memory). Visual information is stored for up to half a second in iconic memory and sounds are stored for slightly longer (up to 2 seconds) in echoic memory. This enables us to remember a sentence as a sentence, rather than merely as an unconnected string of isolated words, or a film as a film, rather than as a series of disjointed images.

Attention and Perception

Having detected information, our mental resources are concentrated on specific elements - this is attention.

> Attention can be thought of as the concentration of mental effort on sensory or mental events.

Although attention can move very quickly from one item to another, it can only deal with one item at a time. Attention can take the form of:

- selective attention,
- divided attention,
- focused attention
- sustained attention.

Selective attention occurs when a person is monitoring several sources of input, with greater attention being given to one or more sources which appear more important. A person can be consciously attending to one source whilst still sampling other sources in the background. Psychologists refer to this as the 'cocktail party effect' whereby you can be engrossed in a conversation with one person but your attention is temporarily diverted if you overhear your name being mentioned at the other side of the room, even though you were not aware of listening in to other people's conversations. Distraction is the negative side of selective attention.

Divided attention is common in most work situations, where people are required to do more than one thing at the same time. Usually, one task suffers at the expense of the other, more so if they are similar in nature. This type of situation is also sometimes referred to as time sharing. Focused attention is merely the skill of focussing one's attention upon a single source and avoiding distraction.

Sustained attention as its name implies, refers to the ability to maintain attention and remain alert over long periods of time, often on one task. Most of the research has been carried out in connection with monitoring radar displays, but there is also associated research which has concentrated upon inspection tasks.

Attention is influenced by arousal level and stress. This can improve attention or damage it depending on the circumstances. This is also discussed latter in the book.

Perception involves the organisation and interpretation of sensory data in order to make it meaningful, discarding non-relevant data, i.e. transforming data into information. Perception is a highly sophisticated mechanism and requires existing knowledge and experience to know what data to keep and what to discard, and how to associate the data in a meaningful manner.

> Perception can be defined as the process of assembling sensations into a useable mental representation of the world. Perception creates faces, melodies, works of art, illusions, etc. out of the raw material of sensation.

> Examples of the perceptual process:
> - the image formed on the retina is inverted and two dimensional, yet we see the world the right way up and in three dimensions;
> - if the head is turned, the eyes detect a constantly changing pattern of images, yet we perceive things around us to have a set location, rather than move chaotically.

Decision Making

Having recognised coherent information from the stimuli reaching our senses, a course of action has to be decided upon. In other words decision making occurs.

> Decision making is the generation of alternative courses of action based on available information, knowledge, prior experience, expectation, context, goals, etc. and selecting one preferred option. It is also described as thinking, problem solving and judgement.

This may range from deciding to do nothing, to deciding to act immediately in a very specific manner. A fire alarm bell, for instance, may trigger a well-trained sequence of actions without further thought (i.e. evacuate); alternatively, an unfamiliar siren may require further information to be gathered before an appropriate course of action can be initiated.

We are not usually fully aware of the processes and information which we use to make a decision. Tools can be used to assist the process of making a decision. For instance, in aircraft maintenance engineering, many documents (e.g. maintenance manuals, fault diagnosis manuals), and procedures are available to supplement the basic decision making skills of the individual. Thus, good decisions are based on knowledge supplemented by written information and procedures, analysis of observed symptoms, performance indications, etc. It can be dangerous to believe that existing knowledge and prior experience will always be sufficient in every situation as will be shown in the section entitled 'Information Processing Limitations'.

Finally, once a decision has been made, an appropriate action can be carried out. Our senses receive feedback of this and its result. This helps to improve knowledge and refine future judgement by learning from experience.

Memory

Memory is critical to our ability to act consistently and to learn new things. Without memory, we could not capture a 'stream' of information reaching our senses, or draw on past experience and apply this knowledge when making decisions.

> Memory can be considered to be the storage and retention of information, experiences and knowledge, as well as the ability to retrieve this information.

Memory depends on three processes:

- registration - the input of information into memory;
- storage - the retention of information;
- retrieval - the recovery of stored information.

It is possible to distinguish between three forms of memory:

a. ultra short-term memory (or sensory storage);
b. short term memory (often referred to as working memory)
c. long term memory.

Ultra short-term memory has already been described when examining the role of sensory stores. It has a duration of up to 2 seconds (depending on the sense) and is used as a buffer, giving us time to attend to sensory input.

Short term memory receives a proportion of the information received into sensory stores, and allows us to store information long enough to use it (hence the idea of 'working memory'). It can store only a relatively small amount of information at one time, i.e. 5 to 9 (often referred to as 7 ±2) items of information, for a short duration, typically 10 to 20 seconds. As the following example shows, capacity of short term memory can be enhanced by splitting information in to 'chunks' (a group of related items).

> A telephone number, e.g. 01222555234, can be stored as 11 discrete digits, in which case it is unlikely to be remembered. Alternatively, it can be stored in chunks of related information, e.g. in the UK, 01222 may be stored as one chunk, 555 as another, and 234 as another, using only 3 chunks and therefore, more likely to be remembered. In mainland Europe, the same telephone number would probably be stored as 01 22 25 55 23 4, using 6 chunks. The size of the chunk will be determined by the individual's familiarity with the information (based on prior experience and context), thus in this example, a person from the UK might recognise 0208 as the code for London, but a person from mainland Europe might not.

The duration of short term memory can be extended through rehearsal (mental repetition of the information) or encoding the information in some meaningful manner (e.g. associating it with something as in the example above).

The capacity of long-term memory appears to be unlimited. It is used to store information that is not currently being used, including:

- knowledge of the physical world and objects within it and how these behave;
- personal experiences;
- beliefs about people, social norms, values, etc.;
- motor programmes, problem solving skills and plans for achieving various activities;
- abilities, such as language comprehension.

Information in long-term memory can be divided into two types: (i) semantic and (ii) episodic. Semantic memory refers to our store of general, factual knowledge about the world, such as concepts, rules, one's own language, etc. It is information that is not tied to where and when the knowledge was originally acquired. Episodic memory refers to memory of specific events, such as our past experiences (including people, events and objects). We can usually place these things within a certain context. It is believed that episodic memory is heavily influenced by a person's expectations of what should have happened, thus two people's recollection of the same event can differ.

Motor Programmes

If a task is performed often enough, it may eventually become automatic and the required skills and actions are stored in long term memory. These are known as motor programmes and are ingrained routines that have been established through practice. The use of a motor programme reduces the load on the central decision maker. An often quoted example is that of driving a car: at first, each individual action such as gear changing is demanding, but eventually the separate actions are combined into a motor programme and can be performed with little or no awareness. These motor programmes allow us to carry out simultaneous activities, such as having a conversation whilst driving.

Situation Awareness

Although not shown explicitly in Figure is given before (i.e. functional model of human information processing), the process of attention, perception and judgement should result in awareness of the current situation.

> Situation awareness is the synthesis of an accurate and up-to-date 'mental model' of one's environment and state, and the ability to use this to make predictions of possible future states.

Situation awareness has traditionally been used in the context of the flight deck to describe the pilot's awareness of what is going on around him, e.g. where he is geographically, his orientation in space, what mode the aircraft is in, etc. In the maintenance engineering context, it refers to[1]:

- the perception of important elements, e.g. seeing loose bolts or missing parts, hearing information passed verbally;
- the comprehension of their meaning, e.g. why is it like this? Is this how it should be?
- the projection of their status into the future, e.g. future effects on safety, schedule, airworthiness.

> An example is an engineer seeing (or perceiving) blue streaks on the fuselage. His comprehension may be that the lavatory fill cap could be missing or the drainline leaking. If his situation awareness is good, he may appreciate that such a leak could allow blue water to freeze, leading to airframe or engine damage.

As with decision making, feedback improves situation awareness by informing us of the accuracy of our mental models and their predictive power. The ability to project system status backward, to determine what events may have led to an observed system state, is also very important in aircraft maintenance engineering, as it allows effective fault finding and diagnostic behaviour.

Situation awareness for the aircraft maintenance engineer can be summarised as:

- the status of the system the engineer is working on;
- the relationship between the reported defect and the intended rectification;
- the possible effect on this work on other systems;
- the effect of this work on that being done by others and the effect of their work on this work.

This suggests that in aircraft maintenance engineering, the entire team needs to have situation awareness - not just of what they are doing individually, but of their colleagues' activities as well.

Information Processing Limitations

The basic elements of human information processing have now been explored. It is important to appreciate that these elements have limitations. As a consequence, the aircraft engineer, like other skilled professionals, requires support such as reference to written material (e.g. manuals).

Attention and Perception

A proportion of 'sensed' data may be lost without being 'perceived'. An example with which most people are familiar is that of failing to perceive something which someone has said to you, when you are concentrating on something else, even though the words would have been received at the ear without any problem. The other side of the coin is the ability of the information processing system to perceive something (such as a picture, sentence, concept, etc.) even though some of the data may be missing. The danger, however, is that people can fill in the gaps with information from their own store of knowledge or experience, and this may lead to the wrong conclusion being drawn.

Once we have formed a mental model of a situation, we often seek information which will confirm this model and, not consciously, reject information which suggests that this model is incorrect.

There are many well-known visual 'illusions' which illustrate the limits of human perception. Figure shows how the perceptual system can be misled into believing that one line is longer than the other, even though a ruler will confirm that they are exactly the same.

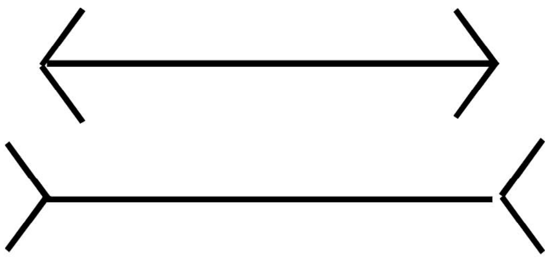


Fig. The Muller-Lyer Illusion

Figure illustrates that we can perceive the same thing quite differently (i.e. the letter "B" or the number "13"). This shows the influence of context on our information processing.

Fig. The importance of context.

In aviation maintenance it is often necessary to consult documents with which the engineer can become very familiar. It is possible that an engineer can scan a document and fail to notice that subtle changes have been made. He sees only what he expects to see (expectation). To illustrate how our eyes can deceive us when quickly scanning a sentence, read quickly the sentence below in Figure.

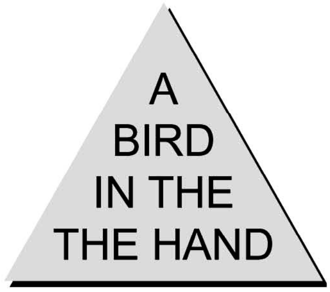


Fig. The effects of expectation

At first, most people tend to notice nothing wrong with the sentence. Our perceptual system sub-consciously rejects the additional "THE".

As an illustration of how expectation, can affect our judgement, the same video of a car accident was shown to two groups of subjects. One group were told in advance that they were to be shown a video of a car crash; the other were told that the car had been involved in a 'bump'. Both groups were asked to judge the speed at which the vehicles had collided. The first group assessed the speed as significantly higher than the second group.

Expectation can also affect our memory of events. The study outlined above was extended such that subjects were asked, a week later, whether they recalled seeing glass on the road after the collision. (There was no glass). The group who had been told that they would see a crash, recalled seeing glass; the other group recalled seeing no glass.

Decision Making, Memory, and Motor Programmes

a. Attention and perception shortcomings can clearly impinge on decision making. Perceiving something incorrectly may mean that an incorrect decision is made, resulting in an inappropriate action. Figure 8 also shows the dependence on memory to make decisions. It was explained earlier that sensory and short-term memory have limited capacity, both in terms of capacity and duration. It is also important to bear in mind that human memory is fallible, so that information:
   - may not be stored;
   - may be stored incorrectly;
   - may be difficult to retrieve.

All these may be referred to as forgetting, which occurs when information is unavailable (not stored in the first place) or inaccessible (cannot be retrieved). Information in short-term memory is particularly susceptible to interference, an example of which would be trying to remember a part number whilst trying to recall a telephone number.

It is generally better to use manuals and temporary aides-memoires rather than to rely upon memory, even in circumstances where the information to be remembered or recalled is relatively simple. For instance, an aircraft maintenance engineer may think that he will remember a torque setting without writing it down, but between consulting the manual and walking to the aircraft (possibly stopping to talk to someone on the way), he may forget the setting or confuse it (possibly with a different torque setting appropriate to a similar task with which he is more familiar). Additionally, if unsure of the accuracy of memorised information, an aircraft maintenance engineer should seek to check it, even if this means going elsewhere to do so. Noting something down temporarily can avoid the risk of forgetting or confusing information. However, the use of a personal note book to capture such information on a permanent basis can be dangerous, as the information in it may become out-of-date.

In the B737 double engine oil loss incident, the AAIB report stated:

> "Once the Controller and fitter had got to T2 and found that this supportive material [Task Cards and AMM extracts] was not available in the workpack, they would have had to return to Base Engineering or to have gone over to the Line Maintenance office to get it. It would be, in some measure, understandable for them to have a reluctance to recross the exposed apron area on a winter's night to obtain a description of what they were fairly confident they knew anyway. However, during the course of the night, both of them had occasion to return to the Base Maintenance hangar a number of times before the task had been completed. Either could, therefore, have referred to or even drawn the task descriptive papers before the job was signed off. The question that should be addressed, therefore, is whether there might be any factors other than overconfidence in their memories, bad judgement or idleness which would dispose them to pass up these opportunities to refresh their memories on the proper and complete procedures."

CLAUSTROPHOBIA, PHYSICAL ACCESS AND FEAR OF HEIGHTS

Although not peculiar to aircraft maintenance engineering, working in restricted space and at heights is a feature of this trade. Problems associated with physical access are not uncommon. Maintenance engineers and technicians often have to access, and work in, very small spaces (e.g. in fuel tanks), cramped conditions (such as beneath flight instrument panels, around rudder pedals), elevated locations (on cherry-pickers or staging), sometimes in uncomfortable climatic or environmental conditions (heat, cold, wind, rain, noise). This can be aggravated by aspects such as poor lighting or having to wear breathing apparatus.

Human Performance and Sleep

Sleep deprivation means an overall loss of sleep, while sleep distrurbance refers only to the disruption of the normal sleeping schedule. In long-range flying, sleep disturbance is virtually inevitable as aircraft fly round the clock and the irregular working periods break into the normal body nights. Avoidance of sleep deprivation and minimizing sleep disturbance must remain the objective of those planning such activities.

It is generally thought that the main problem facing crew members is that of disturbance but it is clear differences in tolerances to the stress of long-range flying and generalisations cannot be made such sleep loss cannot be ignored.

Much research has been done on the effect of disturbed sleep. Vigilance and adversely affected, for example, simply by displacing the sleeping period by two to four hours.
It is difficult to demonstrate consistent results in studies using partial sleep loss due to the almost limitless variations in conditions surrounding the case and a complex interaction of the task, the situation and personal factors. However, clear reduction in performance of certain tasks has been shown following loss decreased progressively during the experiment .

Even small periods of sleep deprivation have been shown to affect performance. In one experiment it was demonstrated that more signals were missed and there were occasional lapses in performance following a sleep loss of five hours on one night or two and a half hours on two consecutive nights.

In fact, lapses and inconsistency in performance are characteristics of the sleep-deprived person. An analogy may be that he is not like an aircraft which performs perfectly until it runs out of fuel and then suddenly stopes flying or lide a mechanical toy which slows down steadily and gradually before it finally ceases to perform. He is more like an old car which runs, falter,s runs again, and so on; one moment it works fine, the next it misfires and its performance plummets dramatically only to recover again.

The performance decrement resulting from sleep deprivation increases with altitudee and is further increased with higher work load. This has a particular significance in long-range flying which is typified by sleep disturbance and deprivation and high cruise altitudes.

Laboratory studies often suffer from some lack of credibility when viewed from industry and this was mentioned earlier relative to drug research. Sometime the task and the environment appear to be too remote from the real working situation. Frequently the test subjects, usually as a result of economic constraint, are not representative of the people actually involved with the job in industry in terms of age, skill or motivation; they are often young students, nurses or military personnel. Sometimes they appear too few to encompass the range of individual differences which can reasonably be expected to be encountered operationally.

In studying sleep and circadian rhythm problems, subjective and objective data have been obtained in numerous studies in the fields, covering world routes such as Tokyo – Moscow, Brussels – Rio, Dublin – New York, Amesterdam – New York and London – Hong Kong. In all such work an almost insurmountable difficulty is faced in trying to control tightly the many variables involved in the operation. This does not mean that the work is without value, only that interpretation calls for much care.

One study reported in 1985 which was sponsored by the CAA in the UK, attempted to avoid many of the pitfalls noted here, The study investigated the effect of one night’s sleep loss on the performance of 16 pilots in actual flight, in a flight simulator and in a variety of laboratory tests. This comprehensive programme demonstrated that flying performance deteriorates considerably with sleep deprivation. The performance loss was somewhat greater in the simulator than in the actual aircraft, possibly due to motivational factors. All the laboratory tests (with one exception) also revealed a performance decrement. There appeared to be some correlation between many of the experimental measures and the introversion/ extraversion dimension of personality. The findings of this important study suggested that loss of sleep was profoundly disruptive of the performance of pilots. The study provided some scientific and objective data to support the numerous subjective confidential reports from pilots submitted to the ASRS and CHIRP centres relating reduced flying performance to disturbance in the walking/sleeping cycle, as well as earlier surveys.

In addition to the effect of sleep loss on the performance of specific tasks it has been shown that subjective attitudes are also affected; mood, appearance and beahviour all appear to suffer. Even small amounts of sleep loss seem to affect motivation. As motivation represents the difference between what a person can and will do in particular set of circumstances, this has a direct relevance to performance.

The effect of sleep loss is task-dependent. The more complex task tends to suffer more than the simple task but the more interesting task suffers less than the monotonous or duller task. Vigilance and monitoring tasks, increasing with the trend towards automation of flight deck activities in modern aircraft, are therefore particularly vulnerable to sleep loss and this fact should be an important consideration in the design of equipment and procedures.

One of the most dangerous aspects of performance degradation with sleep loss is that a person is unlikely to be aware of the manner and extent of his deteriorating performance. We might compare this lack of awareness of performance deterioration with hypoxia and alcohol consumption. Subjective feelings of sleepiness correlate well with periods of reduced performance and so a recognition of these feelings can provide a warning signal.

Research has been conducted to determine the level of performance which can be expected just after awakening. An early study done in connection with the US space programme showed that performance of a number of tasks was reduced for several minutes after waking. This and other studies showed the major performance loss to occur within the first three to four minutes with a measurable loss, depending on the task , extending for some minutes longer. Work in France has shown it possible to measure performance decrement as much as 20 minutes after waking. Later work suggested that performance after waking may be better if the person expects to stay awake than if he is to be allowed to return to sleep after the test. This again suggested the importance of motivational factors in task performance. Careful attention to this sleep inertia effect must be given when considering whether to permit staff engaged in critical activities to nap at their duty station.

Physical Access and Claustrophobia

There are many circumstances where people may experience various levels of physical or psychological discomfort when in an enclosed or small space, which is generally considered to be quite normal. When this discomfort becomes extreme, it is known as claustrophobia.

Claustrophobia can be defined as abnormal fear of being in an enclosed space.

It is quite possible that susceptibility to claustrophobia is not apparent at the start of employment. It may come about for the first time because of an incident when working within a confined space, e.g. panic if unable to extricate oneself from a fuel tank. If an engineer suffers an attack of claustrophobia, they should make their colleagues and supervisors aware so that if tasks likely to generate claustrophobia cannot be avoided, at least colleagues may be able to assist in extricating the engineer from the confined space quickly, and sympathetically. Engineers should work in a team and assist one another if necessary, making allowances for the fact that people come in all shapes and sizes and that it may be easier for one person to access a space, than another. However, this should not be used as an excuse for an engineer who has put on weight, to excuse himself from jobs which he would previously have been able to do with greater ease!

Fear of Heights

Working at significant heights can also be a problem for some aircraft maintenance engineers, especially when doing 'crown' inspections (top of fuselage, etc.). Some engineers may be quite at ease in situations like these whereas others may be so uncomfortable that they are far more concerned about the height, and holding on to the access equipment, than they are about the job in hand. In such situations, it is very important that appropriate use is made of harnesses and safety ropes. These will not necessarily remove the fear of heights, but will certainly help to reassure the engineer and allow him to concentrate on the task in hand. The FAA's hfskyway website provides practical guidance to access equipment when working at height. Ultimately, if an engineer finds working high up brings on phobic symptoms (such as severe anxiety and panic), they should avoid such situations for safety's sake. However, as with claustrophobia, support from team members can be helpful.

Shortly before the Aloha accident, during maintenance, the inspector needed ropes attached to the rafters of the hangar to prevent falling from the aircraft when it was necessary to inspect rivet lines on top of the fuselage. Although unavoidable, this would not have been conducive to ensuring that the inspection was carried out meticulously (nor was it, as the subsequent accident investigation revealed). The NTSB investigation report stated:

"Inspection of the rivets required inspectors to climb on scaffolding and move along the upper fuselage carrying a bright light with them; in the case of an eddy current inspection, the inspectors needed a probe, a meter, and a light. At times, the inspector needed ropes attached to the rafters of the hangar to prevent falling from the airplane when it was necessary to inspect rivet lines on top of the fuselage. Even if the temperatures were comfortable and the lighting was good, the task of examining the area around one rivet after another for signs of minute cracks while standing on scaffolding or on top of the fuselage is very tedious. After examining more and more rivets and finding no cracks, it is natural to begin to expect that cracks will not be found."

Please refer to Photograph below.

Managers and supervisors should attempt to make the job as comfortable and secure as reasonably possible (e.g. providing knee pad rests, ensuring that staging does not wobble, providing ventilation in enclosed spaces, etc.) and allow for frequent breaks if practicable.

ENVIRONMENTAL TOLERANCES

Stress

Stress was defined by Hans Selye as a nonspecific response of the body to any demand made upon it. This concept assumes that some "normal" or "optimal" state of bodily functions exists and that stressors (i.e. stimuli or situations that stress the person) cause a deviation from this normal state. Stress generally represents an attempt by the body to adapt to or cope with situational demands and to return to the normal state as soon as possible. It can be differentiated into life stress, environmental stress and cognitive stress. Life stress is produced by adverse occurrences in a person's life (e.g. divorce, family bereavement). Environmental and cognitive stress are more closely related to the specific activities which humans undertake.

Environmental stress includes the effects of factors such as temperature, humidity, noise, pressure, illumination and vibration. Cognitive stress refers to the cognitive (or mental) demands of the task itself. Countermeasures to minimize the potential untoward effects of environmental and cognitive stress are within the purview of ergonomics.

Stress has traditionally been linked to arousal, which refers to nonspecific changes (e.g. hormonal and brain activities) in the body to external stimulation. In general, stress and arousal levels are positively related — that is to say, high stress is associated with high arousal level. The Yerkes-Dodson law depicted in Figure below relates performance and arousal. It shows that people's performance levels increase according to the degree of arousal to a point beyond which any additional boost in arousal will generally be detrimental to task performance. The over-all shape of the relationship curve remains the same across different tasks, but the exact shape and location of each curve vary according to task complexity.

Stress is related to a person's ability to pay attention to cues in the environment. In a simple situation with few cues, stress will improve performance by causing attention to be focused. In a complex situation with many cues, stress will decrease performance because many cues will go unheeded. This explains many accidents in which crew under stress "locked on" to some particular instrument which was defective (even if the instrument was of minor importance), failing to attend to other pieces of crucial information.

Noise

Noise is defined as any unwanted sound. There are two important aspects of noise which must be considered: the sources of noise, and the physiological and psychological effects on the person exposed to it. Noise affects a person in many ways depending on whether it is expected, whether it makes a task more difficult, and whether the person is relaxed or alert.

Major sources of noise in fixed-wing aircraft include the engines, the air conditioning, pressurization and hydraulic systems, and boundary layer turbulence. Inside the aircraft, noise is louder near the sides of the fuselage than at the centre. Noise level in the cockpit is easily changed by the interaction of the airflow with the fuselage surface. Soundproofing will reduce noise, but it will increase aircraft weight as well. This has many undesirable effects such as increases in fuel cost. Design improvement to reduce noise at its source would be a better alternative. For example, removing the windshield wipers in one particular large jet transport reduced the flight deck noise level by 2 dB.

The most important pathogenic effect of noise, impaired hearing, has already been discussed below in topic Basic Facts about Ergonomics. Other physiological effects include changes in blood pressure and heart rate, headaches, tiredness and gastrointestinal problems such as ulcers. In the past, prolonged monitoring of high-frequency (HF) radio represented a significant exposure to noise. This has been alleviated by the introduction of selective calling (SELCAL). Technological progress in communications — as well as in other areas — will certainly provide new improvements in hearing protection. The fact remains, however, that crew members who are exposed to intense aircraft noise over a long period of time can be expected to suffer hearing loss in addition to the natural loss through ageing.

Noise affects performance by interfering with the detection and understanding of task-related signals or speech. It interferes with verbal communication by affecting the signal-to-noise ratio and by decreasing speech intelligibility. It further affects verbal communication by impairing hearing.

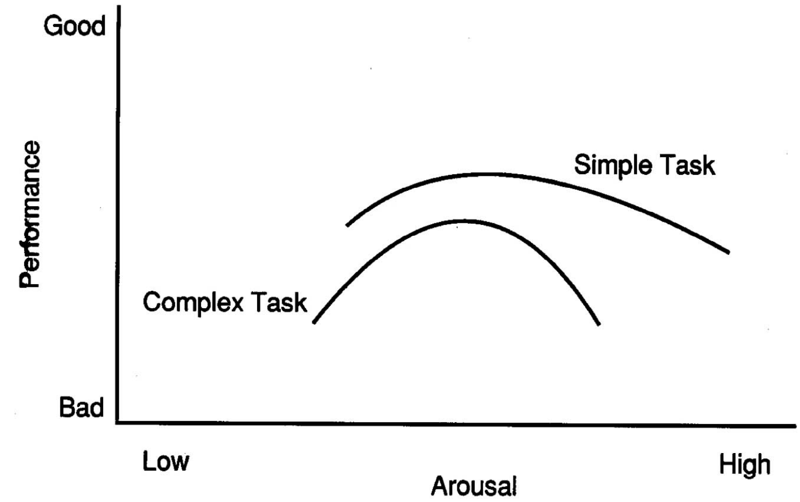


Fig. The Yerkes-Dodson law relating performance and arousal

> A twin-engine Beechcraft B-99 crashed during an instrument approach to the Shenandoah Valley Airport, Virginia, in September 1985. The NTSB concluded that among the factors which contributed to the flightcrew's errors was "… intracockpit communications difficulties associated with high ambient noise levels in the airplane …"

Because it is annoying for most people, noise can have an impact on psychological conditions. On the flight deck, this annoyance is compounded by the problems noise generates in communication. This may result in frustration and anxiety over the need to repeat messages or to understand them. This in turn may increase workload and fatigue. While it is the ergonomist's task to try to minimize noise through design and by providing hearing protection, crew members should be aware of the insidious effects of noise and the damage it can provoke, and of methods to reduce noise levels or to protect oneself from its detrimental effects.

Temperature

Temperature extremes are one of the most common environmental stressors. Since humans are comfortable only over a narrow band of temperatures, it is necessary to know how well they function at different temperature levels before remedial measures can be derived. Questions about air-conditioning requirements and human performance under heat or cold stress should be answered and taken into account during system design. Cabin environmental control systems are the principal means for controlling the internal aircraft environment.

Humans generate heat while performing mechanical work, and to a lesser extent, when resting. The excess heat is transferred to the environment, primarily by perspiration and sweating, in order to maintain a relatively constant body temperature of 37 degrees Celsius (C). The success of body temperature regulation depends on various factors: ambient temperature, humidity, and air velocity. If body temperature increases by more than 2 degrees C, physiological efficiency will be impaired.

> In February 1984, a Cessna T-303 crashed during landing at Hickory, North Carolina, U.S.A. The aircraft overran the runway and collided with a fence. The pilot was hampered by an inoperative heater and a dome light that could not be turned off.

The physiological effects of ambient temperature extremes are well known, but the effects of heat stress on human performance are more complex. It is generally accepted that excessive heat will cause performance decrement, but there is little agreement regarding how much decrement will take place, or how long it will take to occur. People can withstand exposure to excessive temperatures for only a short period of time before measurable degradation sets in. Acclimatization prolongs this period. In non-acclimatized persons, degradation appears when the ambient temperature exceeds 30 degrees C, the relative humidity is high, and exposure exceeds three hours. Obviously, clothing and physical activity level play important roles, too.

When exposed to cold, the body attempts to maintain its core temperature by shivering and restricting blood flow to the body surface. Body temperatures below 35 degrees C are dangerous. Consciousness becomes clouded at 34 degrees C, unconsciousness follows around 30 degrees C, cardiac irregularities are usual between 30 and 28 degrees C, and death is imminent. Although humidity is not a factor, air velocity is important; as a result, wind chill indices are increasingly being provided in weather reports. (Wind chill is not a psychological effect — it effectively lowers body temperature.) Cold increases both reaction and movement time, and manual dexterity begins to deteriorate when hand-skin temperature falls below 18 degrees C.

Humidity

Humidity may become an issue with high-altitude jet transport aircraft because of the low relative humidity at their operational altitudes. The discomfort arising from low relative humidity may not imply physical indisposition. Over-all dehydration can be prevented with adequate fluid intake. Diuretics like coffee or tea should be avoided. The installation of humidifiers on aircraft could raise cabin/cockpit humidity, but there are potential problems such as weight penalty, condensation and mineral contaminations that the designer must consider.

Pressure

Cabin pressurization eliminates many problems associated with high altitude flying, but it introduces other potential problems, the most important being the risk of a rapid decompression. The time of useful consciousness (TUC) following a rapid decompression depends on aircraft altitude, the rate at which pressure falls, and the level of physical activity of the individual at the time of the event. At typical jet transport aircraft altitudes (35 000 feet) TUC will vary between 33 and 54 seconds. Those average values can be expected to drop by a half at 40 000 feet. This emphasizes the importance of immediate availability of supplemental oxygen to crew members.

The technical reliability of automatic delivery systems, as well as the design of certain types of flight crew quick-donning masks have sometimes been sub-optimal. It should be borne in mind that oxygen systems will be used in conditions accompanied by anxiety and other stressors, and simplicity of use and reliability are of utmost importance.

Illumination

The nature and quantity of cockpit illumination required for a certain task may vary considerably. Factors of importance are the speed and accuracy with which the displays must be read, the ambient illumination, other light sources (in particular, sunshine), and the presence of glare. Glare is defined as a condition of vision where there is discomfort or a reduction in the ability to see significant objects, or both, due to an unsuitable distribution or range of luminance (i.e. density of light, or light intensity per unit projected area) or to extreme contrasts in space or time.

Glare is an important aspect of the quality of the illuminated environment. It can be caused by bright light sources or light reflection off environmental surfaces. Glare may produce discomfort or annoyance, and may interfere with visual performance. The type of reflection off surfaces depends on the properties of the surface (e.g. whether it is polished, rough or matted). Some evidence suggests that there is an element of subjectivity in tolerance to glare. The most effective techniques for reducing glare include blocking the glare surface or placing supplementary lighting to offset the effects of glare.

Vibration

Vibration is any form of oscillating motion that changes its magnitude of displacement periodically with reference to a point, and it is a widespread physical phenomenon. The movement of pistons within the cylinders of engines or the disturbances generated in aircraft flying through turbulent air are forms of vibration which can be transmitted to humans. Vibration is generally transmitted through direct contact between the body and the vibrating structure, and it can have potentially harmful effects.

Vibration is of operational significance in aviation because it may impair visual acuity, interfere with neuromuscular control and lead to fatigue. Although better than before, high levels of vibration can still be encountered in helicopters as well as in fixed-wing aircraft during low-level flight.

Protection against vibration can be provided by attention to its source, by modification of the transmission pathway or by the alteration of the dynamic properties of the aircraft body. Reduction of vibration emanating from aircraft engines is a primary task for design and maintenance engineers. The installation of devices called dynamic vibration absorbers has reduced vibration levels on helicopters. Another ergonomic approach is by means of vibration isolation of the flight crew seats.

BASIC FACTS ABOUT ERGONOMICS

Introduction

While in many countries the terms ergonomics and Human Factors are used interchangeably, there is a small difference in emphasis. Human Factors has acquired a wider meaning, including aspects of human performance and system interfaces which are not generally considered in the mainstream of ergonomics. Chapter 1 proposes that the two terms be considered synonymous, to preclude dwelling on academic or semantic considerations and to avoid confusion; however, it indicates that the term ergonomics is used in many States to refer strictly to the study of human-machine system design issues. From this perspective, ergonomics is the study of the principles of interaction between human and equipment, for the purpose of applying them in design and operations. Ergonomics studies human attributes, determining what requirements in hardware and software result from the characteristics of the activities involved. It attempts to solve the problem of adapting technology and working conditions to humans. Throughout this chapter, this latter concept of ergonomics has been adopted, and as such, it is clearly differentiated from Human Factors.

A systems approach to safety

Safety in aviation through design can best be achieved following a system approach strategy. A system approach is a way of breaking down the “real world” into identifiable components, and looking at how these components interact and integrate. The Liveware-Hardware interface in the SHEL model, introduced in Chapter 1, can be seen as a human-machine system, comprising people and machines interacting in an environment in order to achieve a set of system goals. Ergonomics will try to optimize the interaction between people and machines in the system (the L-H interface), while taking into consideration the characteristics of all system components (e.g. the environment as well as the software).

A simplified representation of the person-machine system is shown in Figure below. The machine component is displayed on the right. Displays (e.g. visual and auditory) inform the human about the status of the internal system or about conditions external to the system, while controls allow the human to effect changes in the system status. The human component of the system is shown on the left side of Figure. Information displayed must be perceived and processed by the human, and then conscious decisions may be made. Motor responses may be sent to effect changes in control settings. The line depicted in Figure separating the machine and human represents the human-machine interface. Information travels through this interface in both directions; ergonomics is very much concerned with getting the information across this interface, and the ergonomist must ensure that displays and controls are compatible with human capabilities and task needs.

System goals must be defined before a person-machine system can be specified and designed. These goals, together with the identified operational constraints, spell out the conditions within which the person-machine system will function. Operation of the system outside this set of conditions may lead to unsafe conditions.

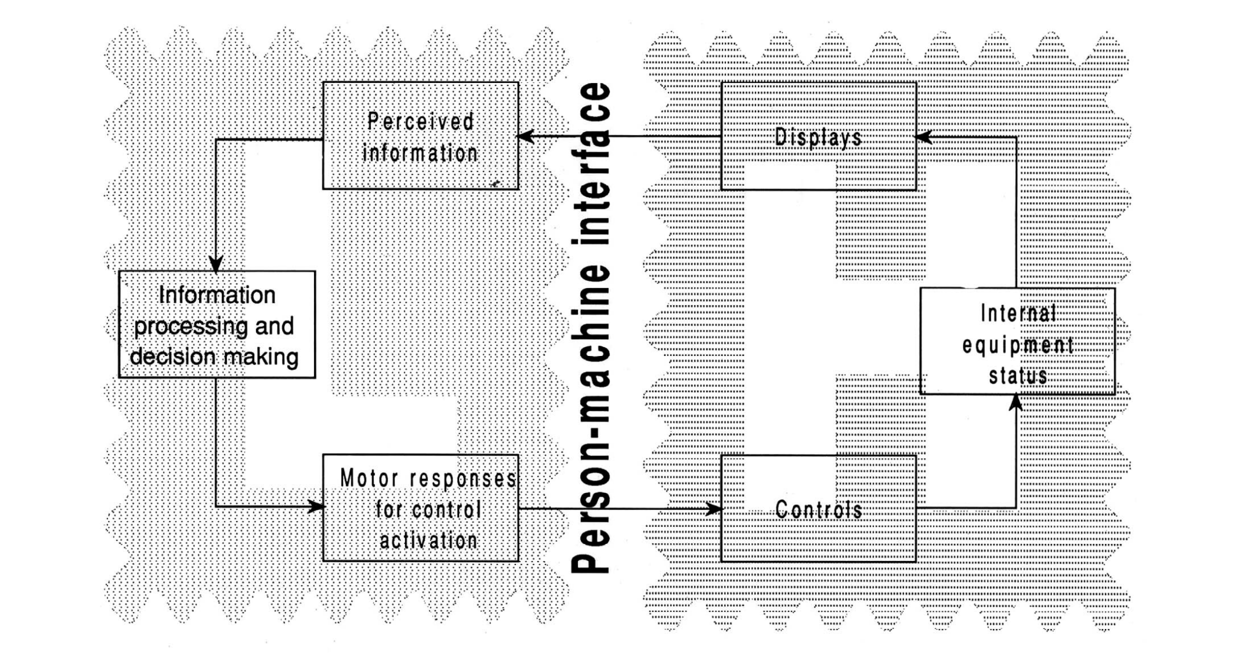


Fig. Representation of a person-system machine

Another important task of the ergonomist is the allocation of functions and tasks to the human and machine components. The system design team (including the ergonomist) decides what functions should be given to the hardware and software and to the human, based on considerations such as human characteristics, task needs, workload, costs, training requirements, and technologies available. Functions allocated inappropriately may jeopardize system effectiveness and safety. The tendency to compare human and machine, in terms of the functions for which humans are superior to machines vis-à-vis those for which machines are superior to humans, should not be allowed to lead to a simplistic allocation of functions entirely to the human or the machine. Humans and machines should be complementary in the accomplishment of tasks. Furthermore, this complementarity should be designed with adequate flexibility so that function allocation can be adapted to various operational situations (from routine flight to emergencies).

The ergonomist must proceed systematically in order to achieve the desired system goals. The following set of example questions illustrates how an ergonomist may proceed when designing systems:

- What inputs and outputs must be provided to satisfy systems goals?
- What operations are required to produce system outputs?
- What functions should the person perform in the system?
- What are the training and skills requirements for the human operators?
- Are the tasks demanded by the system compatible with human capabilities?
- What equipment interfaces does the human need to perform the job?

A system designed without proper regard to these questions may end up like the one shown in Figure below.

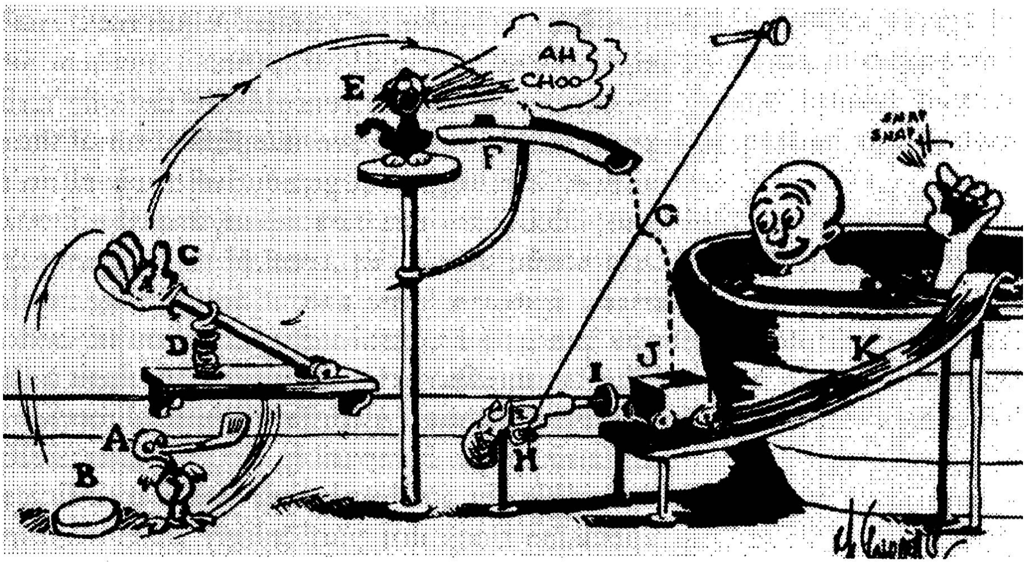


Fig. If the soap falls out of the bathtub, try this!

Human error is a very complex issue. This term must be used judiciously, as it may be perceived as a loaded term implying blame. Moreover, the word "error" implies deviation from a definable correct or appropriate behaviour. In fact, appropriate behaviour is often difficult to define, and human error is increasingly being postulated as a symptom of deficiencies in equipment design or system performance rather than a cause in itself. Despite these cautions, human error continues to be an important concept in understanding the nature of and the factors affecting human behaviour, and various classifications of human errors have been proposed by different authors.

To minimize human error, one must first understand its nature. There are basic concepts associated with the nature of human error: the origins and frequencies of errors can be fundamentally different; and the consequences of errors can also be significantly different. While some errors may be due to carelessness, negligence or poor judgement, many are induced by poorly designed equipment or may result from the normal reaction of a person to a stressful situation. Errors due to poor equipment design or stressful situations are likely to be repeated and can be remedied through the practice of ergonomics.

Each of the interfaces in the SHEL model has a potential for error where there is a mismatch between its components. For example:

- The Liveware-Hardware interface is a frequent source of error: knobs and levers which are poorly located or improperly coded create mismatches at this interface.Chapter 4. Ergonomics 1-4-5
- In the Liveware-Software interface, delays and errors may occur while seeking vital information from confusing, misleading or excessively cluttered documentation and charts. Problems can also be related to information presentation and computer software design.
- Errors associated with the Liveware-Environment interface are caused by environmental factors such as noise, heat, lighting, air quality and vibration and by the disturbance of biological rhythms.

- In the Liveware-Liveware interface, the focus is on the interaction between people because this process may affect crew and system effectiveness. This interaction also includes leadership and command, shortcomings in which may reduce operational efficiency and cause misunderstanding and errors.

Considerations which prevent errors such as these are in the mainstream of ergonomics.

The control of human error requires two different approaches. First, it is desirable to minimize the occurrence of errors (total elimination of human error is not a realistic goal, since errors are a normal part of human behaviour). For example, errors may be reduced by ensuring a high level of staff competence; by designing controls and displays so that they match human characteristics; by providing proper checklists, procedures, manuals, maps and charts; by controlling noise, vibration, temperature extremes and other stressful conditions; and by providing training and awareness programmes aimed at increasing co-operation and communication among crew members. The second approach in the control of human error involves minimizing the impact or consequences of errors by providing safety buffers such as cross-monitoring, crew co-operation and fail-safe equipment design.

■■■

CHAPTER 3
SOCIAL PSYCHOLOGY

The previous chapter considered the abilities and limitations of the individual. This chapter draws together issues relating to the social context in which the aircraft maintenance engineer works. This includes the organisation in which he works and how responsibilities may be delegated, motivation, and aspects of team working, supervision and leadership.

THE SOCIAL ENVIRONMENT

Aircraft maintenance engineers work within a "system". As indicated in Figure, there are various factors within this system that impinge on the aircraft maintenance engineer, ranging from his knowledge, skills and abilities, the environment in which he works is discussed latter in this book, to the culture of the organisation for which he works. Even beyond the actual company he works for, the regulatory requirements laid down for his trade clearly impact on his behaviour. As will be seen latter in this book on Human Error, all aspects of this system may contribute towards errors that the engineer might make.

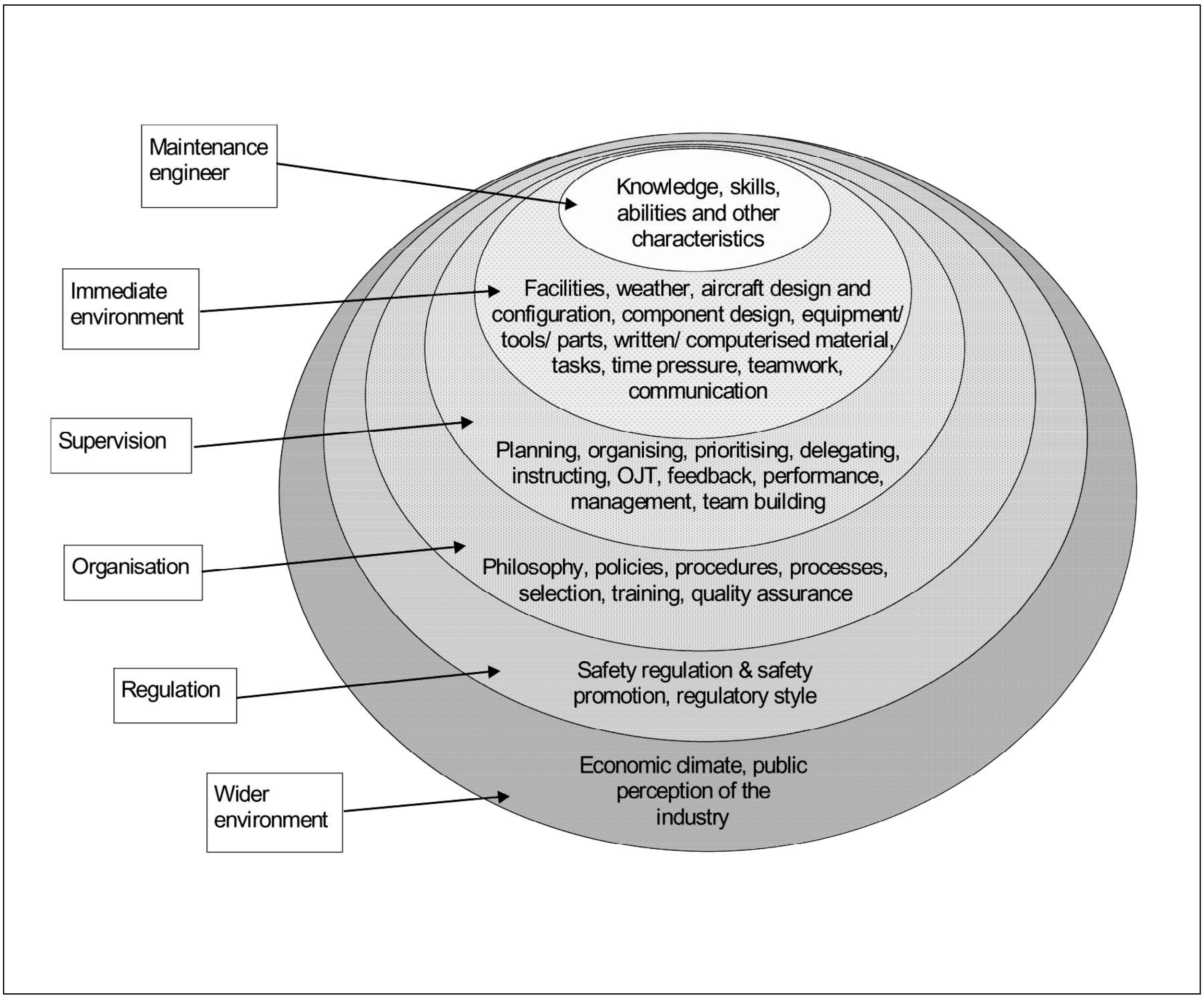


Fig. The maintenance system

The vast majority of aircraft maintenance engineers work for a company, either directly, or as contract staff. It is important to understand how the organisation in which the engineer works might influence him. Every organisation or company employing aircraft maintenance engineers will have different "ways of doing things". This is called the organisational culture. They will have their own company philosophy, policies, procedures, selection and training criteria, and quality assurance methods.

The impact of the organisation may be positive or negative. Organisations may encourage their employees (both financially and with career incentives), and take notice of problems that their engineers encounter, attempting to learn from these and make changes where necessary or possible. On the negative side, the organisation may exert pressure on its engineers to get work done within certain timescales and within certain budgets. At times, individuals may feel that these conflict with their ability to sustain the quality of their work. These organisational stresses may lead to problems of poor industrial relations, high turnover of staff, increased absenteeism, and most importantly for the aviation industry, more incidents and accidents due to human error[1].

RESPONSIBILITY: INDIVIDUAL AND GROUP

Being an aircraft maintenance engineer is a responsible job. Clearly, the engineer plays a part in the safe and efficient passage of the travelling public when they use aircraft.

> If someone is considered responsible, they are liable to be called to account as being in charge or control of, or answerable for something.

Within aircraft maintenance, responsibility should be spread across all those who play a part in the activity. This ranges from the accountable manager who formulates policy, through management that set procedures, to supervisors, teams of engineers and individuals within those teams. Flight crew also play a part as they are responsible for carrying out preflight checks and walkarounds and highlighting aircraft faults to maintenance personnel.

Working as an Individual or as a Group

Traditionally, in the maintenance engineering environment, responsibility has been considered in terms of the individual rather than the group or team. This is historical, and has much to do with the manner in which engineers are licensed and the way in which work is certified. This has both advantages and disadvantages. The main advantage to individual responsibility is that an engineer understands clearly that one or more tasks have been assigned to him and it is his job to do them (it can also be a strong incentive to an engineer to do the work correctly knowing that he will be the one held responsible if something goes wrong). The main disadvantage of any emphasis upon personal responsibility, is that this may overlook the importance of working together as a cohesive team or group to achieve goals.

In practice, aircraft maintenance engineers are often assigned to groups or teams in the workplace. These may be shift teams, or smaller groups within a shift. A team may be made up of various engineering trades, or be structured around aircraft types or place of work (e.g. a particular hangar). Although distinct tasks may be assigned to individuals within a team, the responsibility for fulfilling overall goals would fall on the entire team. Team working is discussed in more detail in Section 6.

Individual Responsibility

All aircraft maintenance engineers are skilled individuals having undertaken considerable training. They work in a highly professional environment in the UK and generally have considerable pride in their work and its contribution to air safety.

All individuals, regardless of their role, grade or qualifications should work in a responsible manner. This includes not only Licensed Aircraft Engineers (LAEs), but non-licensed staff. Airworthiness Notice No. 3 details the certification responsibilities of LAEs. This document states that "The certifying engineer shall be responsible for ensuring that work is performed and recorded in a satisfactory manner...".

Please refer to Photograph below.

Likewise, non-certifying technicians also have a responsibility in the maintenance process. An organisation approved in accordance with JAR145 must establish the competence of every person, whether directly involved in hands-on maintenance or not. The CAA has previously ruled that an organisation can make provision on maintenance records or work sheets for the mechanic(s) involved to sign for the work. Whilst this is not the legally required certification under the requirements of ANO Article 12 or JAR 145.50, it provides the traceability to those who were involved in the job. The LAE is then responsible for any adjustment or functional test and the required maintenance records are satisfied before making the legal certification.

Group or Team Responsibility

Group responsibility has its advantages and disadvantages. The advantages are that each member of the group ought to feel responsible for the output of that group, not just their own output as an individual, and ought to work towards ensuring that the whole ‘product’ is safe. This may involve cross-checking others’ work (even when not strictly required), politely challenging others if you think that something is not quite right, etc.

The disadvantage of group responsibility is that it can potentially act against safety, with responsibility being devolved to such an extent that no-one feels personally responsible for safety (referred to as diffusion of responsibility). Here, an individual, on his own, may take action but, once placed within a group situation, he may not act if none of the other group members do so, each member of the group or team assuming that ‘someone else will do it’. This is expanded upon further in the section on peer pressure later in this book.

> Social psychologists have carried out experiments whereby a situation was contrived in which someone was apparently in distress, and noted who came to help. If a person was on their own, they were far more likely to help than if they were in a pair or group. In the group situation, each person felt that it was not solely his responsibility to act and assumed that someone else would do so.

Other recognised phenomena associated with group or team working and responsibility for decisions and actions which aircraft maintenance engineers should be aware of are:

Intergroup conflict in which situations evolve where a small group may act cohesively as a team, but rivalries may arise between this team and others (e.g. between engineers and planners, between shifts, between teams at different sites, etc.). This may have implications in terms of responsibility, with teams failing to share responsibility between them. This is particularly pertinent to change of responsibility at shift handovers, where members of the outgoing shift may feel no ‘moral’ responsibility for waiting for the incoming shift members to arrive and giving a verbal handover in support of the written information on the workcards or task sheets, whereas they might feel such responsibility when handing over tasks to others within their own shift.

Group polarisation is the tendency for groups to make decisions that are more extreme than the individual members’ initial positions. At times, group polarisation results in more cautious decisions. Alternatively, in other situations, a group may arrive at a course of action that is riskier than that which any individual member might pursue. This is known as risky shift. Another example of group polarisation is groupthink in which the desire of the group to reach unanimous agreement overrides any individual impulse to adopt proper, rational (and responsible) decision-making procedures.

Social loafing has been coined to reflect the tendency for some individuals to work less hard on a task when they believe others are working on it. In other words, they consider that their own efforts will be pooled with that of other group members and not seen in isolation.

Responsibility is an important issue in aircraft maintenance engineering, and ought to be addressed not only by licensing, regulations and procedures, but also by education and training, attempting to engender a culture of shared, but not diffused, responsibility.

MOTIVATION AND DE-MOTIVATION

Motivated behaviour is goal-directed, purposeful behaviour, and no human behaviour occurs without some kind of motivation underpinning it. In aircraft maintenance, engineers are trained to carry out the tasks within their remit. However, it is largely their motivation which determines what they actually do in any given situation. Thus, "motivation reflects the difference between what a person can do and what he will do".

Motivation can be thought of as a basic human drive that arouses, directs and sustains all human behaviour. Generally we say a person is motivated if he is taking action to achieve something.

Motivation is usually considered to be a positive rather than a negative force in that it stimulates one to achieve various things. However just because someone is motivated, this does not mean to say that they are doing the right thing. Many criminals are highly motivated for instance. Motivation is difficult to measure and predict. We are all motivated by different things, for example, an artist might strive over many months to complete a painting that he may never sell, whereas a businessman may forfeit all family life in pursuit of financial success.

With respect to aviation safety, being appropriately motivated is vital. Ideally, aircraft maintenance engineers ought to be motivated to work in a safe and efficient manner. However, many factors may cause conflicting motivations to override this ideal. For instance, the motivation of some financial bonus, or de-motivation of working outdoors in extreme cold weather might lead to less consideration of safety and increase the likelihood of risk taking, corner cutting, violating procedures and so on. Aircraft maintenance engineers should be aware of conflicting motivations that impinge on their actions and attempt to examine their motivations for working in a certain way.

Maslow's Hierarchy of Needs

Possibly one of the most well known theories which attempts to describe human motivation is Maslow's hierarchy of needs. Maslow considered that humans are driven by two different sets of motivational forces:

- those that ensure survival by satisfying basic physical and psychological needs;
- those that help us to realise our full potential in life known as self-actualisation needs (fulfilling ambitions, etc.).

Figure shows the hypothetical hierarchical nature of the needs we are motivated to satisfy. The theory is that the needs lower down the hierarchy are more primitive or basic and must be satisfied before we can be motivated by the higher needs. For instance, you will probably find it harder to concentrate on the information in this document if you are very hungry (as the lower level physiological need to eat predominates over the higher level cognitive need to gain knowledge). There are always exceptions to this, such as the mountain climber who risks his life in the name of adventure. The higher up the hierarchy one goes, the more difficult it becomes to achieve the need. High level needs are often long-term goals that have to be accomplished in a series of steps.

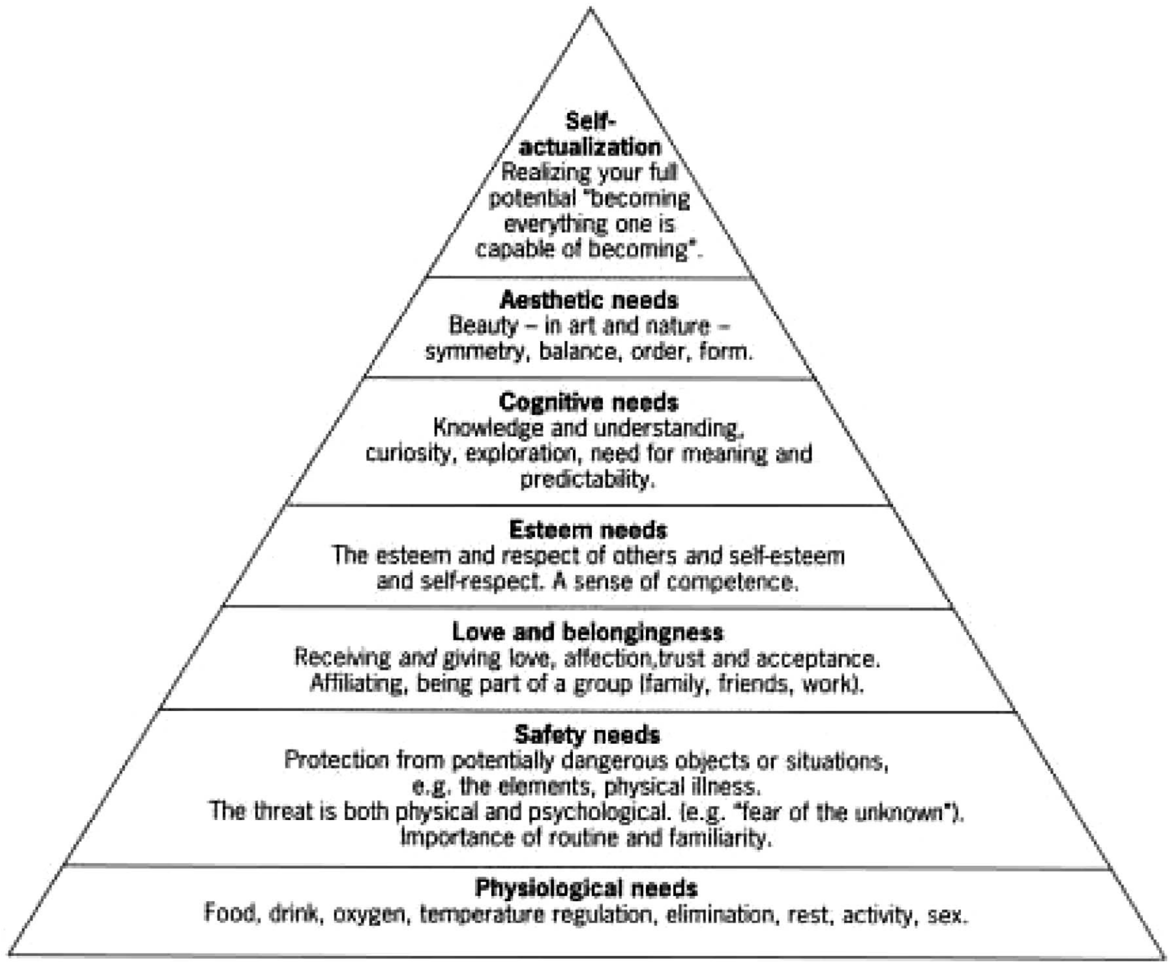


Fig. Maslow's hierarchy of needs. Source: Maslow, 1954

An aircraft maintenance engineer will fulfil lower level needs by earning money to buy food, pay for a home and support a family. They may well be motivated by middle level needs in their work context (e.g. social groups at work, gaining status and recognition). It is noteworthy that for shift workers, tiredness may be a more powerful motivator than a higher order need (such as personal satisfaction to get the job done in time or accurately).

An interesting experiment on motivation was carried out in 1924 at the Hawthorne Works of the Western Electric Company in Chicago. Here, the management altered various factors such as rest periods, lighting levels, working hours, etc. and each time they did so, performance improved, even when the apparent improvements were taken away! This suggested that it was not the improvements themselves which were causing the increased production rates, but rather the fact that the staff felt that management were taking notice of them and were concerned for their welfare. This phenomenon is known as the Hawthorne effect.

De-motivation

Highly motivated people tend to show the following characteristics:

- high performance and results being consistently achieved;
- the energy, enthusiasm and determination to succeed;
- unstinting co-operation in overcoming problems;
- willingness to accept responsibility;
- willingness to accommodate change.

People who are de-motivated lack motivation, either intrinsically or through a failure of their management to motivate the staff who work for them. De-motivated people tend to demonstrate the following characteristics:

- apathy and indifference to the job, including reduced regard for safety whilst working;
- a poor record of time keeping and high absenteeism;
- an exaggeration of the effects/difficulties encountered in problems, disputes and grievances;
- a lack of co-operation in dealing with problems or difficulties;
- unjustified resistance to change.

However, care should be taken when associating these characteristics with lack of motivation, since some could also be signs of stress.

There is much debate as to the extent to which financial reward is a motivator. There is a school of thought which suggests that whilst lack of financial reward is a de-motivator, the reverse is not necessarily true. The attraction of the extra pay offered to work a ‘ghoster’ can be a strong motivator for an individual to ignore the dangers associated with working when tired.

The motivating effects of job security and the de-motivating impact of lack of job security is also an area that causes much debate. The ‘hire and fire’ attitude of some companies can, potentially, be a major influence upon safety, with real or perceived pressure upon individuals affecting their performance and actions. It is important that maintenance engineers are motivated by a desire to ensure safety (Maslow’s ‘self esteem/self respect’), rather than by a fear of being punished and losing their job (Maslow’s ‘security’). It is possible that the “can do” culture, which is evident in some areas of the industry, may be generated by the expectancy that if individuals do not ‘deliver’, they will be punished (or even dismissed) and, conversely, those who do ‘deliver’ (whether strictly by the book or not, finding ways around lack of time, spares or equipment) are rewarded and promoted. This is not motivation in the true sense but it has its roots in a complex series of pressures and drives and is one of the major influences upon human performance and human error in maintenance engineering.

Motivation

Motivation reflects the difference between what a person can do and actually will do, and is what drives or induces a person to behave in a particular fashion. Clearly, people are different and driven by different motivational forces. Even when selection, training and checking ensure capability to perform, it is motivation that determines whether a person will do so in a given situation.

There is a relationship between expectancy and reward as motivators, since the utility of a reward and the subjective probability of its achievement determine the level of effort which will be applied to obtain the reward. This effort must be accompanied by the proper skills. It is important for high performers to see that they are in a better position than poor performers to achieve a reward, otherwise motivation may decline. Job satisfaction motivates people to higher performance.

Modifying behaviour and performance through rewards is called positive reinforcement; discouraging undesirable behaviour by use of penalties or punishment is called negative reinforcement. Even though positive reinforcement can be more effective in improving performance, both must be available to management. Different responses are to be expected from different individuals in relation to positive and negative reinforcers. Care should be taken not to generate an effect which is opposite from that which is intended.

INFLUENCING MOTIVATION AT WORK

Job satisfaction

In the search to find what really motivates people to higher performance, increasing attention has been paid in recent years to what been called job satisfaction.

There are many factors witch may influence a person's overall attitude to the job. These include, amongst others, financial rewards, management personnel policies, work colleagues, the working environment, and the nature of task itself. The extent to witch these factors will apply an influence will depend on the persons own preferences and values. It is possible to measure the satisfaction level of the separate elements of a job and also the job it self, using specially designed questionnaires and interviews.

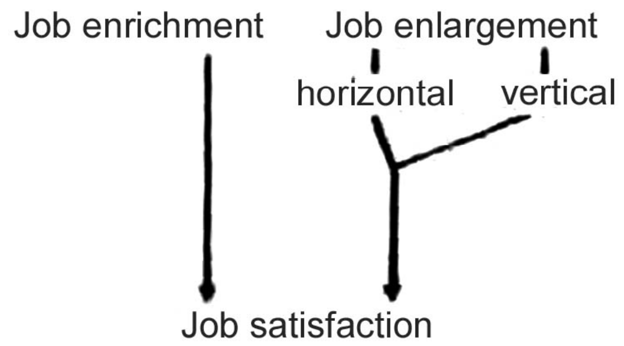
While job satisfaction may be desirable end in itself it cannot be assumed that it necessarily or automatically result in improved performance. Eliminating proficiency checks, for instance, may raise the job satisfaction of some pilots by reducing anxiety and extra study, leaving more time for sailing or fishing. But overall performance at work could be expected to fall, not rise. There is not much evidence from industry to suggest that increasing job satisfactions will result in higher performance unless the satisfying outcome or rewards are tied to performance and seen to tied.

In Taylor's work at end of the 19th Venture, money was considered of paramount importance in creating motivation at work. To day it is known that once income rise appreciably above subsistence levels, dissatisfaction with relative incomes. In others words, not that may income is not enough, but that some other comparable person is getting more.

Using material incentives to raise production or performance is not quite such a simple solution as it sounds. Expectation are constantly rising; more is needed to produce any results. And one person's higher reward may become the basis of dissatisfaction for his colleague. Incentives can become institutionalized as rights rather than rewards for good performance and their withdrawal can then be seen as a form of punishment. Annual Christmas or holiday bonuses are an example of this phenomenon. In spite of these limitation, incentives still have an important place in the overall scheme.

One airline invites all its newly appointed captains to a company dinner, attended by company president. This certainly initially enhances motivation, but as it is a single event in the captain's career other factors gradually erode the effect. It should not, of course, be a single event and recurrent activity should be developed to sustain the high level of initial motivation apparent in many such newly appointed captains.

A rationally critical attitude of an employee towards his supervisory or management policies should not be confused with job dissatisfaction or low motivation. On the contrary, those who are greatly motivated to achieve the goals, performance, production, or product quality entrusted to them, are likely to initiate more criticism of whatever deficiencies appear in the organization, frustrating there efforts. Those who are uncritical and display a high level of acceptance of the status quo and apparent satisfaction, may be simply displaying apathy and complacency. The hostile response some managements to such critical attitudes may reflect a lack of security or self-confidence rather than ignorance of the motivational factors involved, though in their case, poor management quality is indicated.



To increase job satisfaction, job enrichment have been used. Job enrichment mainly involves active participation of staff in policy and decision-making concerning their work. As an illustration, airline cabin pursers could be involved in decisions on the type and timing of meals to be served on board. The check-in agent could be consulted on how to handle irate passengers who have been over-booked by the airline. Job enlargement increases the number and variety of tasks (horizontal enlargement) or increases a person's control of the routine planning of his tasks (vertical enlargement). This might be seen in the delegation by the aircraft captain of certain of his tasks to the first officer, which provides horizontal enlargement of the first officer's job. Similarly, giving the flight engineer certain radio, navigation or visual lookout tasks also introduces horizontal enlargement. If crew members are allowed to become routinely involved in, say, their own duty scheduling, then this would be considered vertical enlargement. Both methods of increasing job satisfaction have shown premise in industry but are not, in themselves, the complete answer.

While the relationship between job satisfaction and performance may be variable and uncertain, other relationships are well established. Setting clear, precise and acceptable goals and targets, preferably with some degree of challenge attached to them, is very effective in enhancing performance. There should be clear targets and acceptable tolerances established for most tasks which are related to safety and efficiency. This may refer to the aircraft approach speed or the time taken to deliver a passenger's luggage to the customs hall after arrival. It can apply to an airline's schedule punctuality. Many staff feel more content if they have clear targets to meet, and providing these are realistic they can contribute to job satisfaction.

Complacency, professionalism and discipline

The history of civil aircraft operation is strewn with exhortations to crew members to avoid complacency, be vigilant, display professionalism and exercise proper discipline. There have been various periods when one or other of these forms of exhortation was more or less in fashion.

They all reflect aspects of behaviour which go beyond technical skills and can be seen as indications of motivation. There can be little doubt that every crew member would see all these behavioural characteristics as relevant to safe and efficient performance in flight. Yet some are motivated towards the desired behaviour while some are not. And even those so motivated periodically experience a variation in the strength of motivation.

Attempting to modify behaviour by means of exhortation is unlikely to have any long-term effect unless the exhortation is accompanied by other measures. The work of the ASRS and CHIRP confidential reporting systems is very valuable. However, the polite interferences in some of their periodic bulletins (Callback and Feedback) that the readers should smarten up are unlikely, by themselves, to have a significant long-term effect. A more profound inquiry into the nature of the forces which drive the activities of people is necessary in order to learn whether they can be manipulated and if so, how. It is also necessary in order to learn how to design the overall flight deck and cabin systems to live safely with the different motives which control the performance of crew members at work.

PEER PRESSURE

In the working environment of aircraft maintenance, there are many pressures brought to bear on the individual engineer. We have already discussed the influence of the organisation, of responsibility and motivational drives. In addition to these, there is the possibility that the aircraft maintenance engineer will receive pressure at work from those that work with him. This is known as peer pressure.

> Peer pressure is the actual or perceived pressure which an individual may feel, to conform to what he believes that his peers or colleagues expect.

For example, an individual engineer may feel that there is pressure to cut corners in order to get an aircraft out by a certain time, in the belief that this is what his colleagues would do under similar circumstances. There may be no actual pressure from management to cut corners, but subtle pressure from peers, e.g. taking the form of comments such as “You don’t want to bother checking the manual for that. You do it like this…” would constitute peer pressure.

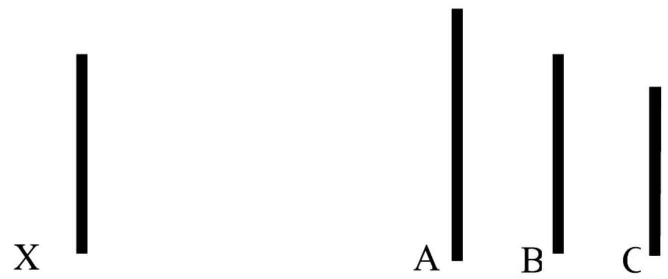
Peer pressure thus falls within the area of conformity. Conformity is the tendency to allow one’s opinions, attitudes, actions and even perceptions to be affected by prevailing opinions, attitudes, actions and perceptions.

Experiments in Conformity

Asch carried out several experiments investigating the nature of conformity, in which he asked people to judge which of lines A, B & C was the same length as line X. (see Figure). He asked this question under different conditions:

- where the individual was asked to make the judgement on his own;

- where the individual carried out the task after a group of 7-9 confederates of Asch had all judged that line A was the correct choice. Of course, the real participant did not know the others were "stooges"



(B is the same length as X)

Fig. An experiment to illustrate conformity.

In the first condition, very few mistakes were made (as would be expected of such a simple task with an obvious answer). In the latter condition, on average, participants gave wrong answers on one third of the trials by agreeing with the confederate majority. Clearly, participants yielded to group pressure and agreed with the incorrect 'group' finding (however, it is worth mentioning that there were considerable individual differences: some participants never conformed, and some conformed all the time).

Further research indicated that conformity does not occur with only one confederate (as then it is a case of 'my word against yours'). However, it is necessary to have only three confederates to one real participant to attain the results.

The degree to which an individual's view is likely to be affected by conformity or peer pressure, depends on many factors, including:

- culture (people from country x tend to conform more than those from country y);
- gender (men tend to conform less than women);
- self-esteem (a person with low self-esteem is likely to conform more);
- familiarity of the individual with the subject matter (a person is more likely to conform to the majority view if he feels that he knows less about the subject matter than they do);
- the expertise of the group members (if the individual respects the group or perceives them to be very knowledgeable he will be more likely to conform to their views);
- the relationship between the individual and group members (conformity increases if the individual knows the other members of the group, i.e. it is a group of peers).

Countering Peer Pressure and Conformity

The influence of peer pressure and conformity on an individual's views can be reduced considerably if the individual airs their views publicly from the outset. However, this can be very difficult: after Asch's experiments, when asked, many participants said they agreed with the majority as they did not want to appear different or to look foolish.

Conformity is closely linked with 'culture' (described in the next section). It is highly relevant in the aircraft maintenance environment where it can work for or against a safety culture, depending on the attitudes of the existing staff and their influence over newcomers. In other words, it is important for an organisation to engender a positive approach to safety throughout their workforce, so that peer pressure and conformity perpetuates this. In this instance, peer pressure is clearly a good thing. Too often, however, it works in reverse, with safety standards gradually deteriorating as shift members develop practices which might appear to them to be more efficient, but which erode safety. These place pressure, albeit possibly unwittingly, upon new engineers joining the shift, to do likewise.

CULTURE ISSUES

There can be a degree of mistrust of anything new in the workplace, (e.g. an individual joining a company whose expertise has not yet been proven, or contracting out maintenance to another company, etc.). There may be a tendency for groups within organisation and the organisation itself to think that their own methods are the best and that others are not as good. This viewpoint is known as the group's or organisation's culture.

> The culture of an organisation can be described as 'the way we do things here'. It is a group or company norm.

Figure indicates that there can be an overall organisational culture, and a number of different 'sub-cultures', such as safety culture, professional/technical culture, etc. It is possible for cultural differences to exist between sites or even between shifts within the same organisation. The prevailing culture of the industry as a whole also influences individual organisations.

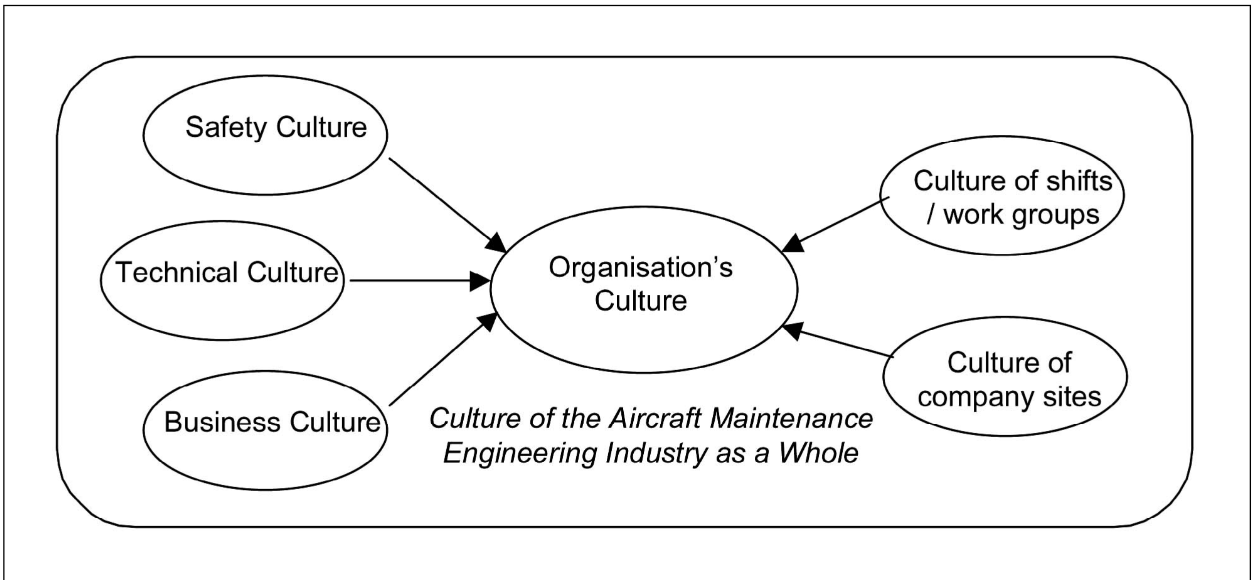


Fig. The influences on an organisation's culture

Culture is not necessarily always generated or driven from the top of an organisation (as one might think), but this is the best point from which to influence the culture.

Safety Culture

The ICAO Human factors Digest No. 10, "Human Factors, Management and Organisation" (Circular 247), discusses corporate culture and the differences between safe and unsafe corporate cultures.

ICAO HF Digest 10 describes a safety culture as "a set of beliefs, norms, attitudes, roles and social and technical practices concerned with minimising exposure of employees, managers, customers and members of the general public to conditions considered dangerous or hazardous"

Gary Eiff from Purdue University discusses safety culture in his paper "Organizational Culture and its Effect on Safety". He suggests that "A safety culture exists only within an organisation where each individual employee, regardless of their position, assumes an active role in error prevention", stressing that "Safety cultures do not …spring to life simply at the declaration of corporate leaders".

The culture of an organisation can best be judged by what is done rather than by what is said. Organisations may have grand 'mission statements' concerning safety but this does not indicate that they have a good safety culture unless the policies preached at the top are actually put into practise at the lower levels. It may be difficult to determine the safety culture of an organisation by auditing the procedures and paperwork; a better method is to find out what the majority of the staff actually believe and do in practice.

A method for measuring attitudes to safety has been developed by the Health and Safety Executive utilising a questionnaire approach. Examples of the statements which employees are asked the extent to which they agree are:

- It is necessary to bend some rules to achieve a target;
- Short cuts are acceptable when they involve little or no risk;
- I often come across situations with which I am unfamiliar;
- I sometimes fail to understand which rules apply;
- I am not given regular break periods when I do repetitive and boring jobs;
- There are financial rewards to be gained from breaking the rules.

The results are scored and analysed to give an indication of the safety culture of the organisation, broken down according to safety commitment, supervision, work conditions, logistic support, etc. In theory, this enables one organisation to be objectively compared with another.

Professor James Reason describes the key components of a safety culture, summarised as follows:

- The 'engine' that continues to propel the system towards the goal of maximum safety health, regardless of the leadership's personality or current commercial concerns;
- Not forgetting to be afraid;
- Creating a safety information system that collects, analyses and disseminates information from incidents and near-misses as well as from regular proactive checks on the system's vital signs;
- A good reporting culture, where staff are willing to report near-misses;
- A just culture - an atmosphere of trust, where people are encouraged, even rewarded, for providing essential safety related information - but in which they are clear about where the line must be drawn between acceptable and unacceptable behaviour;
- A flexible culture;
- Respect for the skills, experience and abilities of the workforce and first line supervisors;
- Training investment;

- A learning culture - the willingness and the competence to draw the right conclusions from its safety information system, and the will to implement major reforms when their need is indicated.

Social Culture

The influence of social culture (an individual's background or heritage) can be important in determining how an individual integrates into an organisational culture. The way an individual behaves outside an organisation is likely to have a bearing on how they behave within it. Internal pressures and conflicts within groups at work can be driven by underlying social cultural differences (e.g. different nationalities, different political views, different religious beliefs, etc.). This is an extremely complex subject, however, and in-depth discussion is beyond the scope of this text.

> Whilst safety culture has been discussed from the organisational perspective, the responsibility of the individual should not be overlooked. Ultimately, safety culture is an amalgamation of the attitude, beliefs and actions of all the individuals working for the organisation and each person should take responsibility for their own contribution towards this culture, ensuring that it is a positive contribution rather than a negative one.

TEAM WORKING

The responsibility of aircraft maintenance engineers within teams has been discussed in section 2 and the influence of peers on the behaviour of the individual highlighted in section 4. This section looks in more detail at team working in aircraft maintenance.

The Concept of A Team

A lot has been written on the concept of a team, and it is beyond the scope of this document to give anything but a flavour of this.

> Whereas individualism encourages independence, teams are associated with interdependence and working together in some way to achieve one or more goals.

Teams may comprise a number of individuals working together towards one shared goal. Alternatively, they may consist of a number of individuals working in parallel to achieve one common goal. Teams generally have a recognised leader and one or more follower(s). Teams need to be built up and their identity as a team needs to be maintained in some way.

A team could be a group of engineers working on a specific task or the same aircraft, a group working together on the same shift, or a group working in the same location or site. There are natural teams within the aircraft maintenance environment. The most obvious is the supervisor and the engineers working under his supervision. A team could also be a Licensed Aircraft Engineer (LAE) and unlicensed engineers working subject to his scrutiny. A team may well comprise engineers of different technical specialities (e.g. sheet/metal structures, electrical/ electronics/avionics, hydraulics, etc.).

There has been a great deal of work carried out on teamwork, in particular "Crew Resource Management (CRM)" in the cockpit context and, more recently, "Maintenance Resource Management (MRM)" in the maintenance context. The ICAO Human Factors Digest No. 12 "Human Factors in Aircraft Maintenance and Inspection" (ICAO Circular 253), includes a

Chapter on team working, to which the reader is directed for further information. MRM is addressed separately (section 8) since it covers more than just teamwork.

Some Advantages and Disadvantages of Team Working 6.2.1 The discussion on motivation suggests that individuals need to feel part of a social group. In this respect, team working is advantageous. However, the work on conformity suggests that they feel some pressure to adhere to a group's views, which may be seen as a potential disadvantage.

Working as part of a team has a number of potential benefits which include:

- individuals can share resources (knowledge, tools, etc.);
- they can discuss problems and arrive at shared solutions;
- they can check each others' work (either "officially" or "unofficially").

Teams can be encouraged to take ownership of tasks at the working level. This gives a team greater responsibility over a package of work, rather than having to keep referring to other management for authorisation, support or direction. However, groups left to their own devices need proper leadership (discussed in section 7). Healthy competition and rivalry between teams can create a strong team identity and encourage pride in the product of a team. Team identity also has the advantage that a group of engineers know one another's capabilities (and weaknesses).

As noted, if work has to be handed over to another group or team (e.g. shift handover), this can cause problems if it is not handled correctly. If one team of engineers consider that their diligence (i.e. taking the trouble to do something properly and carefully) is a waste of time because an incoming team's poor performance will detract from it, then it is likely that diligence will become more and more rare over time.

Important Elements of Team Working

For teams to function cohesively and productively, team members need to have or build up certain interpersonal and social skills. These include communication, co-operation, co-ordination and mutual support.

Communication

Communication is essential for exchanging work-related information within the team. For example, a team leader must ensure that a team member has not just heard an instruction, but understood what is meant by it. A team member must highlight problems to his colleagues and/or team leader. Furthermore, it is important to listen to what others say.

Co-operation

'Pulling together' is inherent in the smooth running of a team. Fairness and openness within the team encourage cohesiveness and mutual respect. Disagreements must be handled sensitively by the team leader.

Co-ordination

Co-ordination is required within the team to ensure that the team leader knows what his group members are doing. This includes delegation of tasks so that all the resources within the team are utilised. Delegated tasks should be supervised and monitored as required. The team leader must ensure that no individual is assigned a task beyond his capabilities. Further important aspects of co-ordination are agreement of responsibilities (i.e. who should accomplish which tasks and within what timescale), and prioritisation of tasks.

Mutual Support

a. Mutual support is at the heart of the team's identity. The team leader must engender this in his team. For instance, if mistakes are made, these should be discussed and corrected constructively.

b. It is worth noting that in many companies, line engineers tend to work as individuals whereas base engineers tend to work in teams. This may be of significance when an engineer who normally works in a hangar, finds himself working on the line, or vice versa. This was the case in the Boeing 737 incident involving double engine oil pressure loss, where the Base Controller took over a job from the Line Maintenance engineer, along with the line maintenance paperwork. The line maintenance paperwork is not designed for recording work with a view to a handover, and this was a factor when the job was handed over from the Line engineer to the Base Controller.

MANAGEMENT, SUPERVISION AND LEADERSHIP

The previous section made frequent reference to the team leader. Management, supervision and leadership are all skills that a team leader requires. Of course, management is also a function within an organisation (i.e. those managers responsible for policy, business decisions, etc.), as is the supervisor (i.e. in an official role overseeing a team).

> Managers and supervisors have a key role to play in ensuring that work is carried out safely. It is no good instilling the engineers and technicians with 'good safety practice' concepts, if these are not supported by their supervisors and managers.

The Management Role

Line Managers, particularly those working as an integral part of the 'front line' operation, may be placed in a situation where they may have to compromise between commercial drivers and 'ideal' safety practices (both of which are passed down from 'top management' in the organisation). For example, if there is a temporary staff shortage, he must decide whether maintenance tasks can be safely carried out with reduced manpower, or he must decide whether an engineer volunteering to work a "ghoster" to make up the numbers will be able to perform adequately. The adoption of Safety Management Principles may help by providing Managers with techniques whereby they can carry out a more objective assessment of risk.

The Supervisory Role

Supervision may be a formal role or post (i.e. a Supervisor), or an informal arrangement in which a more experienced engineer 'keeps an eye on' less experienced staff. The Supervisor is in a position not only to watch out for errors which might be made by engineers and technicians, but will also have a good appreciation of individual engineer's strengths and weaknesses, together with an appreciation of the norms and safety culture of the group which he supervises. It is mainly his job to prevent unsafe norms from developing, and to ensure that good safety practices are maintained. There can be a risk however, that the Supervisor becomes drawn down the same cultural path as his team without realising. It is good practice for a Supervisor to step back from the day-to-day work on occasion and to try to look at his charges' performance objectively.

It can be difficult for supervisory and management staff to strike the right balance between carrying out their supervisory duties and maintaining their engineering skills and knowledge (and appropriate authorisations), and they may get out of practice. In the UK Air Accidents Investigation Branch (AAIB) investigation reports of the BAC 1- 11, A320 and B737 incidents, a common factor was: "Supervisors tackling long duration, hands-on involved tasks[2]". In the B737 incident, the borescope inspection was carried out by the Base Controller, who needed to do the task in order to retain his borescope authorisation. Also, there is unlikely to be anyone monitoring or checking the Supervisor, because:

- of his seniority;
- he is generally authorised to sign for his own work (except, of course, in the case where a duplicate inspection is required);
- he may often have to step in when there are staff shortages and, therefore, no spare staff to monitor or check the tasks;
- he may be 'closer' (i.e. more sensitive to) to any commercial pressures which may exist, or may perceive that pressure to a greater extent than other engineers.

It is not the intention to suggest that supervisors are more vulnerable to error; rather that the circumstances which require supervisors to step in and assist tend to be those where several of the 'defences' (see Chapter 8 - error) have already failed and which may result in a situation which is more vulnerable to error.

MANAGEMENT'S CONTRIBUTION TO SAFETY

In 1986, a major aircraft manufacturer completed a world-wide airline operators survey with a view to helping control what was dubbed "crew-caused accidents". The ensuing report became widely publicized and a milestone within the airline training community since it provided valuable information applicable to flight crew training. Although, by its nature, the survey focused narrowly on flight crews, the researchers were confronted with evidence which suggested that there was more than just crew error to safe airline operations.

The report indicates that one characteristic of the airlines identified as safer was management emphasis on safety. These airlines:

> " … characterize safety as beginning at the top of the organization with a strong emphasis on safety and this permeates the entire operation. Flight operations and training managers recognize their responsibility to flight safety and are dedicated to creating and enforcing safety-oriented policies … There is a method of getting information to the flight crews expeditiously and a policy that encourages confidential feedback from pilots to management … This management attitude, while somewhat difficult to describe, is a dynamic force that sets the stage for standardization and discipline in the cockpit brought about and reinforced by a training programme oriented to safety issues."

Three years later, in an address given before the Aero Club of Washington, D.C., on 28 March 1989, an internationally recognized advocate of safety through management asserted:

> "Management attitudes can be translated into concrete action in many ways. Most obvious are the fundamentals: the provision of well-equipped, well-maintained, standardized cockpits; the careful development and implementation of, and rigid adherence to, standardized operating procedures; and a thorough training and checking program that ensures that the individual pilots have the requisite skills to operate the aircraft safely. These actions build the foundations upon which everything else rests."

The crash of a De Havilland DHC-6-300 Twin Otter on 28 October 1989 into high terrain, near Halawa Bay, Molokai, Hawaii, while attempting to continue a VFR flight into deteriorating VMC provides an instructive example of “management failure”. The aircraft accident report includes the following conclusion:

> “In summary, the Safety Board concludes that [the company’s] management provided inadequate supervision of its personnel, training and flight operations. The numerous deficiencies evident during the investigation relative to the IFR training of the pilots, the reduced ground school training, the lack of CRM training, the captain’s known behavioural traits, and the policy of not using the weather radar systems installed on the airplanes, were the responsibility of the airline’s management to correct. The failure of the management personnel to correct these deficiencies contributed to the events that led to this accident.”

The quotations in the previous paragraphs set the underlying rationale for this section and demonstrate the critical contribution of management to sociotechnical systems safety, which is the objective of this chapter. Before addressing what management can do, however, it is pertinent to discuss why management should act on safety. Why management should take an active stance on safety.

Why Management should take an Active Stance on Safety

Aside from the moral considerations regarding potential injury or loss of human life and preservation of property, management should act because of the economics of aviation safety. Section 2 discusses the dilemma of dividing finite resources between production and safety goals. Although seemingly incompatible in the short-term, these goals are perfectly compatible when considered from a long-term perspective. It is a recognized generalization that the safest organizations are often the most efficient. There are inevitable trade-offs between safety and finance. However, safe organizations do not allow these trade-offs or apparent incompatibilities to reduce the safety standards below a minimum standard which is defined beforehand and thus becomes one of the objectives of the organization.

When contemplating trade-offs between safety and production, management should evaluate the financial consequences of the decision. Since this trade-off involves risk, management must consider the cost involved in accepting such risk, i.e. how much will it cost the organization to have an accident. While there are insured costs1-2-20 Human Factors Training Manual (those covered by paying premiums to insurance companies) which can be recovered, there are also uninsured costs which cannot, and they may be generally double or triple the insured costs. Typical uninsured costs of an accident include:

- insurance deductibles
- lost time and overtime
- cost of the investigation
- cost of hiring and training replacements
- loss of productivity of injured personnel
- cost of restoration of order
- loss of use of equipment
- cost of rental or lease of replacement equipment
- increased operating costs on remaining equipment

- loss of spares or specialized equipment
- fines and citations
- legal fees resulting from the accident
- increased insurance premiums
- liability claims in excess of insurance
- loss of business and damage to reputation
- cost of corrective action

Those in the best position to effect accident prevention by eliminating unacceptable risks are those who can introduce changes in the organization, its structure, corporate culture, policies and procedures, etc. No one is in a better position to produce these changes than management. Therefore, the economics of aviation safety and the ability to produce systemic and effective change underlie the justification for management to act on safety.

What management can do to take an active stance on safety

In a document such as this manual which is directed to such a wide audience in different States, in different sizes of organizations and, most importantly, in different structures of organizations, it is impossible to be prescriptive about management actions in relation to safety. There are, nonetheless, a few general principles which apply anywhere; these are discussed in the balance of this section.

Allocation of resources. From the simplest of perspectives, management's most obvious contribution to safety is in the allocation of adequate and necessary resources to safely achieve the production goals of the organization. The issues underlying this allocation are discussed below as well as in the opening paragraphs of this section. In practical terms, the first quotation can be viewed as a listing of the "most wanted" items management should pursue when deciding on the allocation of resources.

On Monday, 14 November 1988, an Embraer 110 Bandeirante aircraft on a scheduled passenger flight crashed in the vicinity of the Ilmajoki Airport in Finland. The Finnish Board of Inquiry came to the conclusion that the immediate cause of the accident was the [flight crew] decision to continue the NDB approach below the minimum descent altitude, without the required visual contact. The Board also found as a contributing factor the performance pressures that originated from the airline's poor safety culture. In pursuing the organizational issues which might have contributed to the accident, the investigation revealed:

> "… serious deficiencies in the operation of the airline as well as in the activities of the airport operator and the authorities. Also the legislation was found to be out of date and insufficient, especially as far as commercial flight operations are concerned."

The report is an outstanding example of systemic approaches to accident investigation and as such, it is extremely rich in prevention lessons. The discussion about regulatory compliance is particularly applicable to this section. The report first discusses the very important contribution of regulatory compliance to safety in the following terms:

> "… Flight safety is also affected by the effectiveness of the supervision carried out by the authorities and by what measures are undertaken in response to what is uncovered in the supervision. If the authorities cannot or will not intervene when safety regulations have

been violated or if these violations are not even noticed due to ineffective supervision, the violations will probably begin to be regarded as a minor matter …"

Having established the importance of regulatory compliance, the report then goes on to consider an important shortcoming in regulations — formal compliance — as follows:

> "… If the authorities are unable to assess the substantive conditions for operating an airline, or they do not have sufficient authority to do so, the supervision and the resulting measures must be carried out purely on formal grounds. Instead of broad assessment, this merely leads to the judging of violations committed by individuals, and it is not possible to come to grips with fundamental factors in the organization and operative environment that endanger safety …"

The report's conclusion on the scope and reach of regulatory compliance as a tool in pursuing safety, as it applies not only to the accident under investigation but to the aviation system as a whole, leaves no room for misunderstanding:

> "… in the course of the investigation, no particular reason arose to question in general the sufficient competence of the pilots or other operational personnel. What is primarily at issue is the company's poor safety culture … Because of this, measures that are directed by the National Board of Aviation at the licenses and ratings of individual pilots would scarcely affect the safety of the company's flight operations unless, at the same time, one can ensure that the company management adopts the proper attitude and has sufficient qualifications for carrying out its functions."

Safety programmes and safety feedback systems. There are other activities involving allocation of resources which are not as obvious but are nevertheless equally important. These activities are discussed in-depth in the Accident Prevention Manual (Doc 9422) and are mentioned briefly in this section. The most important is the implementation, continued operation and visible support of a company safety programme. Such programmes should include not only flight operations safety, but also maintenance safety, ramp safety, etc. The programme should be administered by an independent company safety officer who reports directly to the highest level of corporate management. Company safety officers and their staff must be quality control managers, looking for corporate safety deficiencies rather than pointing fingers at individual errors. To discharge their responsibilities, safety officers need information which may come from several sources: internal safety audits which identify potential safety hazards, internal incident reporting systems, internal investigation of critical incidents as well as performance monitoring programmes — both for the company and the industry. An often-overlooked source of information is the participation in industry-wide safety fora, such as conferences and workshops organized by international associations.

Armed with the information thus obtained, the safety officer may then implement a programme of disseminating critical safety information to all personnel. The stage for setting a safety-oriented organizational climate is thus set.

Standard operating procedures. There is an even more subtle activity that management can undertake to contribute to safety. The development of, implementation of and adherence to standardized operating procedures (SOPs) have recently been recognized as a major contribution by management to safety. Failure to conform to sound SOPs has indeed been linked to numerous accidents and incidents. There are Human Factors considerations related to SOPs which concern both the underlying philosophy and the design of such procedures. Procedures are specifications for conducting predetermined actions; they specify a progression of actions to assist operational personnel in achieving their tasks in a manner which is logical, efficient and, most importantly, error-resistant. Procedures are not produced in a vacuum nor are they inherent in the equipment; they are based on a broad concept of operation. There is a link between procedures and philosophy, which Wiener and Degani have called “The four Ps of operations”: Philosophy, Policies, Procedures and Practices.

These researchers contend that, by establishing a philosophy of operations, management states how it wants the organization to function. Such philosophy can only be established by the highest corporate level. From philosophy, policies can be developed. Policies are broad specifications of the manner in which management expects tasks to be accomplished — training, flying, maintenance, exercise of authority, personal conduct, etc. Policies are usually dictated by line management. The procedures, normally developed by supervisors, determine how tasks will be accomplished. The procedures must be designed to be consistent with the policies, which must be consistent with the over-all guiding philosophy. Lastly, management must effect the quality control to make sure that practices in the operational environment do not deviate from written procedures. Any attempt to shortcut this process may well produce inconsistent procedures, which will breed doubts among the operational personnel about the preferred behaviour management expects from them to accomplish their task.

Philosophies, policies and procedures must be developed with due consideration for the operational environment in which they will be used. Incompatibility of the procedures with the operational environment can lead to the informal adoption of unsafe operating practices. External activities, type of operation and the layout of the cockpit or workstation are factors to be considered when evaluating the operational environment in which SOPs will be used. Feedback from operational situations, through the observed practices of or reports from operational personnel, is essential to guarantee that the bridge between the Ps and the operational environment remains intact.

The example of the Ground Proximity Warning System (GPWS) Policy, as instituted by one operator, illustrates this point:

- Philosophy: it is a corporate goal to be a safe and secure airline, as stated in the corporate mission and goals.
- Policy: in the event of a full, or partial, “Pull-up” or other hard (red) warning, the following action must be taken promptly:
    a. Below MSA (Minimum Safe Altitude)
    Announce “PULL-UP Go-Around”
    Immediately complete the pull-up manoeuvre in all circumstances.

    b. At and Above MSA
    Immediately assess aircraft position, altitude and vertical speed. If proximity to MSA is in doubt, take action as in a) above.
- Procedure: GPWS pull-up manoeuvre is described in fleet-specific manuals. Describe the call-outs by the handling pilot and the non-handling pilot — procedures at and below MSA and procedures above MSA; define MSA during climb and descent in case of ambiguities and include additional operational information deemed appropriate for the crews to observe the GPWS Policy.

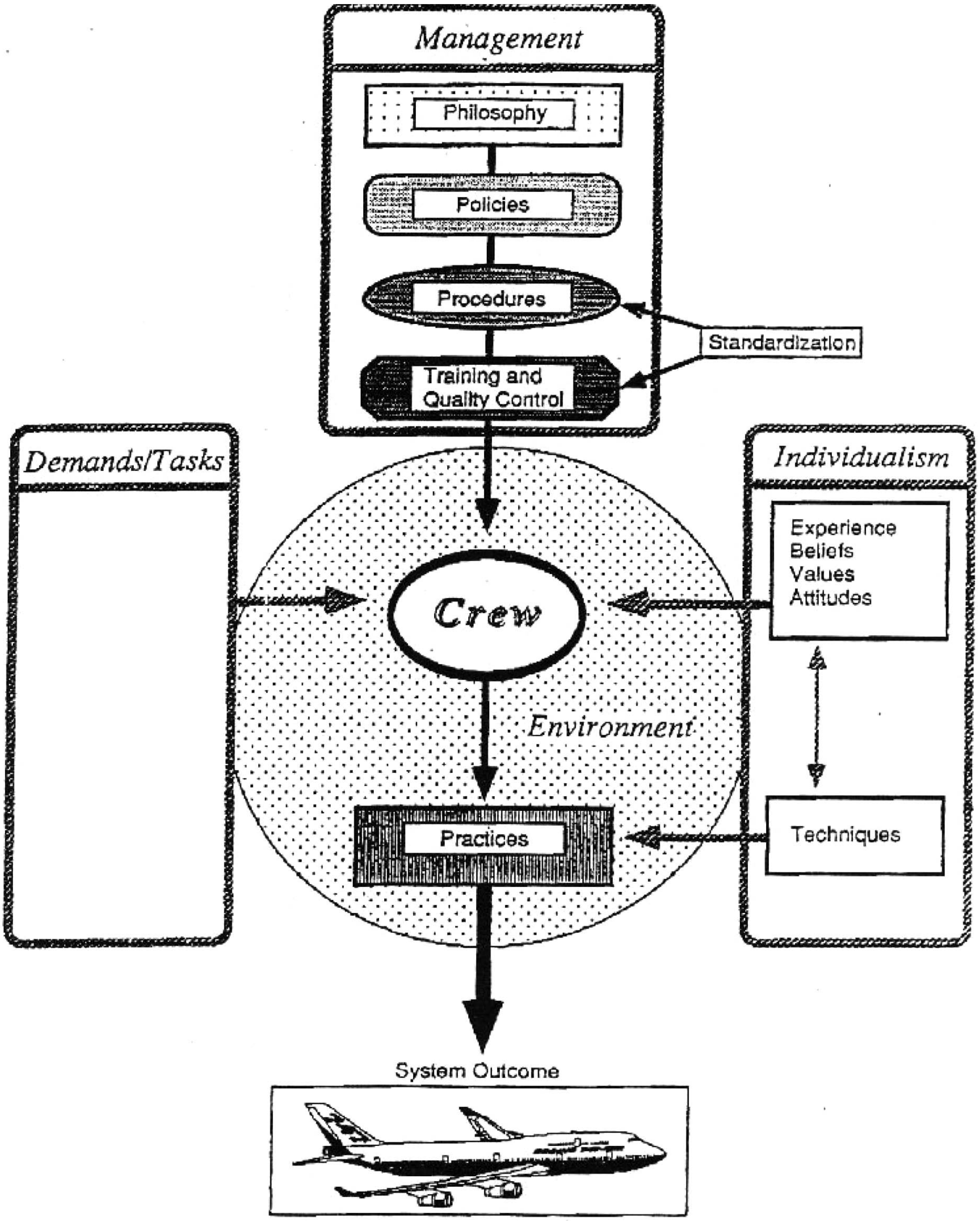


Figure The four Ps

- Practices: do flight crews observe the policy and follow the procedure in operational conditions?

In the GPWS example discussed above, the operator's original policy mandated an immediate pull-up upon receipt of any GPWS warning, regardless of altitude and position of the aircraft. Operational feedback obtained through the operator's internal safety information system, however, indicated that during the first calendar year after this policy was implemented, GPWS alerts had not been followed by a pull-up in 60% of occasions. This was due to a variety of reasons, including false and nuisance warnings. Of particular concern was the fact that pull-ups had not been initiated on 20% of occasions when the warning had been genuine. An obvious discrepancy between the three first Ps and the last one — Practices — was evident. The safety services of the operator determined that the reason for this discrepancy between philosophy, policy, procedures and practice centred around the unreliability of the technology which resulted in false and nuisance warnings. In some cases, warnings had been triggered at 37 000 ft flying in cruise, immediately after take-off, when there were no obstacles in the flight path or in holding patterns, with other aircraft 1 000 ft below the host GPWS. This feedback data and its analysis led the operator to review its GPWS policy and amend it to that included with the immediate intent of ensuring compliance with the policy on all occasions.

Internal feedback and trend-monitoring systems. The previous paragraph illustrates the importance of the feedback from the "front end", that is, from day-to-day operations, so that management can effect the control of the operations that policies and procedures support. Figure depicts three possible feedback loops. Loop 1 feeds back a company's accident statistics. In most cases, the information supplied is too late for control, because the events that safety management seeks to eliminate have already occurred. Loop 2 carries information about unsafe acts observed in daily operations. However, unsafe acts represent only the tip of the iceberg since many actions that cause accidents cannot be recognized as such in advance. This information is usually disseminated at the lower levels of the organization, i.e. operational personnel and supervisors. Loop 3 provides the greatest opportunity for proactive control of safety.

Risk management. The feedback loops, and loop 3 in particular, allow managers to assess the level of risks involved in the operations and to determine logical approaches when deciding to act upon them. The concept of risk management is discussed in the Accident Prevention Manual and is introduced in this chapter. The basic theory is based on the following assumptions:

- There is always risk. Some risks can be accepted, some — but not all — can be eliminated and some can be reduced to the point where they are acceptable.
- Decisions on risk are managerial decisions; hence the term "risk management".
- Risk management decisions follow a logical pattern.

Characteristics of a Leader

There are potentially two types of leader in aircraft maintenance: the person officially assigned the team leader role (possibly called the Supervisor), an individual within a group that the rest of the group tend to follow or defer to (possibly due to a dominant personality, etc.). Ideally of course, the official team leader should also be the person the rest of the group defer to.

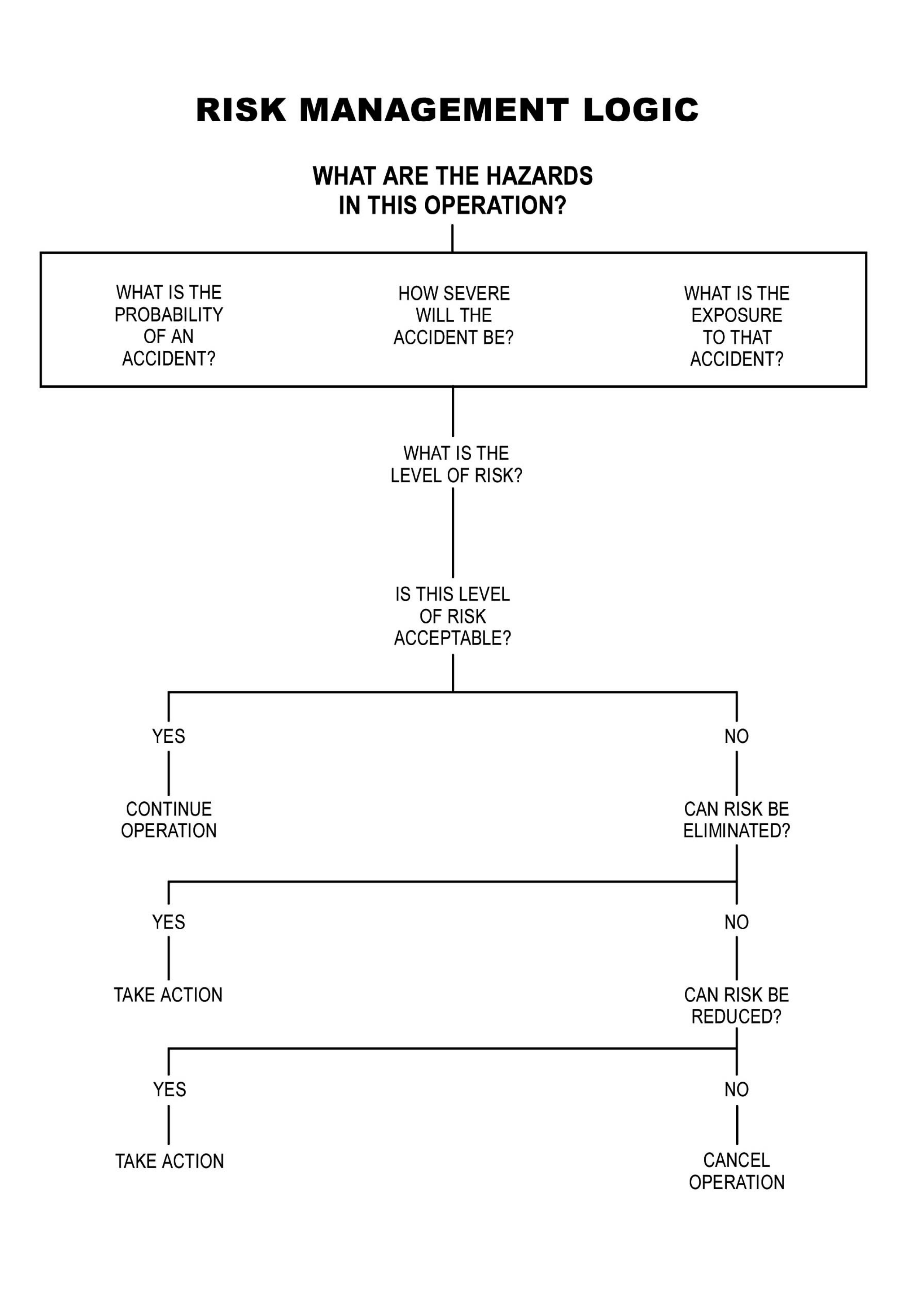


Fig. Risk Management Logic

> A leader in a given situation is a person whose ideas and actions influence the thought and the behaviour of others.

A good leader in the maintenance engineering environment needs to possess a number of qualities:

- Motivating his team;
- Reinforcing good attitudes and behaviour;
- Demonstrating by example;
- Maintaining the group;
- Fulfilling a management role.

These will now be examined in a little more detail:

Motivating the Team

Just as the captain of a football team motivates his fellow players, the leader of a maintenance team must do likewise. This can be done by ensuring that the goals or targets of the work which need to be achieved are clearly communicated and manageable. For instance, the team leader would describe the work required on an aircraft within a shift. He must be honest and open, highlighting any potential problems and where appropriate encouraging team solutions.

Reinforcing Good Attitudes and Behaviour

When team members work well (i.e. safely and efficiently), this must be recognised by the team leader and reinforced. This might be by offering a word of thanks for hard work, or making a favourable report to senior management on an individual. A good leader will also make sure that bad habits are eliminated and inappropriate actions are constructively criticised.

Demonstrating by Example

A key skill for a team leader is to lead by example. This does not necessarily mean that a leader must demonstrate that he is adept at a task as his team (it has already been noted that a Supervisor may not have as much opportunity to practise using their skills). Rather, he must demonstrate a personal understanding of the activities and goals of the team so that the team members respect his authority. It is particularly important that the team leader establishes a good safety culture within a team through his attitude and actions in this respect.

Maintaining the Group

Individuals do not always work together as good teams. It is part of the leader's role to be sensitive to the structure of the team and the relationships within it. He must engender a 'team spirit' where the team members support each other and feel responsible for the work of the team. He must also recognise and resolve disputes within the team and encourage co-operation amongst its members.

Fulfilling a Management Role

The team leader must not be afraid to lead (and diplomatically making it clear when necessary that there cannot be more than one leader in a team). The team leader is the link between higher levels of management within the organisation and the team members who actually work on the aircraft. He is responsible for co-ordinating the activities of the team on a day-to-day basis, which includes allocation of tasks and delegation of duties. There can be a tendency for team members to transfer some of their own responsibilities to the team leader, and he must be careful to resist this.

> Skilled management, supervision and leadership play a significant part in the attainment of safety and high quality human performance in aircraft maintenance engineering.

In terms of the relationship between managers, supervisors and engineers, a 'them and us' attitude is not particularly conducive to improving the safety culture of an organisation. It is important that managers, supervisors, engineers and technicians all work together, rather than against one another, to ensure that aircraft maintenance improves airworthiness.

MAINTENANCE RESOURCE MANAGEMENT (MRM)

Although not part of the JAR66-9 syllabus, Maintenance Resource Management (MRM) is nevertheless included as a specific topic because it is implicit in many of the areas covered in this chapter, such as team working, communication, responsibility, shift handovers. The discussion of MRM in this text is intended only as an introduction to the basic concepts. For in-depth information concerning MRM, the reader is referred to the "Maintenance Resource Management Handbook[1]" produced on behalf of the FAA.

> MRM is not about addressing the individual human factors of the engineer or his manager; rather, it looks at the larger system of human factors concerns involving engineers, managers and others, working together to promote safety.

The term 'Maintenance Resource Management' became better known after the Aloha accident in 1988, when researchers took Crew Resource Management (CRM) concepts and applied them to the aircraft maintenance environment. CRM concerns the process of managing all resources in and out of the cockpit to promote safe flying operations. These resources not only include the human element, but also mechanical, computer and other supporting systems. MRM has many similarities to CRM, although the cockpit environment and team is somewhat different from that found in aircraft maintenance. The FAA MRM handbook highlights the main differences between CRM and MRM, and these are summarised in Table 2.

Table 2 : Examples of the Differences Between CRM and MRM Highlighted in the FAA Maintenance Resource Management Handbook

CRM	MRM
Human error	
Errors tend to be 'active' in that their consequences follow on immediately after the error.	The consequences of an engineer's error are often not immediately apparent, and this has implications for training for error avoidance.
Communication	
Much of flight operations are characterised by synchronous, "face-to-face" communications, or immediate voice communications (e.g. with ATC) over the radio.	Maintenance operations tend to be characterised by "asynchronous" communications such as technical manuals, memos, Advisory Circulars, Airworthiness Directives, workcards and other non-immediate formats. Much of the information transfer tends to be of a non-verbal nature.
"Team" composition	
Flight crews are mostly homogenous by nature, in that they are similar in education level and experience, relative to their maintenance counterparts.	Maintenance staff are diverse in their range of experiences and education and this needs to be taken into account in a MRM programme.
Teamwork	
Flight deck crew team size is small - two or three members; although the wider team is obviously larger (i.e. flight deck crew + cabin crew, flight crew + ATC, ground crew, etc.)	Maintenance operations are characterised by large teams working on disjointed tasks, spread out over a hangar. In addition, a maintenance task may require multiple teams (hangar, planning department, technical library, management) each with their own responsibilities. Therefore MRM places equal emphasis on inter-team teamwork skills.
Situation awareness	
The flight environment is quickly changing, setting the stage for the creation of active failures. Situation awareness in CRM is tailored to avoid these errors; Line Oriented Flight Training (LOFT) simulations provide flight crews with real-time, simulations to improve future situation awareness.	The maintenance environment, thought hectic, changes slowly relative to flight operations. In terms of situation awareness, engineers must have the ability to extrapolate the consequences of their errors over hours, days or even weeks. To do this, the situation awareness cues that are taught must be tailored to fit the maintenance environment using MRM-specific simulations.

Leadership

Similar to teamwork issues, leadership skills in CRM often focus mainly on intra-team behaviours or 'how to lead the team', as well as followership skills. Inter-team interaction is somewhat limited during flight.	Because supervisors or team leaders routinely serve as intermediaries among many points of the organisation, engineer leaders must be skilled not only in intra-team behaviours, but in handling team 'outsiders' (personnel from other shifts, managers outside the immediate workgroup, etc.) during any phase of the maintenance problem. These outsiders also vary widely in experience, mannerisms, etc. A good MRM programme should take these into account.

One of the early MRM training programmes was developed by Gordon Dupont for Transport Canada1. It introduced "The Dirty Dozen", which are 12 areas of potential problems in human factors. A series of posters has been produced, one for each of these headings, giving a few examples of good practices or "safety nets" which ought to be adopted. These are summarised in Table 3 and addressed in most maintenance human factors programmes.

Table 3 : Examples of Potential Human Factors Problems from the "Dirty Dozen"

Problem Example	**Potential Solutions**
1. Lack of communication	Use logbooks, worksheets, etc. to communicate and remove doubt. Discuss work to be done or what has been completed. Never assume anything.
2. Complacency	Train yourself to expect to find a fault. Never sign for anything you didn't do [or see done].
3. Lack of knowledge	Get training on type. Use up-to-date manuals. Ask a technical representative or someone who knows.
4. Distraction	Always finish the job or unfasten the connection. Mark the uncompleted work. Lockwire where possible or use torqueseal. Double inspect by another or self. When you return to the job, always go back three steps. Use a detailed check sheet.
5. Lack of teamwork	Discuss what, who and how a job is to be done. Be sure that everyone understands and agrees.
6. Fatigue	Be aware of the symptoms and look for them in yourself and others. Plan to avoid complex tasks at the bottom of your circadian rhythm. Sleep and exercise regularly. Ask others to check your work.

7. Lack of parts	Check suspect areas at the beginning of the inspection and AOG the required parts. Order and stock anticipated parts before they are required. Know all available parts sources and arrange for pooling or loaning. Maintain a standard and if in doubt ground the aircraft.
8. Pressure	Be sure the pressure isn't self-induced. Communicate your concerns. Ask for extra help. Just say 'No'.
9. Lack of assertiveness	If it's not critical, record it in the journey log book and only sign for what is serviceable. Refuse to compromise your standards.
10. Stress	Be aware of how stress can affect your work. Stop and look rationally at the problem. Determine a rational course of action and follow it. Take time off or at least have a short break. Discuss it with someone. Ask fellow workers to monitor your work. Exercise your body.
11. Lack of awareness	Think of what may occur in the event of an accident. Check to see if your work will conflict with an existing modification or repair. Ask others if they can see any problem with the work done.
12. Norms	Always work as per the instructions or have the instruction changed. Be aware the "norms" don't make it right.

The UK Human Factors Combined Action Group (UK-HFCAG) have suggested a generic MRM syllabus which organisations may wish to adopt. MRM training programmes have been implemented by several airlines and many claim that such training is extremely successful. There has been work carried out to evaluate the success of MRM and the reader is directed in particular at research by Taylor 2, which looks at the success of MRM programmes in various US airlines.

■■■

CHAPTER 4
FACTORS AFFECTING PERFORMANCE

The performance abilities and limitations of aircraft maintenance engineers have been described in Chapter 2. Other factors may also impinge on the engineer, potentially rendering him less able to carry out his work and attain the levels of safety required. These include fitness and health, stress, time pressures, workload, fatigue and the effects of medication, alcohol and drugs. These subjects are discussed in this chapter.

FITNESS AND HEALTH

The job of an aircraft maintenance engineer can be physically demanding. In addition, his work may have to be carried out in widely varying physical environments, including cramped spaces, extremes of temperature, etc. (as discussed in the next chapter). There are at present no defined requirements for physical or mental fitness for engineers or maintenance staff. ICAO Annex 1 states:

> "An applicant shall, before being issued with any licence or rating [for personnel other than flight crew members], meet such requirements in respect of age, knowledge, experience and, where appropriate, medical fitness and skill, as specified for that licence or rating."

In the UK, the ICAO requirements are enforced through the provision of Article 13 (paragraph 7) of the Air Navigation order (ANO). This states:

> "The holder of an aircraft maintenance engineer's licence shall not exercise the privileges of such a licence if he knows or suspects that his physical or mental condition renders him unfit to exercise such privileges."

There are two aspects to fitness and health: the disposition of the engineer prior to taking on employment and the day-to-day well being of the engineer once employed.

Pre-employment Disposition

Some employers may require a medical upon commencement of employment. This allows them to judge the fitness and health of an applicant (and this may also satisfy some pension or insurance related need). There is an obvious effect upon an engineer's ability to perform maintenance or carry out inspections if through poor physical fitness or health he is constrained in some way (such as his freedom of movement, or his sight). In addition, an airworthiness authority, when considering issuing a licence, will consider these factors and may judge the condition to be of such significance that a licence could not be issued. This would not, however, affect the individual's possibility of obtaining employment in an alternative post within the industry where fitness and health requirements are less stringent.

Day-to-Day Fitness and Health

Fitness and health can have a significant affect upon job performance (both physical and cognitive). Day-to-day fitness and health can be reduced through illness (physical or mental) or injury.

JAR 66.50 imposes a requirement that "certifying staff must not exercise the privileges of their certification authorisation if they know or suspect that their physical or mental condition renders them unfit."

Responsibility falls upon the individual aircraft maintenance engineer to determine whether he is not well enough to work on a particular day. Alternatively, his colleagues or supervisor may persuade or advise him to absent himself until he feels better. In fact, as the CAA's Airworthiness Notice No. 47 (AWN47) 1 points out, it is a legal requirement for aircraft maintenance engineers to make sure they are fit for work:

> "Fitness: In most professions there is a duty of care by the individual to assess his or her own fitness to carry out professional duties. This has been a legal requirement for some time for doctors, flight crew members and air traffic controllers. Licensed aircraft maintenance engineers are also now required by law to take a similar professional attitude. Cases of subtle physical or mental illness may not always be apparent to the individual but as engineers often work as a member of a team any sub-standard performance or unusual behaviour should be quickly noticed by colleagues or supervisors who should notify management so that appropriate support and counselling action can be taken."

Many conditions can impact on the health and fitness of an engineer and there is not space here to offer a complete list. However, such a list would include:

- Minor physical illness (such as colds, 'flu, etc.);
- More major physical illness (such as HIV, malaria, etc.);
- Mental illness (such as depression, etc.);
- Minor injury (such as a sprained wrist, etc.);
- Major injury (such as a broken arm, etc.);
- Ongoing deterioration in physical condition, possibly associated with the ageing process (such as hearing loss, visual defects, obesity, heart problems, etc.);
- Affects of toxins and other foreign substances (such as carbon monoxide poisoning, alcohol, illicit drugs, etc.).

This document does not attempt to give hard and fast guidelines as to what constitutes 'unfit for work'; this is a complex issue dependent upon the nature of the illness or condition, its effect upon the individual, the type of work to be done, environmental conditions, etc. Instead, it is important that the engineer is aware that his performance, and consequently the safety of aircraft he works on, might be affected adversely by illness or lack of fitness.

An engineer may consider that he is letting down his colleagues by not going to work through illness, especially if there are ongoing manpower shortages. However, he should remind himself that, in theory, management should generally allow for contingency for illness. Hence the burden should not be placed upon an individual to turn up to work when unfit if no such contingency is available. Also, if the individual has a contagious illness (e.g. 'flu), he may pass this on to his colleagues if he does not absent himself from work and worsen the manpower problem in the long run. There can be a particular problem with some contract staff due to loss of earnings or even loss of contract if absent from work due to illness. They may be tempted to disguise their illness, or may not wish to admit to themselves or others that they are ill. This is of course irresponsible, as the illness may well adversely affect the contractor's standard of work.

Positive Measures

Aircraft maintenance engineers can take common sense steps to maintain their fitness and health. These include:

- Eating regular meals and a well-balanced diet;
- Taking regular exercise (exercise sufficient to double the resting pulse rate for 20 minutes, three times a week is often recommended);
- Stopping smoking;
- Sensible alcohol intake (for men, this is no more than 3 - 4 units a day or 28 per week, where a unit is equivalent to half a pint of beer or a glass of wine or spirit);

Finally, day-to-day health and fitness can be influenced by the use of medication, alcohol and illicit drugs. These are covered later in Section 6.

STRESS: DOMESTIC AND WORK RELATED

Stress is an inescapable part of life for all of us.

> Stress can be defined as any force, that when applied to a system, causes some significant modification of its form, where forces can be physical, psychological or due to social pressures.

From a human viewpoint, stress results from the imposition of any demand or set of demands which require us to react, adapt or behave in a particular manner in order to cope with or satisfy them. Up to a point, such demands are stimulating and useful, but if the demands are beyond our personal capacity to deal with them, the resulting stress is a problem.

Causes and Symptoms

Stress is usually something experienced due to the presence of some form of stressor, which might be a one-off stimulus (such as a challenging problem or a punch on the nose), or an on-going factor (such as an extremely hot hangar or an acrimonious divorce). From these, we get acute stress (typically intense but of short duration) and chronic stress (frequent recurrence or of long duration) respectively.

Different stressors affect different people to varying extents. Stressors may be:

- Physical - such as heat, cold, noise, vibration, presence of something damaging to health (e.g. carbon monoxide);
- Psychological - such as emotional upset (e.g. due to bereavements, domestic problems, etc.), worries about real or imagined problems (e.g. due to financial problems, ill health, etc.);
- Reactive - such as events occurring in everyday life (e.g. working under time pressure, encountering unexpected situations, etc.).

AWN47 points out that:

> "A stress problem can manifest itself by signs of irritability, forgetfulness, sickness absence, mistakes, or alcohol or drug abuse. Management have a duty to identify individuals who may be suffering from stress and to minimise workplace stresses. Individual cases can be helped by sympathetic and skilful counselling which allows a return to effective work and licensed duties."

In brief, the possible signs of stress can include:

- Physiological symptoms - such as sweating, dryness of the mouth, etc.;
- Health effects - such as nausea, headaches, sleep problems, diarrhoea, ulcers, etc.;
- Behavioural symptoms - such as restlessness, shaking, nervous laughter, taking longer over tasks, changes to appetite, excessive drinking, etc.;
- Cognitive effects - such as poor concentration, indecision, forgetfulness, etc.;
- Subjective effects - such as anxiety, irritability, depression, moodiness, aggression, etc.

It should be noted that individuals respond to stressful situations in very different ways. Generally speaking though, people tend to regard situations with negative consequences as being more stressful than when the outcome of the stress will be positive (e.g. the difference between being made redundant from work and being present at the birth of a son or daughter).

Domestic Stress

When aircraft maintenance engineers go to work, they cannot leave stresses associated with home behind. Pre-occupation with a source of domestic stress can play on one's mind during the working day, distracting from the working task. Inability to concentrate fully may impact on the engineer's task performance and ability to pay due attention to safety.

Domestic stress typically results from major life changes at home, such as marriage, birth of a child, a son or daughter leaving home, bereavement of a close family member or friend, marital problems, or divorce.

Work Related Stress

Aircraft maintenance engineers can experience stress for two reasons at work: because of the task or job they are undertaking at that moment, or because of the general organisational environment. Stress can be felt when carrying out certain tasks that are particularly challenging or difficult. This stress can be increased by lack of guidance in this situation, or time pressures to complete the task or job (covered later in this chapter). This type of stress can be reduced by careful management, good training, etc.

Within the organisation, the social and managerial aspects of work can be stressful. Chapter 3 discussed the impact on the individual of peer pressure, organisational culture and management, all of which can be stressors. In the commercial world that aircraft maintenance engineers work in, shift patterns, lack of control over own workload, company reorganisation and job uncertainty can also be sources of stress.

Stress Management

Once we become aware of stress, we generally respond to it by using one of two strategies: defence or coping.

Coping strategies involve dealing with the source of the stress rather than just the symptoms (e.g. delegating workload, prioritising tasks, sorting out the problem, etc.).

Unfortunately, it is not always possible to deal with the problem if this is outside the control of the individual (such as during an emergency), but there are well-published techniques for helping individuals to cope with stress2. Good stress management techniques include:

- Relaxation techniques;
- Careful regulation of sleep and diet;
- A regime of regular physical exercise;
- Counselling - ranging from talking to a supportive friend or colleague to seeking professional advice.

There is no magic formula to cure stress and anxiety, merely common sense and practical advice.

TIME PRESSURE AND DEADLINES

There is probably no industry in the commercial environment that does not impose some form of deadline, and consequently time pressure, on its employees. Aircraft maintenance is no exception. It was highlighted in the previous section that one of the potential stressors in maintenance is time pressure. This might be actual pressure where clearly specified deadlines are imposed by an external source (e.g. management or supervisors) and passed on to engineers, or perceived where engineers feel that there are time pressures when carrying out tasks, even when no definitive deadlines have been set in stone. In addition, time pressure may be self-imposed, in which case engineers set themselves deadlines to complete work (e.g. completing a task before a break or before the end of a shift).

Management have contractual pressures associated with ensuring an aircraft is released to service within the time frame specified by their customers. Striving for higher aircraft utilisation means that more maintenance must be accomplished in fewer hours, with these hours frequently being at night. Failure to do so can impact on flight punctuality and passenger satisfaction. Thus, aircraft maintenance engineers have two driving forces: the deadlines handed down to them and their responsibilities to carry out a safe job. The potential conflict between these two driving pressures can cause problems.

The Effects of Time Pressure and Deadlines

As with stress, it is generally thought that some time pressure is stimulating and may actually improve task performance. However, it is almost certainly true that excessive time pressure (either actual or perceived, external or self-imposed), is likely to mean that due care and attention when carrying out tasks diminishes and more errors will be made. Ultimately, these errors can lead to aircraft incidents and accidents.

It is possible that perceived time pressure would appear to have been a contributory factor in the BAC 1-11 accident described in Chapter 1. Although the aircraft was not required the following morning for operational use, it was booked for a wash. The wash team had been booked the previous week and an aircraft had not been ready. This would have happened again, due to short-staffing, so the Shift Manager decided to carry out the windscreen replacement task himself so that the aircraft would be ready in time.

An extract from the NTSB report on the Aloha accident refers to time pressure as a possible contributory factor in the accident: “The majority of Aloha's maintenance was normally conducted only during the night. It was considered important that the airplanes be available again for the next day's flying schedule. Such aircraft utilization tends to drive the scheduling, and indeed, the completion of required maintenance work. Mechanics and inspectors are forced to perform under time pressure. Further, the intense effort to keep the airplanes flying may have been so strong that the maintenance personnel were reluctant to keep airplanes in the hangar any longer than absolutely necessary.”

Managing Time Pressure and Deadlines

One potential method of managing time pressures exerted on engineers is through regulation. For example, FAA research has highlighted the need to insulate aircraft maintenance engineers from commercial pressures. They consider this would help to ensure that airworthiness issues will always take precedence over commercial and time pressures. Time pressures can make ‘corner-cutting’ a cultural norm in an organisation. Sometimes, only an incident or accident reveals such norms (the extract from the Aloha accident above exemplifies this).

Those responsible for setting deadlines and allocating tasks should consider:

- Prioritising various pieces of work that need to be done;
- The actual time available to carry out work (considering breaks, shift handovers, etc.);
- The personnel available throughout the whole job (allowing a contingency for illness);
- The most appropriate utilisation of staff (considering an engineer’s specialisation, and strengths and limitations);
- Availability of parts and spares.

It is important that engineering staff at all levels are not afraid to voice concerns over inappropriate deadlines, and if necessary, cite the need to do a safe job to support this. As highlighted in Chapter 3, within aircraft maintenance, responsibility should be spread across all those who play a part. Thus, the aircraft maintenance engineer should not feel that the ‘buck stops here’.

WORKLOAD - OVERLOAD AND UNDERLOAD

The preceding sections on stress and time pressure have both indicated that a certain amount of stimulation is beneficial to an aircraft maintenance engineer, but that too much stimulation can lead to stress or over-commitment in terms of time. It is noteworthy that too little stimulation can also be a problem.

Before going on to discuss workload, it is important to consider this optimum level of stimulation or arousal.

Arousal

Arousal in its most general sense, refers to readiness of a person for performing work. To achieve an optimum level of task performance, it is necessary to have a certain level of stimulation or arousal. This level of stimulation or arousal varies from person to person. There are people who are overloaded by having to do more than one task at a time; on the other hand there are people who appear to thrive on stress, being happy to take on more and more work or challenges. Figure 16 shows the general relationship between arousal and task performance.

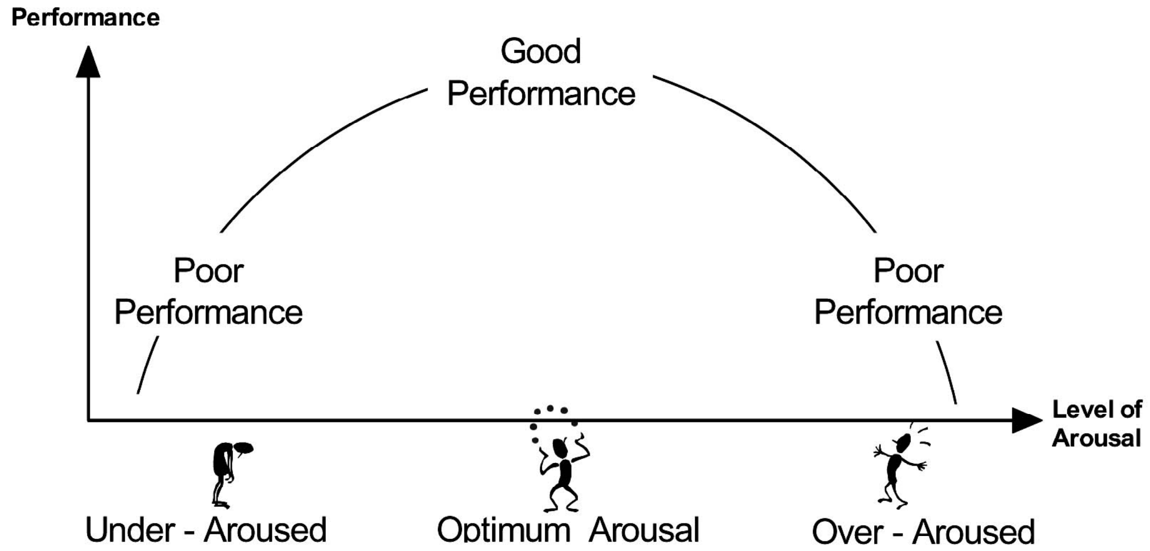


Fig. Optimum arousal leads to best task performance (adapted from Thom 1999)

At low levels of arousal, our attentional mechanisms will not be particularly active and our performance capability will be low (complacency and boredom can result). At the other end of the curve, performance deteriorates when arousal becomes too high. To a certain extent, this is because we are forced to shed tasks and focus on key information only (called narrowing of attention). Best task performance occurs somewhere in the middle.

In the work place, arousal is mainly influenced by stimulation due to work tasks. However, surrounding environmental factors such as noise may also influence the level of arousal.

Factors Determining Workload

An individual aircraft maintenance engineer can usually identify what work he has to do quite easily. It is more difficult to assess how that work translates into workload.

The degree of stimulation exerted on an individual caused by a task is generally referred to as workload, and can be separated into physical workload and mental workload.

As noted in the section on information processing in Chapter 2, humans have limited mental capacity to deal with information. We are also limited physically, in terms of visual acuity, strength, dexterity and so on. Thus, workload reflects the degree to which the demands of the work we have to do eats into our mental and physical capacities. Workload is subjective (i.e. experienced differently by different people) and is affected by:

- The nature of the task, such as the:
  - physical demands it requires (e.g. strength required, etc.);
  - mental demands it requires (e.g. complexity of decisions to be made, etc.).
- The circumstances under which the task is performed, such as the:
  - standard of performance required (i.e. degree of accuracy);
  - time available to accomplish the task (and thus the speed at which the task must be carried out);
  - requirement to carry out the task at the same time as doing something else;
  - perceived control of the task (i.e. is it imposed by others or under your control, etc.);
  - environmental factors existing at time (e.g. extremes of temperature, etc.).
- The person and his state, such as his:
  - skills (both physical and mental);
  - his experience (particularly familiarity with the task in question);
  - his current health and fitness levels;
  - his emotional state (e.g. stress level, mood, etc.).

As the workload of the engineer may vary, he may experience periods of overload and underload. This is a particular feature of some areas of the industry such as line maintenance.

Overload

Overload occurs at very high levels of workload (when the engineer becomes over aroused). As highlighted previously, performance deteriorates when arousal becomes too high and we are forced to shed tasks and focus on key information. Error rates may also increase. Overload can occur for a wide range of reasons based on the factors highlighted above. It may happen suddenly (e.g. if asked to remember one further piece of information whilst already trying to remember a large amount of data), or gradually. Although JAR145 states that "The JAR145 approved maintenance organisation must employ sufficient personnel to plan, perform, supervise and inspect the work in accordance with the approval"1, and "the JAR145 organisation should have a production man hours plan showing that it has sufficient man hours for the work that is intended to be carried out"1, this does not prevent individuals from becoming overloaded. As noted earlier in this section, it can be difficult to determine how work translates into workload, both for the individual concerned, and for those allocating tasks.

Underload

Underload occurs at low levels of workload (when the engineer becomes under aroused). It can be just as problematic to an engineer as overload, as it too causes a deterioration in performance and an increase in errors, such as missed information. Underload can result from a task an engineer finds boring, very easy, or indeed a lack of tasks. The nature of the aircraft maintenance industry means that available work fluctuates, depending on time of day, maintenance schedules, and so forth. Hence, unless stimulating 'housekeeping' tasks can be found, underload can be difficult to avoid at times.

Workload Management

Unfortunately, in a commercial environment, it is seldom possible to make large amendments to maintenance schedules, nor eliminate time pressures. The essence of workload management in aircraft maintenance should include:

- ensuring that staff have the skills needed to do the tasks they have been asked to do and the proficiency and experience to do the tasks within the timescales they have been asked to work within;
- making sure that staff have the tools and spares they need to do the tasks;
- allocating tasks to teams or individual engineers that are accomplishable (without cutting corners) in the time available;
- providing human factors training to those responsible for planning so that the performance and limitations of their staff are taken into account;
- encouraging individual engineers, supervisors and managers to recognise when an overload situation is building up.

If an overload situation is developing, methods to help relieve this include:

- seeking a simpler method of carrying out the work (that is just as effective and still legitimate);
- delegating certain activities to others to avoid an individual engineer becoming overloaded;
- securing further time in order to carry out the work safely;
- postponing, delaying tasks/deadlines and refusing additional work.

Thus, although workload varies in aircraft maintenance engineering, the workload of engineers can be moderated. Much of this can be done by careful forward planning of tasks, manpower, spares, tools and training of staff.

SLEEP, FATIGUE AND SHIFT WORK

What Is Sleep?

Man, like all living creatures has to have sleep. Despite a great deal of research, the purpose of sleep is not fully understood.

> Sleep is a natural state of reduced consciousness involving changes in body and brain physiology which is necessary to man to restore and replenish the body and brain.

Sleep can be resisted for a short time, but various parts of the brain ensure that sooner or later, sleep occurs. When it does, it is characterised by five stages of sleep:

- Stage 1: This is a transitional phase between waking and sleeping. The heart rate slows and muscles relax. It is easy to wake someone up.
- Stage 2: This is a deeper level of sleep, but it is still fairly easy to wake someone.
- Stage 3: Sleep is even deeper and the sleeper is now quite unresponsive to external stimuli and so is difficult to wake. Heart rate, blood pressure and body temperature continue to drop.
- Stage 4: This is the deepest stage of sleep and it is very difficult to wake someone up.

- Rapid Eye Movement or REM Sleep: Even though this stage is characterised by brain activity similar to a person who is awake, the person is even more difficult to awaken than stage 4. It is therefore also known as paradoxical sleep. Muscles become totally relaxed and the eyes rapidly dart back and forth under the eyelids. It is thought that dreaming occurs during REM sleep.

Stages 1 to 4 are collectively known as non-REM (NREM) sleep. Stages 2-4 are categorised as slow-wave sleep and appear to relate to body restoration, whereas REM sleep seems to aid the strengthening and organisation of memories. Sleep deprivation experiments suggest that if a person is deprived of stage 1-4 sleep or REM sleep he will show rebound effects. This means that in subsequent sleep, he will make up the deficit in that particular type of sleep. This shows the importance of both types of sleep.

As can be seen from Figure below, sleep occurs in cycles. Typically, the first REM sleep will occur about 90 minutes after the onset of sleep. The cycle of stage 1 to 4 sleep and REM sleep repeats during the night about every 90 minutes. Most deep sleep occurs earlier in the night and REM sleep becomes greater as the night goes on.

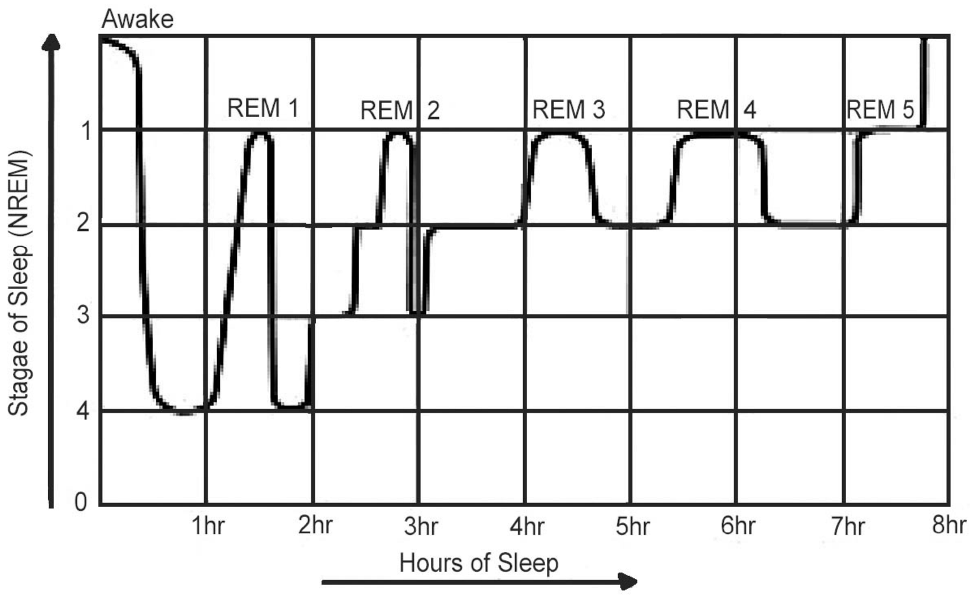


Fig. Typical cycle of stage 1-4 (NREM) sleep and REM sleep in the course of a night. Source: Gross, 19961

Circadian Rhythms

Apart from the alternation between wakefulness and sleep, man has other internal cycles, such as body temperature and hunger/eating. These are known as circadian rhythms as they are related to the length of the day.

Circadian rhythms are physiological and behavioural functions and processes in the body that have a regular cycle of approximately a day (actually about 25 hours in man).

Although, circadian rhythms are controlled by the brain, they are influenced and synchronised by external (environmental) factors such as light.

An example of disrupting circadian rhythms would be taking a flight that crosses time zones. This will interfere with the normal synchronisation with the light and dark (day/night). This throws out the natural link between daylight and the body's internal clock, causing jet lag, resulting in sleepiness during the day, etc. Eventually however, the circadian rhythm readjusts to the revised environmental cues.

Figure below shows the circadian rhythm for body temperature. This pattern is very robust, meaning that even if the normal pattern of wakefulness and sleep is disrupted (by shift work for example), the temperature cycle remains unchanged. Hence, it can be seen that if you are awake at 4-6 o'clock in the morning, your body temperature is in a trough and it is at this time that is hardest to stay awake. Research has shown that this drop in body temperature appears to be linked to a drop in alertness and performance in man.

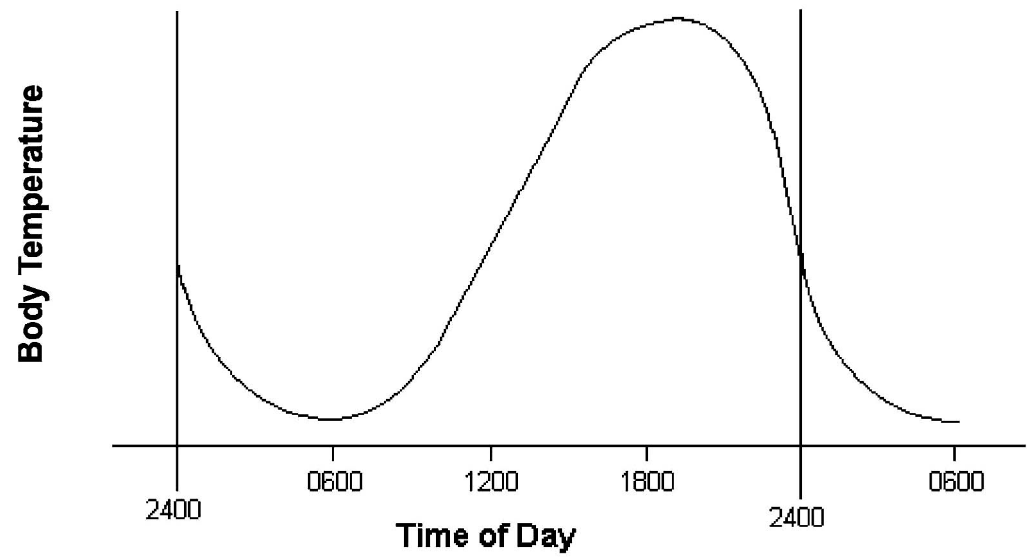


Fig. The Circadian Rhythm for Internal Body Temperature

Although there are many contributory factors, it is noteworthy that a number of major incidents and accidents involving human error have either occurred or were initiated in the pre-dawn hours, when body temperature and performance capability are both at their lowest. These include Three Mile Island, Chernobyl, and Bhopal, as well as the BAC1-11, A320, and B737 incidents summarised in Chapter 1.

The engineer's performance at this 'low point' will be improved if he is well rested, feeling well, highly motivated and well practised in the skills being used at that point.

Fatigue

Fatigue can be either physiological or subjective. Physiological fatigue reflects the body's need for replenishment and restoration. It is tied in with factors such as recent physical activity, current health, consumption of alcohol, and with circadian rhythms. It can only be satisfied by rest and eventually, a period of sleep. Subjective fatigue is an individual's perception of how sleepy they feel. This is not only affected by when they last slept and how good the sleep was but other factors, such as degree of motivation.

Fatigue is typically caused by delayed sleep, sleep loss, desynchronisation of normal circadian rhythms and concentrated periods of physical or mental stress or exertion. In the workplace, working long hours, working during normal sleep hours and working on rotating shift schedules all produce fatigue to some extent.

Symptoms of fatigue (in no particular order) may include:

- diminished perception (vision, hearing, etc.) and a general lack of awareness;
- diminished motor skills and slow reactions;
- problems with short-term memory;
- channelled concentration - fixation on a single possibly unimportant issue, to the neglect of others and failing to maintain an overview;
- being easily distracted by unimportant matters;
- poor judgement and decision making leading to increased mistakes;
- abnormal moods - erratic changes in mood, depressed, periodically elated and energetic;
- diminished standards of own work.

AWN47 highlights the potential for fatigue in aircraft maintenance engineering:

> "Tiredness and fatigue can adversely affect performance. Excessive hours of duty and shift working, particularly with multiple shift periods or additional overtime, can lead to problems. Individuals should be fully aware of the dangers of impaired performance due to these factors and of their personal responsibilities."

Shift Work

Most aircraft movements occur between 6 a.m. and 10 p.m. to fit in with the requirements of passengers. Aircraft maintenance engineers are required whenever aircraft are on the ground, such as during turn arounds. However, this scheduling means that aircraft are often available for more significant maintenance during the night. Thus, aircraft maintenance engineering is clearly a 24 hour business and it is inevitable that, to fulfil commercial obligations, aircraft maintenance engineers usually work shifts. Some engineers permanently work the same shift, but the majority cycle through different shifts. These typically comprise either an 'early shift', a 'late shift' and a 'night shift', or a 'day shift' and a 'night shift' depending on the maintenance organisation.

Advantages and Disadvantages of Shift Work

There are pros and cons to working shifts. Some people welcome the variety of working different times associated with regular shift work patterns. Advantages may include more days off and avoiding peak traffic times when travelling to work. The disadvantages of shift working are mainly associated with:

- working 'unsociable hours', meaning that time available with friends, family, etc. will be disrupted;
- working when human performance is known to be poorer (i.e. between 4 a.m and 6 a.m.);

- problems associated with general desynchronisation and disturbance of the body's various rhythms (principally sleeping patterns).

Working At Night

Shift work means that engineers will usually have to work at night, either permanently or as part of a rolling shift pattern. As discussed earlier in this chapter, this introduces the inherent possibility of increased human errors. Working nights can also lead to problems sleeping during the day, due to the interference of daylight and environmental noise. Blackout curtains and use of ear plugs can help, as well as avoidance of caffeine before sleep.

> In the B737 double engine oil loss incident, the error occurred during the night shift. The accident investigation report commented that: "It is under these circumstances that the fragility of the self monitoring system is most exposed because the safety system can be jeopardised by poor judgement on the part of one person and it is also the time at which people are most likely to suffer impaired judgement" .

Rolling Shift Patterns

When an engineer works rolling shifts and changes from one shift to another (e.g. 'day shift' to 'night shift'), the body's internal clock is not immediately reset. It continues on its old wake-sleep cycle for several days, even though it is no longer possible for the person to sleep when the body thinks it is appropriate, and is only gradually resynchronised. However, by this time, the engineer may have moved onto the next shift. Generally, it is now accepted that shift rotation should be to later shifts (i.e. early shift → late shift → night shift or day shift → night shift) instead of rotation towards earlier shifts (night shift → late shift → early shift).

Continuity of Tasks and Shift Handovers

Many maintenance tasks often span more than one shift, requiring tasks to be passed from one shift to the next. The outgoing personnel are at the end of anything up to a twelve hour shift and are consequently tired and eager to go home. Therefore, shift handover is potentially an area where human errors can occur. Whilst longer shifts may result in greater fatigue, the disadvantages may be offset by the fact that fewer shift changeovers are required (i.e. only 2 handovers with 2 twelve hour shifts, as opposed to 3 handovers with 3 eight hour shifts). Shift handover is discussed further in Chapter 7 when looking at 'work logging and recording'.

Sleep, Fatigue, Shift Work and the Aircraft Maintenance Engineer

Most individuals need approximately 8 hours sleep in a 24 hour period, although this varies between individuals, some needing more and some happy with less than this to be fully refreshed. They can usually perform adequately with less that this for a few days, building up a temporary sleep 'deficit'. However, any sleep deficit will need to be made up, otherwise performance will start to suffer.

> A good rule of thumb is that one hour of high-quality sleep is good for two hours of activity.

As previously noted, fatigue is best tackled by ensuring adequate rest and good quality sleep are obtained. The use of blackout curtains if having to sleep during daylight has already been mentioned. It is also best not to eat a large meal shortly before trying to sleep, but on the other hand, the engineer should avoid going to bed hungry. As fatigue is also influenced by illness, alcohol, etc., it is very important to get more sleep if feeling a little unwell and drink only in moderation between duties (discussed further in the next section). Taking over-the-counter drugs to help sleep should only be used as a last resort.

When rotating shifts are worked, it is important that the engineer is disciplined with his eating and sleeping times. Moreover, out of work activities have to be carefully planned. For example, it is obvious that an individual who has been out night-clubbing until the early hours of the morning will not be adequately rested if rostered on an early shift.

Shift working patterns encountered by aircraft maintenance engineers may include three or four days off after the last night shift. It can be tempting to work additional hours, taking voluntary overtime, or another job, in one or more of these days off. This is especially the case when first starting a career in aircraft maintenance engineering when financial pressures may be higher. Engineers should be aware that their vulnerability to error is likely to be increased if they are tired or fatigued, and they should try to ensure that any extra hours worked are kept within reason.

> It is always sensible to monitor ones performance, especially when working additional hours. Performance decrements can be gradual, and first signs of chronic fatigue may be moodiness, headaches or finding that familiar tasks (such as programming the video recorder) seem more complicated than usual.

Aircraft maintenance is frequently performed at night. Physiologically and mentally we are most alert during daylight hours and prefer to rest or sleep at night. When job requirements disturb this pattern, work performance deficits can follow. This can certainly pose problems in aircraft maintenance where safety is vitally connected to error-free technician performance. In most maintenance-error accidents, like the ones discussed in this chapter, the faulty maintenance work which contributed to the accident was performed during night shift working hours (inducing L-E interface flaw). Operators should carefully examine work assignments for their effects on technicians and their work. Physically demanding tasks should not be followed by tedious work requiring intense concentration. Management should be aware of the hazards of such activities as repetitive inspection of identical items such as rivets or turbine blades. A long history of research shows that operator vigilance declines rapidly on these tasks and error can easily follow. Similarly, use of certain types of equipment is associated with work error. Old-style inspection devices rely heavily on technicians' skill in manipulating equipment and in detecting and interpreting subtle instrument indications. Couple these difficulties with a fatigued technician and the probability for error increases dramatically. Shift supervisors need to be especially observant of technician fatigue and to oversee and perform follow-up checks of tasks to discover any resulting errors. Inspection during daylight hours of maintenance work accomplished the previous night could also go a long way towards reducing the probability of an error such as happened on the accident aircraft.

Finally, it is worth noting that, although most engineers adapt to shift working, it becomes harder to work rotating shifts as one gets older.

For studying more about fatigue, body rythm disturbance and sleep refer Chapter-1; Page 1 and 11.

ALCOHOL, MEDICATION AND DRUG ABUSE

It should come as no surprise to the aircraft maintenance engineer that his performance will be affected by alcohol, medication or illicit drugs. Under both UK and JAA legislation it is an offence for safety critical personnel to carry out their duties whilst under the influence of alcohol or drugs. Article 13 (paragraph 8) of the UK ANO, states:

> “The holder of an aircraft maintenance engineer’s licence shall not, when exercising the privileges of such a licence, be under the influence of drink or a drug to such an extent as to impair his capacity to exercise such privileges.”

The current law which does not prescribe a blood/alcohol limit, is soon to change. There will be new legislation permitting police to test for drink or drugs where there is reasonable cause, and the introduction of a blood/alcohol limit of 20 milligrams of alcohol per 100 millilitres of blood for anyone performing a safety critical role in UK civil aviation (which includes aircraft maintenance engineers).

Alcohol

Alcohol acts as a depressant on the central nervous system, dulling the senses and increasing mental and physical reaction times. It is known that even a small amount of alcohol leads to a decline in an individual’s performance and may cause his judgement (i.e. ability to gauge his performance) to be hindered.

Alcohol is removed from the blood at a fixed rate and this cannot be speeded up in any way (e.g. by drinking strong coffee). In fact, sleeping after drinking alcohol can slow down the removal process, as the body’s metabolic systems are slower.

AWN47 provides the following advice concerning alcohol:

> “Alcohol has similar effects to tranquillisers and sleeping tablets and may remain circulating in the blood for a considerable time, especially if taken with food. It may be borne in mind that a person may not be fit to go on duty even 8 hours after drinking large amounts of alcohol. Individuals should therefore anticipate such effects upon their next duty period. Special note should be taken of the fact that combinations of alcohol and sleeping tablets, or anti-histamines, can form a highly dangerous and even lethal combination.”

As a general rule, aircraft maintenance engineers should not work for at least eight hours after drinking even small quantities of alcohol and increase this time if more has been drunk.

The affects of alcohol can be made considerably worse if the individual is fatigued, ill or using medication.

Medication

Any medication, no matter how common, can possibly have direct effects or side effects that may impair an engineer’s performance in the workplace.

Medication can be regarded as any over-the-counter or prescribed drug used for therapeutic purposes.

There is a risk that these effects can be amplified if an individual has a particular sensitivity to the medication or one of its ingredients. Hence, an aircraft maintenance engineer should be particularly careful when taking a medicine for the first time, and should ask his doctor whether any prescribed drug will affect his work performance. It is also wise with any medication to take the first dose at least 24 hours before any duty to ensure that it does not have any adverse effects.

> Medication is usually taken to relieve symptoms of an illness. Even if the drugs taken do not affect the engineer's performance, he should still ask himself whether the illness has made him temporarily unfit for work.

Various publications, and especially AWN47 give advice relevant to the aircraft maintenance engineer on some of the more common medications. This information is summarised below, however the engineer must use this with caution and should seek further clarification from a pharmacist, doctor or their company occupational health advisor if at all unsure of the impact on work performance.

- **Analgesics** are used for pain relief and to counter the symptoms of colds and 'flu. In the UK, paracetamol, aspirin and ibuprofen are the most common, and are generally considered safe if used as directed. They can be taken alone but are often used as an ingredient of a 'cold relief' medicine. It is always worth bearing in mind that the pain or discomfort that you are attempting to treat with an analgesic (e.g. headache, sore throat, etc.) may be the symptom of some underlying illness that needs proper medical attention.
- **Antibiotics** (such as Penicillin and the various mycins and cyclines) may have short term or delayed effects which affect work performance. Their use indicates that a fairly severe infection may well be present and apart from the effects of these substances themselves, the side-effects of the infection will almost always render an individual unfit for work.
- **Anti-histamines** are used widely in 'cold cures' and in the treatment of allergies (e.g. hayfever). Most of this group of medicines tend to make the user feel drowsy, meaning that the use of medicines containing anti-histamines is likely to be unacceptable when working as an aircraft maintenance engineer.
- Cough suppressants are generally safe in normal use, but if an over-the-counter product contains anti-histamine, decongestant, etc., the engineer should exercise caution about its use when working.
- **Decongestants** (i.e. treatments for nasal congestion) may contain chemicals such as pseudo-ephedrine hydrochloride (e.g. 'Sudafed') and phenylphrine. Side-effects reported, are anxiety, tremor, rapid pulse and headache. AWN47 forbids the use of medications containing this ingredient to aircraft maintenance engineers when working, as the effects compromise skilled performance.
- **'Pep' pills** are used to maintain wakefulness. They often contain caffeine, dexedrine or benzedrine. Their use is often habit forming. Over-dosage may cause headaches, dizziness and mental disturbances. AWN47 states that "the use of 'pep' pills whilst working cannot be permitted. If coffee is insufficient, you are not fit for work."
- **Sleeping tablets** (often anti-histamine based) tend to slow reaction times and generally dull the senses. The duration of effect is variable from person to person. Individuals should obtain expert medical advice before taking them.

Melatonin (a natural hormone) deserves a special mention. Although not available without a prescription in the UK, it is classed as a food supplement in the USA (and is readily available in health food shops). It has been claimed to be effective as a sleep aid, and to help promote the resynchronisation of disturbed circadian rhythms. Its effectiveness and safety are still yet to be proven and current best advice is to avoid this product.

Drugs

Illicit drugs such as ecstasy, cocaine and heroin all affect the central nervous system and impair mental function. They are known to have significant effects upon performance and have no place within the aviation maintenance environment. Of course, their possession and use are also illegal in the UK.

Smoking cannabis can subtly impair performance for up to 24 hours. In particular, it affects the ability to concentrate, retain information and make reasoned judgements, especially on difficult tasks.

■■■

CHAPTER 5
PHYSICAL ENVIRONMENT

The aircraft maintenance engineer can expect to work in a variety of different environments, from 'line' (generally outside the hangar) to 'base' (usually inside a hangar or workshop), in all types of weather and climatic conditions, day and night. This depends largely on the company he works for, and the function he fulfils in the company. Both physical environments have their own specific features or factors that may impinge on human performance. This chapter considers the impact of noise, fumes, illumination, climate and temperature, motion and vibration, as well as the requirement to work in confined spaces and issues associated with the general working environment.

NOISE

The impact of noise on human performance has already been discussed in Chapter 2, when examining 'hearing'. To recap, noise in the workplace can have both short-term and long-term negative effects: it can be annoying, can interfere with verbal communication and mask warnings, and it can damage workers' hearing (either temporarily or permanently). It was noted that the ear is sensitive to sounds between certain frequencies (20 HZ to 20 KHz) and that intensity of sound is measured in decibels (dB), where exposure in excess of 115 dB without ear protection even for a short duration is not recommended. This equates to standing within a few hundred metres of a moving jet aircraft.

Noise can also be defined as any unwanted sound. There are two important aspects of noise which must be considered: the sources of noise, and the physiological and psychological effects on the person exposed to it. Noise affects a person in many ways depending on whether it is expected, whether it makes a task more difficult, and whether the person is relaxed or alert.

Major sources of noise in fixed-wing aircraft include the engines, the air conditioning, pressurization and hydraulic systems, and boundary layer turbulence. Inside the aircraft, noise is louder near the sides of the fuselage than at the centre. Noise level in the cockpit is easily changed by the interaction of the airflow with the fuselage surface. Soundproofing will reduce noise, but it will increase aircraft weight as well. This has many undesirable effects such as increases in fuel cost. Design improvement to reduce noise at its source would be a better alternative. For example, removing the windshield wipers in one particular large jet transport reduced the flight deck noise level by 2 dB.

The most important pathogenic effect of noise, impaired hearing, has already been discussed in 4.2. Other physiological effects include changes in blood pressure and heart rate, headaches, tiredness and gastrointestinal problems such as ulcers. In the past, prolonged monitoring of high-frequency (HF) radio represented a significant exposure to noise. This has been alleviated by the introduction of selective calling (SELCAL). Technological progress in communications — as well as in other areas — will certainly provide new improvements in hearing protection. The fact remains, however, that crew members who are exposed to intense aircraft noise over a long period of time can be expected to suffer hearing loss in addition to the natural loss through ageing.

Noise affects performance by interfering with the detection and understanding of task-related signals or speech. It interferes with verbal communication by affecting the signal-to-noise ratio and by decreasing speech intelligibility. It further affects verbal communication by impairing hearing.

> Noise can be thought of as any unwanted sound, especially if it is loud, unpleasant and annoying.

General background noise can be 'filtered out' by the brain through focused attention (as noted in Chapter 2, Section 3). Otherwise, for more problematic noise, some form of hearing protection (e.g. ear plugs and ear muffs) is commonly used by aircraft maintenance engineers, both on the line and in the hangar, to help the engineer to concentrate.

The noise environment in which the aircraft maintenance engineer works can vary considerably. For instance, the airport ramp or apron area is clearly noisy, due to running aircraft engines or auxiliary power units (APUs), moving vehicles and so on. It is not unusual for this to exceed 85 dB - 90 dB which can cause hearing damage if the time of exposure is prolonged. The hangar area can also be noisy, usually due to the use of various tools during aircraft maintenance. Short periods of intense noise are not uncommon here and can cause temporary hearing loss. Engineers may move to and from these noisy areas into the relative quiet of rest rooms, aircraft cabins, stores and offices.

> It is very important that aircraft maintenance engineers remain aware of the extent of the noise around them. It is likely that some form of hearing protection should be carried with them at all times and, as a rule of thumb, used when remaining in an area where normal speech cannot be heard clearly at 2 metres.

In their day-to-day work, aircraft maintenance engineers will often need to discuss matters relating to a task with colleagues and also, at the end of a shift, handover to an incoming engineer. Clearly, in both cases it is important that noise does not impair their ability to communicate, as this could obviously have a bearing on the successful completion of the task (i.e. safety). Common sense dictates that important matters are discussed away from noisy areas.

FUMES

By its nature, the maintenance of aircraft involves working with a variety of fluids and chemical substances. For instance, engineers may come across various lubricants (oils and greases), hydraulic fluids, paints, cleaning compounds and solder. They will also be exposed to aircraft fuel and exhaust. In fact, there is every possibility that an engineer could be exposed to a number of these at any one time in the workplace. Each substance gives off some form of vapour or fumes which can be inhaled by the aircraft maintenance engineer. Some fumes will be obvious as a result of their odour, whereas others have no smell to indicate their presence. Some substances will be benign most of the time, but may, in certain circumstances, produce fumes (e.g. overheated grease or oils, smouldering insulation).

Fumes can cause problems for engineers mainly as a result of inhalation, but they can also cause other problems, such as eye irritation. The problem may be exacerbated in aircraft maintenance engineering by the confined spaces in which work must sometimes be carried out (e.g. fuel tanks). Here the fumes cannot dissipate easily and it may be appropriate to use breathing apparatus.

It may not always be practical to eradicate fumes from the aircraft maintenance engineer's work place, but where possible, steps should be taken to minimise them. It is also common sense that if noxious fumes are detected, an engineer should immediately inform his colleagues and supervisor so that the area can be evacuated and suitable steps taken to investigate the source and remove them.

> Apart from noxious fumes that have serious health implications and must be avoided, working in the presence of fumes can affect an engineer's performance, as he may rush a job in order to escape them. If the fumes are likely to have this effect, the engineer should increase the ventilation locally or use breathing apparatus to dissipate the fumes.

ILLUMINATION

The nature and quantity of cockpit illumination required for a certain task may vary considerably. Factors of importance are the speed and accuracy with which the displays must be read, the ambient illumination, other light sources (in particular, sunshine), and the presence of glare. Glare is defined as a condition of vision where there is discomfort or a reduction in the ability to see significant objects, or both, due to an unsuitable distribution or range of luminance (i.e. density of light, or light intensity per unit projected area) or to extreme contrasts in space or time.

Glare is an important aspect of the quality of the illuminated environment. It can be caused by bright light sources or light reflection off environmental surfaces. Glare may produce discomfort or annoyance, and may interfere with visual performance. The type of reflection off surfaces depends on the properties of the surface (e.g. whether it is polished, rough or matted). Some evidence suggests that there is an element of subjectivity in tolerance to glare. The most effective techniques for reducing glare include blocking the glare surface or placing supplementary lighting to offset the effects of glare.

In order that aircraft maintenance engineers are able to carry out their work safely and efficiently, it is imperative that their work be conducted under proper lighting conditions. It was noted in Chapter 2, that the cones in the retina of the eye require good light to resolve fine detail. Furthermore, colour vision requires adequate light to stimulate the cones. Inappropriate or insufficient lighting can lead to mistakes in work tasks or can increase the time required to do the work.

> Illumination refers to the lighting both within the general working environment and also in the locality of the engineer and the task he is carrying out. It can be defined as the amount of light striking a surface.

When working outside during daylight, the engineer may have sufficient natural light to see well by. It is possible however that he may be in shadow (possibly caused by the aircraft) or a building. Similarly, cramped equipment compartments will not be illuminated by ambient hangar lighting. In these cases, additional local artificial lighting is usually required (known as task lighting). At night, aerodromes may appear to be awash with floodlights and other aerodrome lighting, but these are unlikely to provide sufficient illumination for an engineer to be able to see what he is doing when working on an aircraft. These lights are not designed and placed for this purpose. Again, additional local artificial lighting is needed, which may be nothing more than a good torch (i.e. one which does not have a dark area in the centre of the beam). However, the drawback of a torch, is that it leaves the engineer with only one hand available with which to work. A light mounted on a headband gets round this problem.

Please refer to Photograph below.

Use of artificial lighting to suppliment the ambient illumination in hanger

> A torch can be very useful to the engineer, but Murphy's Law dictates that the torch batteries will run down when the engineer is across the airfield from the stores. It is much wiser to carry a spare set of batteries than 'take a chance' by attempting a job without enough light.

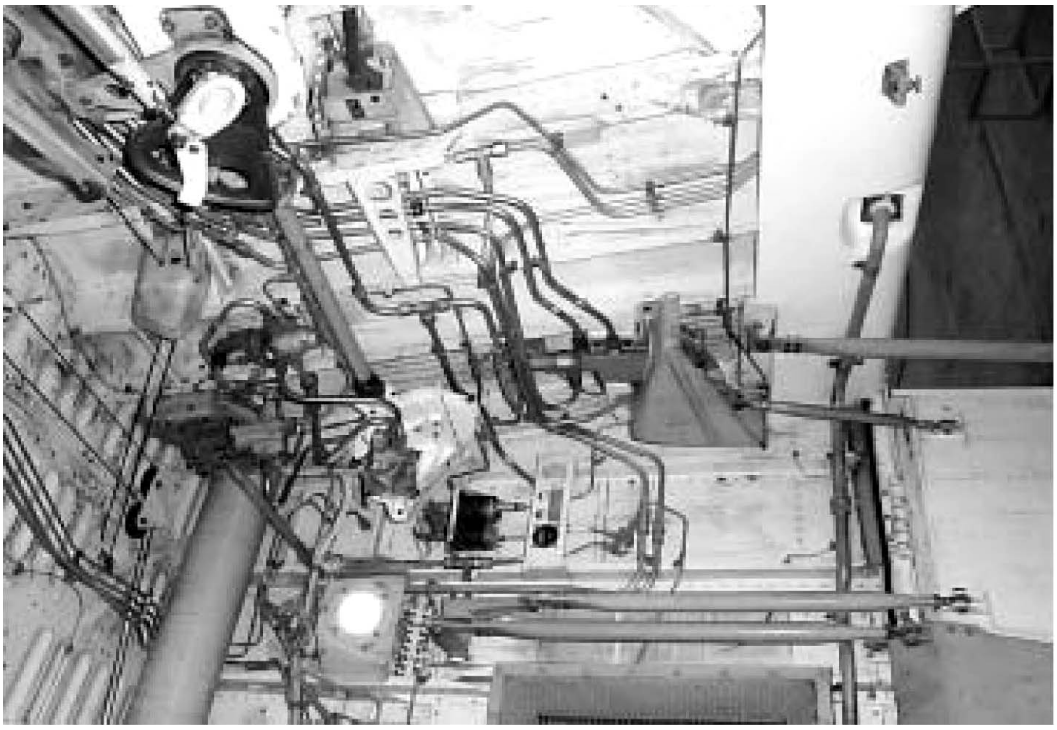
Within the hangar, general area lighting tends to be some distance from the aircraft on which an engineer might work, as it is usually attached to the very high ceiling of these buildings. This makes these lights hard to reach, meaning that they tend to get dusty, making them less effective and, in addition, failed bulbs tend not to be replaced as soon as they go out. In general, area lighting in hangars is unlikely to be as bright as natural daylight and, as a consequence, local task lighting is often needed, especially for work of a precise nature (particularly visual inspection tasks).

An extract from the NTSB report on the Northwest Airlines accident at Tokyo, 1994, illustrates these points:

"The Safety Board believes that the "OK to Close" inspector was hindered considerably by the environment of the pylon area. He indicated, for example, that the combination of location of the scaffolding (at a level just below the underside of the wing that forced him into unusual and uncomfortable physical positions) and inadequate lighting from the base of the scaffolding up toward the pylon, hampered his inspection efforts. Moreover, the underside of the pylon was illuminated by portable fluorescent lights that had been placed along the floor of the scaffolding. These lights had previously been used in areas where airplanes were painted, and, as a result, had been covered with the residue of numerous paint applications that diminished their brightness. These factors combined to cause the inspector to view the fuse pin retainers by holding onto the airplane structure with one hand, leaning under the bat wing doors at an angle of at least 30°, holding a flashlight with the other hand pointing to the area, and moving his head awkwardly to face up into the pylon area."

It is also important that illumination is available where the engineer needs it (i.e. both in the hangar and one the line). Any supplemental task lighting must be adequate in terms of its brightness for the task at hand, which is best judged by the engineer. When using task lighting, it should be placed close to the work being done, but should not be in the engineer's line of sight as this will result in direct glare. It must also be arranged so that it does not reflect off surfaces near where the engineer is working causing indirect or reflected glare. Glare of either kind will be a distraction from the task and may cause mistakes.

Please refer to Photograph below.



Task lighting to facilitate internal insection and work

Poor ambient illumination of work areas has been identified as a significant deficiency during the investigation of certain engineering incidents. It is equally important that lighting in ancillary areas, such as offices and stores, is good.

> The AAIB report for the BAC 1-11 accident says of the unmanned stores area: "The ambient illumination in this area was poor and the Shift Maintenance Manager had to interpose himself between the carousel and the light source to gain access to the relevant carousel drawers. He did not use the drawer labels, even though he now knew the part number of the removed bolt, but identified what he thought were identical bolts by placing the bolts together and comparing them." He also failed to make use of his spectacles.

Relying on touch when lighting is poor is no substitute for actually being able to see what you are doing. If necessary, tools such as mirrors and borescopes may be needed to help the engineer see into remote areas.

CLIMATE AND TEMPERATURE

Humans can work within quite a wide range of temperatures and climatic conditions, but performance is adversely affected at extremes of these. Thus, as can be seen in Figure 19, when it is either too cold and/or wet or too hot and/or humid, performance diminishes.

As has been noted throughout this document, aircraft maintenance engineers routinely work both within the hangar and outside. Clearly, exposure to the widest range of temperature and climate is likely to be encountered outdoors. Here, an engineer may have to work in direct summer sun, strong winds, heavy rain, high humidity, or in the depths of winter. Although hangars must exclude inclement weather, they can be cold and draughty, especially if the hangar doors have to remain open.

JAR AMC 145.25 (c) states: "Hangars used to house aircraft together with office accommodation should be such as to ensure the working environment permits personnel to carry out work tasks in an effective manner. Temperatures should be maintained such that personnel can carry out required tasks without undue discomfort."

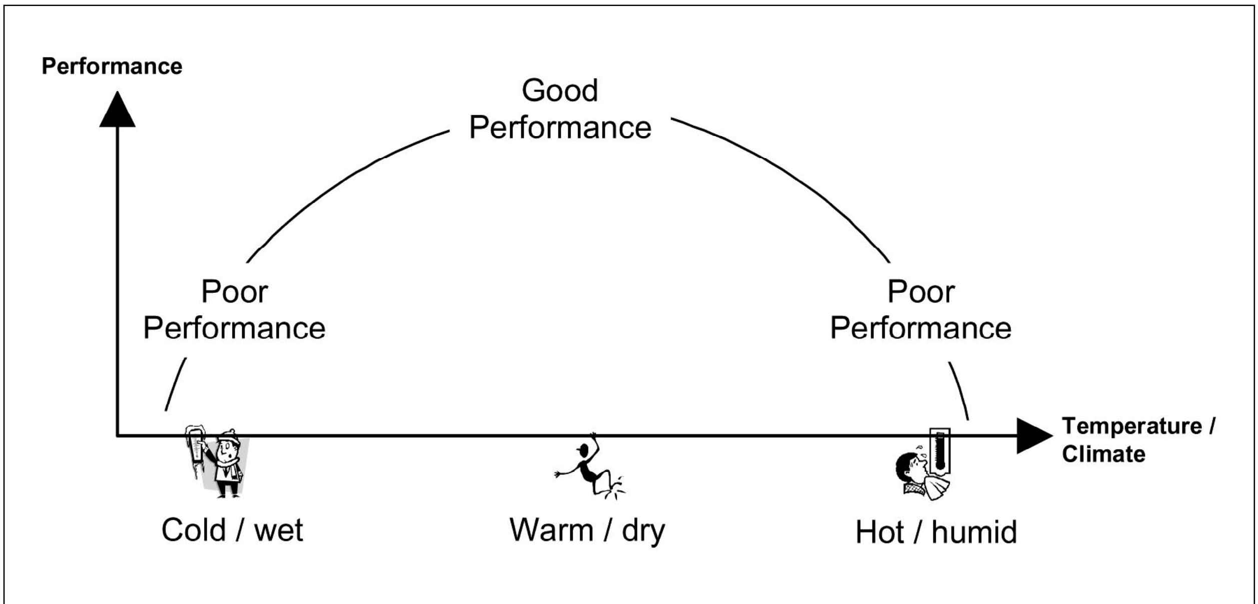


Fig. The relationship between climate, temperature and performance.

Engineers cannot be expected to maintain the rigorous standards expected in their profession in all environmental conditions. JAR 145 Acceptable Means of Compliance (AMC) 145.25(c) requires that environmental conditions be adequate for work to be carried out, stating:

> "The working environment for line maintenance should be such that the particular maintenance or inspection task can be carried out without undue distraction. It therefore follows that where the working environment deteriorates to an unacceptable level in respect of temperature, moisture, hail, ice, snow, wind, light, dust/other airborne contamination, the particular maintenance or inspection tasks should be suspended until satisfactory conditions are re-established"

Unfortunately, in reality, pressure to turn aircraft round rapidly means that some maintenance tasks are not put off until the conditions are more conducive to work.

There was an instance in Scotland, where work on an aircraft was only suspended when it became so cold that the lubricants being used actually froze.

Environmental conditions can affect physical performance. For example, cold conditions make numb fingers, reducing the engineer's ability to carry out fiddly repairs, and working in strong winds can be distracting, especially if having to work at height (e.g. on staging). Extreme environmental conditions may also be fatiguing, both physically and mentally.

There are no simple solutions to the effects of temperature and climate on the engineer. For example, an aircraft being turned around on the apron cannot usually be moved into the hangar so that the engineer avoids the worst of the weather. In the cold, gloves can be worn, but obviously the gloves themselves may interfere with fine motor skills. In the direct heat of the sun or driving rain, it is usually impossible to set up a temporary shelter when working outside.

Temperature

Temperature extremes are one of the most common environmental stressors. Since humans are comfortable only over a narrow band of temperatures, it is necessary to know how well they function at different temperature levels before remedial measures can be derived. Questions about air-conditioning requirements and human performance under heat or cold stress should be answered and taken into account during system design. Cabin environmental control systems are the principal means for controlling the internal aircraft environment.

Humans generate heat while performing mechanical work, and to a lesser extent, when resting. The excess heat is transferred to the environment, primarily by perspiration and sweating, in order to maintain a relatively constant body temperature of 37 degrees Celsius (C). The success of body temperature regulation depends on various factors: ambient temperature, humidity, and air velocity. If body temperature increases by more than 2 degrees C, physiological efficiency will be impaired.

In February 1984, a Cessna T-303 crashed during landing at Hickory, North Carolina, U.S.A. The aircraft overran the runway and collided with a fence. The pilot was hampered by an inoperative heater and a dome light that could not be turned off.

The physiological effects of ambient temperature extremes are well known, but the effects of heat stress on human performance are more complex. It is generally accepted that excessive heat will cause performance decrement, but there is little agreement regarding how much decrement will take place, or how long it will take to occur. People can withstand exposure to excessive temperatures for only a short period of time before measurable degradation sets in. Acclimatization prolongs this period. In non-acclimatized persons, degradation appears when the ambient temperature exceeds 30 degrees C, the relative humidity is high, and exposure exceeds three hours. Obviously, clothing and physical activity level play important roles, too.

When exposed to cold, the body attempts to maintain its core temperature by shivering and restricting blood flow to the body surface. Body temperatures below 35 degrees C are dangerous. Consciousness becomes clouded at 34 degrees C, unconsciousness follows around 30 degrees C, cardiac irregularities are usual between 30 and 28 degrees C, and death is imminent. Although humidity is not a factor, air velocity is important; as a result, wind chill indices are increasingly being provided in weather reports. (Wind chill is not a psychological effect — it effectively lowers body temperature.) Cold increases both reaction and movement time, and manual dexterity begins to deteriorate when hand-skin temperature falls below 18 degrees C.

Humidity

Humidity may become an issue with high-altitude jet transport aircraft because of the low relative humidity at their operational altitudes. The discomfort arising from low relative humidity may not imply physical indisposition. Over-all dehydration can be prevented with adequate fluid intake. Diuretics like coffee or tea should be avoided. The installation of humidifiers on aircraft could raise cabin/cockpit humidity, but there are potential problems such as weight penalty, condensation and mineral contaminations that the designer must consider.

MOTION AND VIBRATION

Vibration

Vibration is any form of oscillating motion that changes its magnitude of displacement periodically with reference to a point, and it is a widespread physical phenomenon. The movement of pistons within the cylinders of engines or the disturbances generated in aircraft flying through turbulent air are forms of vibration which can be transmitted to humans. Vibration is generally transmitted through direct contact between the body and the vibrating structure, and it can have potentially harmful effects.

Vibration is of operational significance in aviation because it may impair visual acuity, interfere with neuromuscular control and lead to fatigue. Although better than before, high levels of vibration can still be encountered in helicopters as well as in fixed-wing aircraft during low-level flight.

Protection against vibration can be provided by attention to its source, by modification of the transmission pathway or by the alteration of the dynamic properties of the aircraft body. Reduction of vibration emanating from aircraft engines is a primary task for design and maintenance engineers. The installation of devices called dynamic vibration absorbers has reduced vibration levels on helicopters. Another ergonomic approach is by means of vibration isolation of the flight crew seats.

Aircraft maintenance engineers often make use of staging and mobile access platforms to reach various parts of an aircraft. As these get higher, they tend to become less stable. For example when working at height on a scissors platform or 'cherry picker', applying force to a bolt being fixed to the aircraft may cause the platform to move away from the aircraft. The extent to which this occurs does not just depend on the height of the platform, but its design and serviceability. Any sensation of unsteadiness may distract an engineer, as he may concentrate more on keeping his balance than the task. Furthermore, it is vitally important that engineers use mobile access platforms properly in order to avoid serious injury.

Please refer to Photograph below.

Mobile access platforms, such as a "Cherry Picker", must be stable in use

Vibration in aircraft maintenance engineering is usually associated with the use of rotating or percussive tools and ancillary equipment, such as generators. Low frequency noise, such as that associated with aircraft engines, can also cause vibration. Vibration between 0.5 Hz to 20 Hz is most problematic, as the human body absorbs most of the vibratory energy in this range. The range between 50-150 Hz is most troublesome for the hand and is associated with Vibratory-induced White Finger Syndrome (VWF). Pneumatic tools can produce troublesome vibrations in this range and frequent use can lead to reduced local blood flow and pain associated with VWF. Vibration can be annoying, possibly disrupting an engineer's concentration.

CONFINED SPACES

Chapter 2, Section 5 highlighted the possibility of claustrophobia being a problem in aircraft maintenance engineering. Working in any confined space, especially with limited means of entry or exit (e.g. fuel tanks) needs to be managed carefully. As noted previously, engineers should ideally work with a colleague who would assist their ingress into and egress out of the confined space. Good illumination and ventilation within the confined space will reduce any feelings of discomfort. In addition, appropriate safety equipment, such as breathing apparatus or lines must be used when required.

WORKING ENVIRONMENT

Various factors that impinge upon the engineer's physical working environment have been highlighted in this chapter. Apart from those already discussed, other physical influences include:

- workplace layout and the cleanliness and general tidiness of the workplace (e.g. storage facilities for tools, manuals and information, a means of checking that all tools have been retrieved from the aircraft, etc.);
- the proper provision and use of safety equipment and signage (such as non-slip surfaces, safety harnesses, etc.);
- the storage and use of toxic chemical and fluids (as distinct from fumes) (e.g. avoiding confusion between similar looking canisters and containers by clear labelling or storage in different locations, etc.).

Please refer to Photograph F in Appendix A.

It is important that tools are close to hand and the work area is tidy

To some extent, some or all of the factors associated with the engineer's workplace may affect his ability to work safely and efficiently. JAR 145.25(c) - Facility Requirements states:

> "The working environment must be appropriate for the task carried out and in particular special requirements observed. Unless otherwise dictated by the particular task environment, the working environment must be such that the effectiveness of personnel is not impaired."

This is expanded upon in AMC 145.25(c).

The working environment comprises the physical environment encapsulated in this chapter, the social environment described in Chapter 3 and the tasks that need to be carried out (examined in the next chapter). This is shown in Figure 20. Each of these three components of the working environment interact, for example:

- engineers are trained to perform various tasks;
- successful task execution requires a suitable physical environment;
- an unsuitable or unpleasant physical environment is likely to be de-motivating.

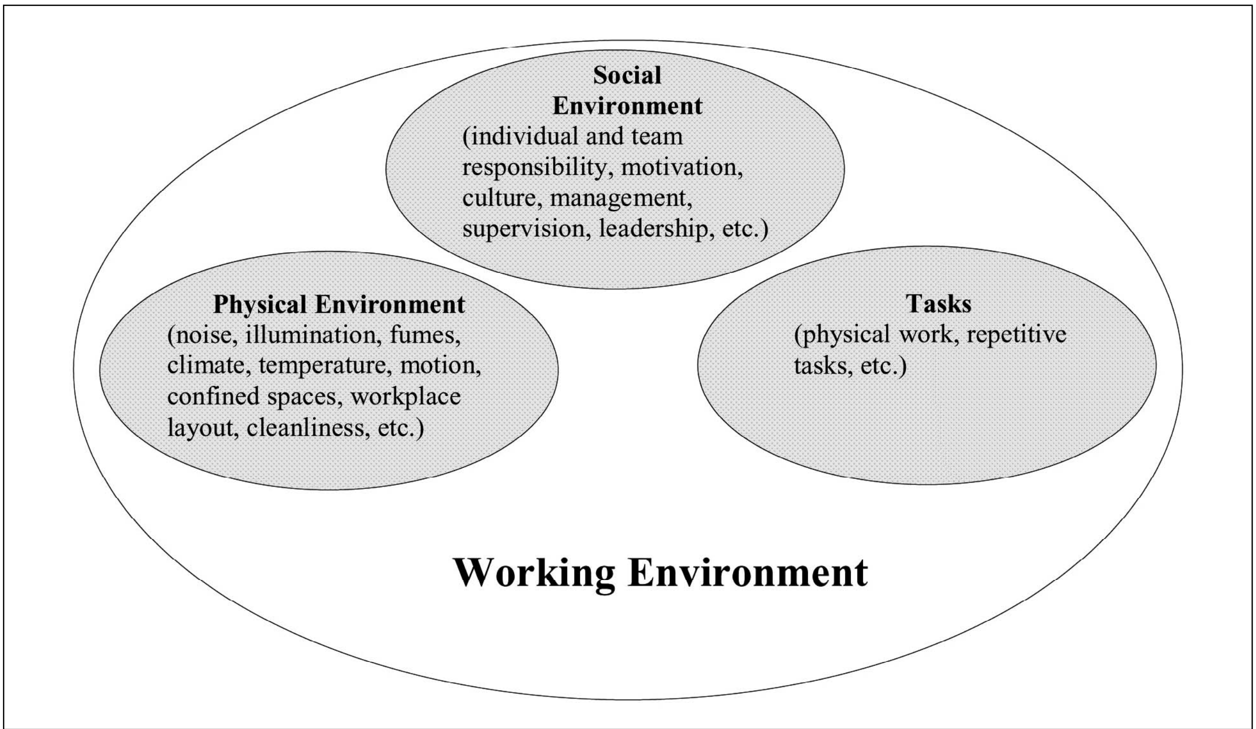


Fig. Components of the 'working environment'

Aircraft maintenance engineering requires all three components of the working environment to be managed carefully in order to achieve a safe and efficient system.

It is important to recognise that engineers are typically highly professional and pragmatic in their outlook, and generally attempt to do the best work possible regardless of their working environment. Good maintenance organisations do their best to support this dedication by providing the necessary conditions for safe and efficient work.

Stress

4.7.1 Stress was defined by Hans Selye as a nonspecific response of the body to any demand made upon it. This concept assumes that some "normal" or "optimal" state of bodily functions exists and that stressors (i.e. stimuli or situations that stress the person) cause a deviation from this normal state. Stress generally represents an attempt by the body to adapt to or cope with situational demands and to return to the normal state as soon as possible. It can be differentiated into life stress, environmental stress and cognitive stress. Life stress is produced by adverse occurrences in a person's life (e.g. divorce, family bereavement).

Environmental and cognitive stress are more closely related to the specific activities which humans undertake. Environmental stress includes the effects of factors such as temperature, humidity, noise, pressure, illumination and vibration. Cognitive stress refers to the cognitive (or mental) demands of the task itself. Countermeasures to minimize the potential untoward effects of environmental and cognitive stress are within the purview of ergonomics.

Stress has traditionally been linked to arousal, which refers to nonspecific changes (e.g. hormonal and brain activities) in the body to external stimulation. In general, stress and arousal levels are positively related — that is to say, high stress is associated with high arousal level. The Yerkes-Dodson law depicted in Figure 4-17 relates performance and arousal. It shows that people's performance levels increase according to the degree of arousal to a point beyond which any additional boost in arousal will generally be detrimental to task performance. The over-all shape of the relationship curve remains the same across different tasks, but the exact shape and location of each curve vary according to task complexity.

Stress is related to a person's ability to pay attention to cues in the environment. In a simple situation with few cues, stress will improve performance by causing attention to be focused. In a complex situation with many cues, stress will decrease performance because many cues will go unheeded. This explains many accidents in which crew under stress "locked on" to some particular instrument which was defective (even if the instrument was of minor importance), failing to attend to other pieces of crucial information.

■■■

CHAPTER 6
TASKS

Licensed aircraft engineering is a specialist occupation undertaken by men and women who have received appropriate training. The possible paths into the profession are shown in Figure below.

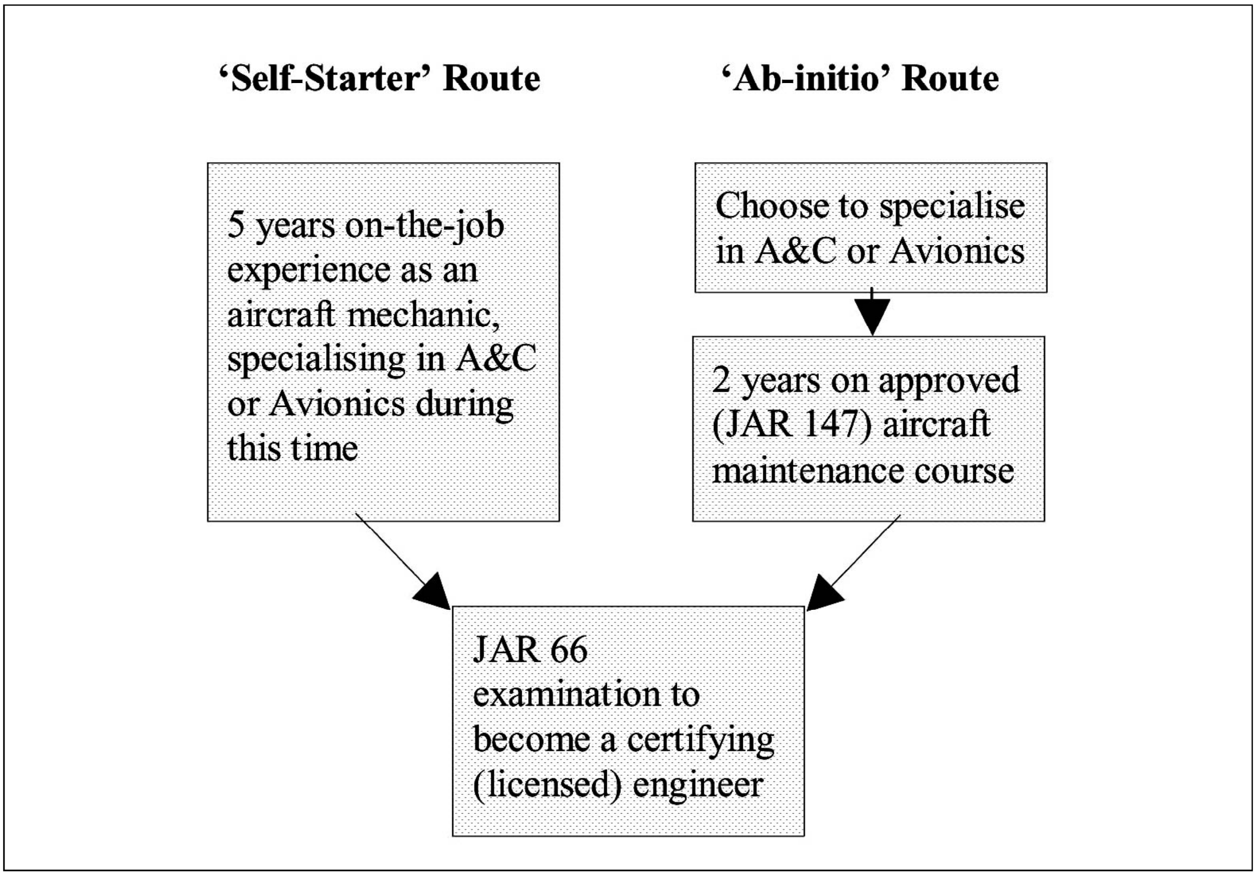


Fig. Routes to becoming a Licensed Aircraft Engineer

As a self starter, training is obtained mainly on-the-job, whereas an approved course is largely classroom-based with a condensed on-the-job element. Given the varied nature of the maintenance tasks in aircraft maintenance, few engineers are 'jacks of all trades'. Most engineers opt to specialise in the tasks they carry out, either as an Airframe and Powerplant specialist (known as A&C in UK), or as an Electrical and Avionics specialist.

When working within an aircraft maintenance organisation, an engineer will also be sent on 'type courses'. These courses provide the engineer with requisite skills and knowledge to carry out tasks on specific aircraft, engines or aircraft systems.

The rest of this chapter examines the nature of the tasks that aircraft maintenance engineers carry out, looking at the physical work, repetitive tasks, visual inspection and the complex systems that they work on.

PHYSICAL WORK

Planning

Blindly starting a task without planning how best to do it is almost certainly the best way to invite problems. Before commencing a task, an individual engineer, engineering team or planner should ask themselves a number of questions. These may include:

- Do I/we know exactly what the task is that has to be done?
- Are the resources available to do it effectively (safely, accurately and within the time permitted)? Where resources include:
- personnel;
- equipment/spares;
- documentation, information and guidance;
- facilities such as hangar space, lighting, etc.
- Do I/we have the skills and proficiency necessary to complete the task?

Please refer to Photograph belolw.

Referring to pertinent maintenance documentation is a key element of planning

Information about specific tasks should be detailed on job cards or task sheets. These will indicate the task (e.g. checks or inspection, repair, replacement, overhaul) and often further details to aid the engineer (such as maintenance manual references, part numbers, etc.).

If the engineer is in any doubt what needs to be done, written guidance material is the best resource. Colleagues may unintentionally give incorrect or imprecise direction (the exception to this is discussing problems that arise that are not covered in the guidance material).

It is generally the shift supervisor's job to ensure that the resources are available for his staff to carry out their tasks. As noted in Chapter 3, Section 2 ('Time Pressure and Deadlines'), it is likely that, within a shift or a team, various sub-tasks are allocated to individuals by the supervisor. Alternatively, he may encourage a team to take ownership of the tasks that need to be completed, giving them the discretion to manage a package of work (as noted in Chapter 3, Section 6 ('Team Working'). Exactly 'who does what' is likely to be based on factors such as individuals' specialisation (i.e. A&C or avionics) and their experience with the task.

Although management have a responsibility to ensure that their engineers have suitable training, at the end of the day, it is up to the individual engineer to decide whether he has the necessary skills and has the proficiency and experience to do what he has been asked to do. He should not be afraid to voice any misgivings, although it is recognised that peer and management pressure may make this difficult.

Physical Tasks

Aircraft maintenance engineering is a relatively active occupation. Regardless of the job being done, most tasks tend to have elements of fine motor control, requiring precision, as well as activities requiring strength and gross manipulation.

From a biomechanical perspective, the human body is a series of physical links (bones) connected at certain points (joints) that allow various movements. Muscles provide the motive force for all movements, both fine and gross. This is known as the musculoskeletal system. The force that can be applied in any given posture is dependent on the strength available from muscles and the mechanical advantage provided by the relative positions of the load, muscle connections, and joints.

As an engineer gets older, the musculoskeletal system stiffens and muscles become weaker. Injuries become more likely and take longer to heal. Staying in shape will minimise the effects of ageing, but they still occur.

It is important that maintenance tasks on aircraft are within the physical limitations of aircraft maintenance engineers. Boeing use a computerised tool 1, based on human performance data (body sizes, strengths, leverages, pivots, etc.), to ensure that modern aircraft are designed such that the majority of maintenance engineers will be able to access aircraft equipment, apply the necessary strength to loosen or tighten objects, etc. (i.e. designed for ease of maintainability).

Clearly we are all different in terms of physical stature and strength and as a consequence, our physical limitations vary. Attempting to lift a heavy object which is beyond our physical capabilities is likely to lead to injury. The use of tools generally make tasks easier, and in some situations, may make a task achievable that was hitherto outside our physical powers (e.g. lifting an aircraft panel with the aid of a hoist).

As noted in Chapter 4, ('Fatigue'), physical work over a period of time will result in fatigue. This is normally not a problem if there is adequate rest and recovery time between work periods. It can, however, become a problem if the body is not allowed to recover, possibly leading to illness or injuries. Hence, engineers should try to take their allocated breaks.

Missing a break in an effort to get a job done within a certain time frame can be counterproductive, as fatigue diminishes motor skills, perception, awareness and standards. As a consequence, work may slow and mistakes may occur that need to be rectified.

As discussed at some length in Chapter 4, ('Day-to-Day Fitness and Health'), it is very important that engineers should try to ensure that their physical fitness is good enough for the type of tasks which they normally do.

REPETITIVE TASKS

Repetitive tasks can be tedious and reduce arousal (i.e. be boring). Most of the human factors research associated with repetitive tasks has been carried out in manufacturing environments where workers carry out the same action many times a minute. This does not generally apply to maintenance engineering.

Repetitive tasks in aircraft maintenance engineering typically refer to tasks that are performed several times during a shift, or a number of times during a short time period, e.g. in the course of a week. An example of this would be the checking life jackets on an aircraft during daily inspections.

Some engineers may specialise in a certain aspect of maintenance, such as engines. As a result, they may possibly carry out the same or similar tasks several times a day.

The main danger with repetitive tasks is that engineers may become so practised at such tasks that they may cease to consult the maintenance manual, or to use job cards. Thus, if something about a task is changed, the engineer may not be aware of the change. Complacency is also a danger, whereby an engineer may skip steps or fail to give due attention to steps in a procedure, especially if it is to check something which is rarely found to be wrong, damaged or out of tolerance. This applies particularly to visual inspection, which is covered in greater detail in the next section.

In the Aloha accident report, the NTSB raised the problem of repetitive tasks:

"The concern was expressed about what kinds of characteristics are appropriate to consider when selecting persons to perform an obviously tedious, repetitive task such as a protracted NDI inspection. Inspectors normally come up through the seniority ranks. If they have the desire, knowledge and skills, they bid on the position and are selected for the inspector job on that basis. However, to ask a technically knowledgeable person to perform an obviously tedious and exceedingly boring task, rather than to have him supervise the quality of the task, may not be an appropriate use of personnel…"

Making assumptions along the lines of 'Oh I've done that job dozens of times!' can occur even if a task has not been undertaken for some time. It is always advisable to be wary of changes to procedures or parts, remembering that 'familiarity breeds contempt'.

VISUAL INSPECTION

Visual inspection is one of the primary methods employed during maintenance to ensure the aircraft remains in an airworthy condition.

Visual inspection can be described as the process of using the eye, alone or in conjunction with various aids to examine and evaluate the condition of systems or components of an aircraft.

Aircraft maintenance engineers may use magnifiers and borescopes to enhance their visual capabilities. The engineer may accompany his visual inspection by examining the element using his other senses (touch, hearing, smell, etc.). He may also manipulate the element being inspected to make further judgements about its condition. For instance, he might feel a surface for unevenness, or push against it to look for any unanticipated movement.

As highlighted in Chapter 2, Section 2 (“Vision and the Aircraft Maintenance Engineer”), good eyesight is of prime importance in visual inspection, and it was noted that the UK CAA have provided some guidance on eyesight in AWN47. Amongst other things, this calls for glasses or contact lenses to be used where prescribed and regular eyesight checks to be made.

Visual inspection is often the principal method used to identify degradation or defect in systems or components of aircraft. Although the engineer’s vision is important, he also has to make judgements about what he sees. To do this, he brings to bear training, experience and common sense. Thus, reliable visual inspection requires that the engineer first sees the defect and then actually recognises that it is a defect. Of course, experience comes with practice, but telltale signs to look for can be passed on by more experienced colleagues.

Please refer to Photograph below.

An engineer making a visual inspection of engine fan blades.

Information such as technical bulletins are important as they prime the inspector of known and potential defects and he should keep abreast of these. For example, blue staining on an aircraft fuselage may be considered insignificant at first sight, but information from a Technical Bulletin of 'blue ice' and external toilet leaks may make the engineer suspicious of a more serious problem

There are various steps that an engineer can take to help him carry out a reliable visual inspection. The engineer should:

- ensure that he understands the area, component or system he has been asked to inspect (e.g. as specified on the work card);
- locate the corresponding area, component or system on the aircraft itself;
- make sure the environment is conducive to the visual inspection task (considering factors described in Chapter 5 - "Physical Environment", such as lighting, access, etc.);
- conduct a systematic visual search, moving his eyes carefully in a set pattern so that all parts are inspected;
- examine thoroughly any potential degradation or defect that is seen and decide whether it constitutes a problem;
- record any problem that is found and continue the search a few steps prior to where he left off.

Visual inspection requires a considerable amount of concentration. Long spells of continuous inspection can be tedious and result in low arousal. An engineer's low arousal or lack of motivation can contribute to a failure to spot a potential problem or a failure in recognising a defect during visual inspection. The effects are potentially worse when an inspector has a very low expectation of finding a defect, e.g. on a new aircraft.

Engineers may find it beneficial to take short breaks between discrete visual inspection tasks, such as at a particular system component, frame, lap joint, etc. This is much better than pausing midway through an inspection.

The Aloha accident highlights what can happen when visual inspection is poor. The accident report included two findings that suggest visual inspection was one of the main contributors to the accident:

- "There are human factors issues associated with visual and non-destructive inspection which can degrade inspector performance to the extent that theoretically detectable damage is overlooked."
- "Aloha Airlines management failed to recognise the human performance factors of inspection and to fully motivate and focus their inspector force toward the critical nature of lap joint inspection, corrosion control and crack detection….."

Finally, non-destructive inspection (NDI) includes an element of visual inspection, but usually permits detection of defects below visual thresholds. Various specialist tools are used for this purpose, such as the use of eddy currents and fluorescent penetrant inspection (FPI).

COMPLEX SYSTEMS

All large modern aircraft can be described as complex systems. Within these aircraft, there are a myriad of separate systems, many of which themselves may be considered complex, e.g. flying controls, landing gear, air conditioning, flight management computers. Table 4 gives an example of the breadth of complexity in aircraft systems.

> Any complex system can be thought of as having a wide variety of inputs. The system typically performs complex modifications on these inputs or the inputs trigger complex responses. There may be a single output, or many distributed outputs from the system.

The purpose, composition and function of a simple system is usually easily understood by an aircraft maintenance engineer. In other words, the system is transparent to him. Fault finding and diagnosis should be relatively simple with such systems (although appropriate manuals etc. should be referred to where necessary).

Table 4 : Example of increasing complexity - the aileron system

TYPE OF AILERON	NATURE OF SYSTEM
Simple aileron movement.	Direct connection from control column to control surface; direct
Servo tab aileron	Direct connection from control column to servo tab; aerodynamic movement of surface.
Powered aileron	Connection from control column to servo valve via input; hydraulic movement of surface; feedback mechanism; position indication.
Powered aileron / roll spoiler	As above but with interface to spoiler input system to provide additional roll capability.
Fly-by-wire aileron system	No connection from control column to surface. Electrical command signal to electro-hydraulic servo valve on actuator; signal modified and limited by intermediate influence of flight control computer.

With a complex system, it should still be clear to an aircraft maintenance engineer what the system's purpose is. However, its composition and function may be harder to conceptualise - it is opaque to the engineer.

To maintain such complex systems, it is likely that the engineer will need to have carried out some form of system-specific training which would have furnished him with an understanding of how it works (and how it can fail) and what it is made up of (and how components can fail). It is important that the engineer understands enough about the overall functioning of a large, complex aircraft, but not so much that he is overwhelmed by its complexity. Thus, system-specific training must achieve the correct balance between detailed system knowledge and analytical troubleshooting skills.

With complex systems within aircraft, written procedures and reference material become an even more important source of guidance than with simple systems. They may describe comprehensively the method of performing maintenance tasks, such as inspections, adjustments and tests. They may describe the relationship of one system to other systems and often, most importantly, provide cautions or bring attention to specific areas or components. It is important to follow the procedures to the letter, since deviations from procedures may have implication on other parts of the system of which the engineer may be unaware.

When working with complex systems, it is important that the aircraft maintenance engineer makes reference to appropriate guidance material. This typically breaks down the system conceptually or physically, making it easier to understand and work on.

In modern aircraft, it is likely that the expertise to maintain a complex system may be distributed among individual engineers. Thus, avionics engineers and A&C engineers may need to work in concert to examine completely a system that has an interface to the pilot in the cockpit (such as the undercarriage controls and indications).

A single modern aircraft is complex enough, but many engineers are qualified on several types and variants of aircraft. This will usually mean that he has less opportunity to become familiar with one type, making it even more important that he sticks to the prescribed procedures and refers to the reference manual wherever necessary. There is a particular vulnerability where tasks are very similar between a number of different aircraft (e.g. spoiler systems on the A320, B757 and B7671), and may be more easily confused if no reference is made to the manual.

■■■

CHAPTER 7
COMMUNICATION

Good communication is important in every industry. In aircraft maintenance engineering, it is vital. Communication, or more often a breakdown in communication, is often cited as a contributor to aviation incidents and accidents. It is for this very reason that it has its own section in the JAR66 Module 9 for Human Factors. This chapter examines the various aspects of communication that affect the aircraft maintenance engineer.

> Communication is defined in the Penguin Dictionary of Psychology as:
>
> "The transmission of something from one location to another. The 'thing' that is transmitted may be a message, a signal, a meaning, etc. In order to have communication both the transmitter and the receiver must share a common code, so that the meaning or information contained in the message may be interpreted without error" .

WITHIN AND BETWEEN TEAMS

As noted in previous chapters, aircraft maintenance engineers often work as teams. Individuals within teams exchange information and need to receive instructions, guidance, etc. Moreover, one team will have to pass on tasks to another team at shift handover. An engineer needs a good understanding of the various processes of communication, as without this, it is impossible to appreciate how communication can go wrong.

Modes of Communication

We are communicating almost constantly, whether consciously or otherwise. An aircraft maintenance engineer might regularly communicate:

- information;
- ideas;
- feelings;
- attitudes and beliefs

As the sender of a message, he will typically expect some kind of response from the person he is communicating with (the recipient), which could range from a simple acknowledgement that his message has been received (and hopefully understood), to a considered and detailed reply. The response constitutes feedback.

As can be seen in the above definition, communication can be:

- verbal/spoken - e.g. a single word, a phrase or sentence, a grunt;
- written/textual - e.g. printed words and/or numbers on paper or on a screen, hand written notes;
- non-verbal -
  - graphic - e.g. pictures, diagrams, hand drawn sketches, indications on a cockpit instrument;
  - symbolic - e.g. 'thumbs up', wave of the hand, nod of the head;
  - body language - e.g. facial expressions, touch such as a pat on the back, posture.

Verbal and Written Communication

Generally speaking, verbal and written communication are purposeful. For a spoken or written message to be understood, the sender has to make sure that the receiver:

- is using the same channel of communication;
- recognises and understands his language;
- is able to make sense of the message's meaning;

The channel of communication is the medium used to convey the message. For spoken communication, this might be face-to-face, or via the telephone. Written messages might be notes, memos, documents or e-mails.

In the UK it is expected that aircraft maintenance engineers will communicate in English. However, it is also vital that the message coding used by the sender is appreciated by the recipient so that he can decode the message accurately. This means that engineers must have a similar knowledge of technical language, jargon and acronyms.

Assuming the channel and language used are compatible, to extract meaning, the engineer has to understand the content of the message. This means that it has to be clear and unambiguous. The message must also be appropriate to the context of the workplace and preferably be compatible with the receiver's expectations. Where any ambiguity exists, the engineer must seek clarification.

Non-verbal Communication

Non-verbal communication can accompany verbal communication, such as a smile during a face-to-face chat. It can also occur independently, for instance a colleague may pass on his ideas by using a sketch rather than the use of words. It can also be used when verbal communication is impossible, such as a nod of the head in a noisy environment.

Non-verbal communication is also the predominant manner by which systems communicate their status. For instance, most displays in the aircraft cockpit present their information graphically.

Body language can be very subtle, but often quite powerful. For example, the message "No" accompanied by a smile will be interpreted quite differently from the same word said whilst the sender scowls.

Communication Within Teams

Individual aircraft maintenance engineers need to communicate:

- before starting a task - to find out what to do;
- during a task - to discuss work in progress, ask colleagues questions, confirm actions or intentions, or to ensure that others are informed of the maintenance state at any particular time;
- at the end of a task - to report its completion and highlight any problems.

Spoken communication makes up a large proportion of day-to-day communication within teams in aircraft maintenance. It relies both on clear transmission of the message (i.e. not mumbled or obscured by background noise) and the ability of the recipient of the message to hear it (i.e. active listening followed by accurate interpretation of the message). Good communication within a team helps to maintain group cohesion.

Spoken messages provide considerable flexibility and informality to express work-related matters when necessary. The key to such communication is to use words effectively and obtain feedback to make sure your message has been heard and understood.

It is much less common for individuals within teams to use written communication. They would however be expected to obtain pertinent written information communicated by service bulletins and work cards and to complete documentation associated with a task.

Communication Between Teams

Communication between teams is critical in aircraft maintenance engineering. It is the means by which one team passes on tasks to another team. This usually occurs at shift handover. The information conveyed will include:

- tasks that have been completed;
- tasks in progress, their status, any problems encountered, etc.;
- tasks to be carried out;
- general company and technical information.

Communication between teams will involve passing on written reports of tasks from one shift supervisor to another. Ideally, this should be backed up by spoken details passed between supervisors and, where appropriate, individual engineers. This means that, wherever necessary, outgoing engineers personally brief their incoming colleagues. The written reports (maintenance cards, procedures, work orders, logs, etc.) and warning flags / placards provide a record of work completed and work yet to be completed - in other words, they provide traceability (see Section 2 below). Furthermore, information communicated at shift handover ensures good continuity. It is important that handovers are not rushed, so as to minimise omissions.

Communication Problems

There are two main ways in which communication can cause problems. These are lack of communication and poor communication. The former is characterised by the engineer who forgets to pass on pertinent information to a colleague, or when a written message is mislaid. The latter is typified by the engineer who does not make it clear what he needs to know and consequently receives inappropriate information, or a written report in barely legible handwriting. Both problems can lead to subsequent human error.

Communication also goes wrong when one of the parties involved makes some kind of assumption. The sender of a message may assume that the receiver understands the terms he has used. The receiver of a message may assume that the message means one thing when in fact he has misinterpreted it. Assumptions may be based on context and expectations, which have already been mentioned in this chapter. Problems with assumptions can be minimised if messages are unambiguous and proper feedback is given.

Basic rules of thumb to help aircraft maintenance engineers minimise poor communication are:

- think about what you want to say before speaking or writing;
- speak or write clearly;
- listen or read carefully;
- seek clarification wherever necessary.

Work Logging and Recording

This is one of the most critical aspects of communication within aviation maintenance, since inadequate logging or recording of work has been cited as a contributor to several incidents.

In the B737 double engine oil loss incident in February 1995, for instance, one of the AAIB conclusions was:

"…the Line Engineer…had not made a written statement or annotation on a work stage sheet to show where he had got to in the inspections" .

The reason for this was because he had intended completing the job himself and, therefore, did not consider that detailed work logging was necessary. However, this contributed towards the incident in that:

"the Night Base Maintenance Controller accepted the tasks on a verbal handover [and] he did not fully appreciate what had been done and what remained to be done" .

Even if engineers think that they are going to complete a job, it is always necessary to keep the record of work up-to-date just in case the job has to be handed over. This may not necessarily be as a result of a shift change, but might be due to a rest break, illness, the need to move to another (possibly more urgent) task, etc.

The exact manner in which work should be logged tends to be prescribed by company procedures. It is usually recorded in written form. However, there is no logical reason why symbols and pictures should not also be used to record work or problems, especially when used for handovers. There are many cases where it may be clearer to draw a diagram rather than to try to explain something in words (i.e. 'a picture is worth a thousand words').

The key aspects of work logging and recording are captured in the CAA's Airworthiness Notice No. 3 (AWN3). This states:

> "In relation to work carried out on an aircraft, it is the duty of all persons to whom this Notice applies to ensure that an adequate record of the work carried out is maintained. This is particularly important where such work carries on beyond a working period or shift, or is handed over from one person to another. The work accomplished, particularly if only disassembly or disturbance of components or aircraft systems, should be recorded as the work progresses or prior to undertaking a disassociated task. In any event, records should be completed no later than the end of the work period or shift of the individual undertaking the work. Such records should include 'open' entries to reflect the remaining actions necessary to restore the aircraft to a serviceable condition prior to release. In the case of complex tasks which are undertaken frequently, consideration should be given to

the use of pre-planned stage sheets to assist in the control, management and recording of these tasks. Where such sheets are used, care must be taken to ensure that they accurately reflect the current requirements and recommendations of the manufacturer and that all key stages, inspections, or replacements are recorded."

New technology is likely to help engineers to record work more easily and effectively in the future. ICAO Digest No.12: "Human Factors in Aircraft Maintenance and Inspection", refers to hand-held computers and an Integrated Maintenance Information System (IMIS). It points out that these devices are likely to encourage the prompt and accurate recording of maintenance tasks.

Modern technology is also being implemented to improve the transfer of information in maintenance manuals to worksheets and workcards. These help to communicate pertinent information to engineers in an accessible and useable format. A contributory factor in the B737 double engine oil loss incident was that the information which should have prompted the engineer to carry out a post-inspection idle engine run to check for leaks was in the maintenance manual but not carried over to the task cards.

Note : For more about documentation refer chapter-1, page 18.

MANUAL, HANDBOOK AND TECHNICAL PAPERS

Functional design

The general principles already discussed are applicable, of course, to the design and production of manuals, handbooks and other technical papers. Good technical writing involves marrying these general principles to specific requirements. For example, is the document to be used as a reference book or is it material to be learned and then recalled from memory later? This will affect the optimum design.

Furthermore, people have different preferences for one form presentation or another. Some preferences are related to cultural backgrounds; the extensive use of cartoons in the USA would not necessarily be suitable in all other countries.

Variations in the effectiveness of layout, of which the general principles were discussed earlier, already appear in the contents list or index. Page numbering on the left side of a contents list has been demonstrated to result in fewer errors from readers and is much aster to type than the more conventional one with the page numbers listed on the right. However, some confusion can then arise if the page is divided into two columns. When page numbers are listed on the right, some publications use leader lines or dots to help alignment of the page number with the relevant item. For documents such as maintenance and operating manuals, which are used primarily for reference on the job, and optimum index and contents list design is essential for efficient working and in emergency situations, for safety.

Patently, indexing of the operating procedures used in the L1011 disaster at Riyadh in 1980 mentioned earlier in this chapter, was functionally inadequate and this was cited in the investigation findings (Saudi Arabian report). Abnormal procedures were distributed between Emergency, Abnormal and Additional sections and about three precious minutes were lost as a result of the crew searching to find the aft cargo compartment smoke warning procedure, possibly creating the difference between life an death.

Numbering of paragraphs is better than lettering, perhaps because people are more easily aware, for example, that 8 comes before 10 than H before J. It is also easier to remember a given number of digits than the same number of letters.

Colour coding is a useful means of distinguishing between different sections of a handbook. But as with all application of colour coding, it must be remembered that some colours can vary and even disappear under different lighting conditions and that many people have some degree of colour vision deficiency. About 5–10% of men suffer from such a disorder, though this is rare in women who, nevertheless, act as carriers of this incurable congenital defect. The most common form is red/green colour-blindness which affects about 4% of males. As red and green have traditionally been allocated certain meanings (danger v. safety, emergency v. normal), the fact that a person may only see them as shades of yellow, yellowish brown, or grey may significantly affect interpretation.

Diagrams, charts and tables

It is often preferable to use diagrams, charts or tables instead of long descriptive text. We have a wide choice of these available and selection of the correct one is important. Research studies are generally available to help make the selection (e.g. Wrigth, 1977). The same data can be presented in a variety of tabular formats, some easier to use and interpret than others (Figure below). Various kinds of graphical presentations are available such as line graphs, histograms, pie diagrams and bar charts and these are useful when making comparisons between different sets of data. Each has tis own special advantages and optimum applications.

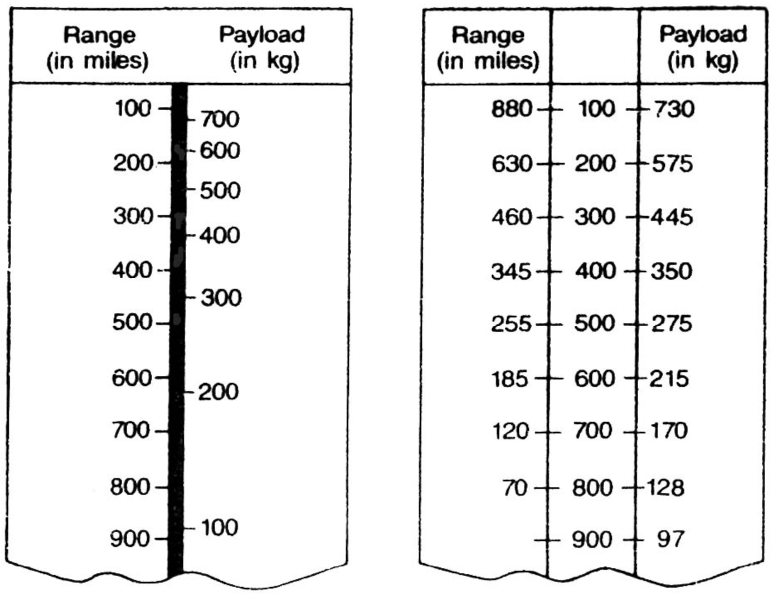


Fig. The same data presented in two different tabular forms

One car manufacturer will publish in its owner's handbook an electrical diagram in the form of a complicated conventional flow diagram, relating the components to their actual location in the car. Another could use a simple functional diagram, which is much easier for determination of electrical current routing, but with no information on component location. So it is necessary to select not only the type of diagram but also the variation of it based on its intended use.

It is interesting to note that geometrical illusions as described in Chapter 5 may also be associated with misreading of graphs. The poggendorf illusion (Figure below) is particularly relevant in this respect. It occurs on a graph when a point is read on a calibrated scale some distance away and the point lies on a sloping lie which runs towards the scale. The error can be minimised by drawing the scales as close as possible to the point to be read (Poulton, 1985).

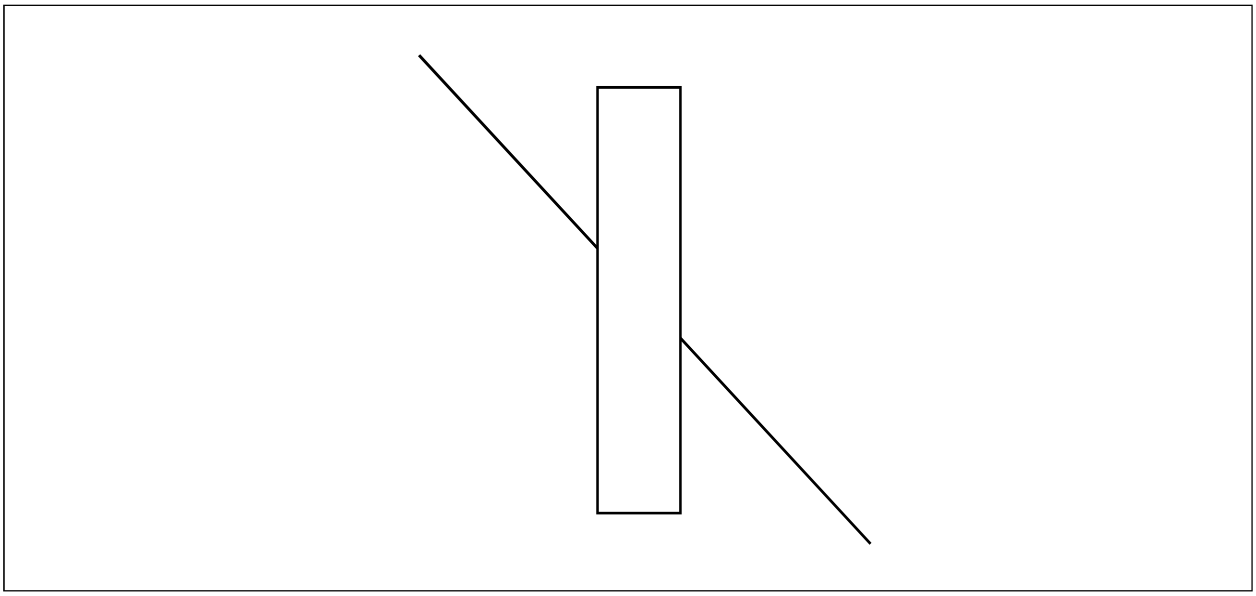


Fig. Poggendorf illusion; the crossing line looks displaced

Perhaps the most significant development in recent years is the presentation different functions that it is not possible to give a simple set of guidelines about their design and use. They seem to motivate the reader, help in recall from long term memory and aid in explanation. They are a useful way of avoiding technical jargon (Fig. below).

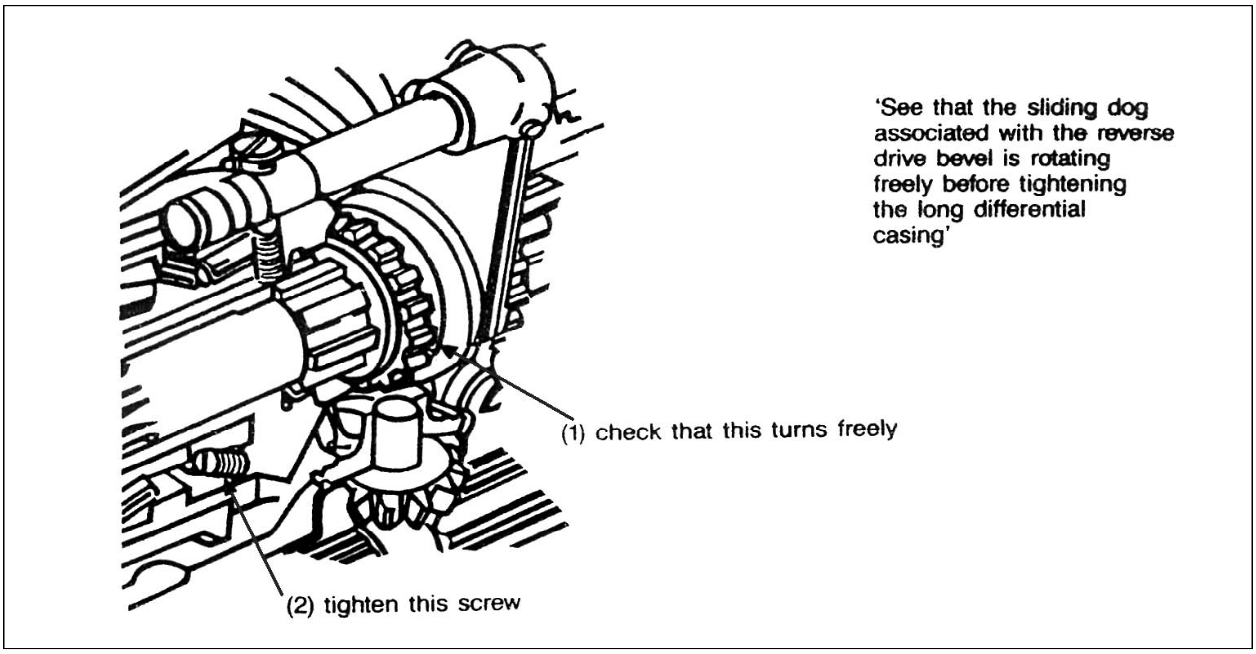


Fig. An example of how an illustration can be used to avoid technical jargon and improve comprehensive. An alternative to the drawing would be the text on the right.

In operations and maintenance manuals he use of illustrations has been extensively developed and there are numerous valuable papers available to guide those preparing such documents (e.g. Brown et. al., 1972; Hartley, 1985; Szlichcinski, 1979; Wright, 1977). From 50 – 80% of system failures have been attributed in various studies to human error (Meister, 1971). Inadequacies in manuals, hand-books and written instructions have contributed to this unreliability.

The use of colour was already referred to in connection with manual indexing. It also has an important role in making complex information easier to understand and easier to describe. It relieves a large part of the discrimination workload. Finding one's way around London's Underground without colour coding of the different lines in the network would be far more difficult, 'simply follow the blue line from London Airport to Piccadilly Circus...'. Colour coding, as was mentioned previously, also has a motivational effect and encourages the reader to look at the illustration. However, apart from the caution mentioned previously in connection with colour vision deficiencies, it must be remembered that when photographing or copying coloured illustrations in black white, some of the colours may not be reproduced and information may thus be lost.

The page and print size must take into account the working environment in which the document is to be used. In the analysis made by the Netherlands Civil Aviation Authority (RLD) of the double 747 disaster at Tenerife in 1977, reference was made to the small size of the airport chart used by the taxying pilot. It was suggested that this may have contributed to the pilot missing the correct runway turn-off and so still being on the active runway when the other aircraft took off.

Such criticisms are not new. In 1975 United Airlines had already conducted a valuable survey of pilots on this kind of chart. The airline sent out some 4000 questionnaires asking pilots to extract certain information fro a number of these charts and at the same time inviting general comments on the form of data presentation. The response was enlightening with not only an unusually high return for this kind of questionnaire but with much detailed constructive criticism. From many criticism, the following are typical: – it would be difficult to extract information from the charts in the cockpit in actual flight conditions with poor light, movement etc.; the chart information is subject to too much interpretation; information on flight procedures to be followed were not clear; there was too much unnecessary clutter on the charts; the printing and pages should be larger. Many specific proposals for detailed improvement of the charts were submitted by this responsive group of pilots. It should be noted here that some airlines produce their own charts which are larger and with bigger print than the widely used charts referred to in this survey.

This survey also revealed the order of error which may be expected from the use of such charts, even in the favourable environment of the pilot's own home with good lighting, no motion and without normal operational time-pressures. Of the questions to extract certain information from the charts, most generated errors in less that 10% of the pilots. However. About one in six questions generated errors from between 20% and 50% of those responding to the survey (united Airlines, 1975). References to the difficulties experienced by pilots in reading such charts have been made elsewhere in authoritative studies (e.g. Ruffel Smith, 1979).

Technical Papers

Many in aviation at one time of another find themselves called upon to prepare a technical paper on some aspect of their work. This may be for any one of the countless conferences, symposia or seminars filling the annual aviation calendar. Organisations such as IATA, ICAO, IFALPA, SAE, AEA, OAA, ISASI, ARINC and many more rely on contributions and the input of practical experience from the international aviation community. This involves those working on the job of operating aircraft and providing organisational, technical and commercial support for the operation.

The extent to which the message in the paper gets accepted and influences events (which is usually the object of the investment of time and money in preparing a paper) depends very much on the quality of the paper. The general principles discussed earlier are, of course, applicable to all technical writing but there are a number of special points which need attention.

It would be quite wrong to believe that a difficult or complex style or writing is a sign of knowledge and skill and will impress an audience. On the contrary, to write complicated new technical material in a simple fashion is the real sign of skill. This is a skill which must be learned.

Recommendations are available for the style to be used, the layout, reference listing, proof reading, typing, use of abbreviations and so on. Excellent guidance can be obtained to simplify the task and to suggest the most effective sequence for preparing the paper (e.g. O'Connor et al., 1977).

There is no use in having a good message if it does not get over. Just a little homework can have a significant effect on the writer's credibility and on the extent to which the audience is influenced by the paper. All aviation papers must be produced in the English language if they are to have an international readership. This homework, then, is even more important for those who are required to write in a language other than their own.

QUESTIONNAIRES AND FORM

Questionnaire Surveys

One very familiar type of document is the questionnaire. Most forms come into this category of documentation. Surveys using questionnaires are particularly useful when we are interested in discovering people's opinions or attitudes. They may relate to the effectiveness of a new weather radar, the comfort of a a passenger seat or a the degree of fear of flying. The information sought may be on sensitive personal questions such as working with staff of different ethnic origins or the use of drugs by flight crews. They may relate to emotive issues such as smoking on board, over-booking or crew complement.

To obtain information on such matters it is, of course, possible simply to sound out colleagues in the office, chat to some of those concerned over a drink or simply apply one's own judgement. But these methods can be very misleading and can generate sometimes an irreversible series of actions based on false premises. When data are required which are not available directly a questionnaire type of survey.

The value of the survey is totally dependent upon the design of the survey programme and the questionnaire. This process is full of traps, With questionnaire form of various kinds constituting such a substantial part of an airline's paper output some attention should be paid to seeing how these traps can be avoided and meaningful information assured. A model of the design process is helpful tasks required in designing such a survey. Using the model, it is first necessary needed from the survey should be well defined and should be limited to only that which is necessary. The survey should not be used to accumulate a mass of interesting but unnecessary data.

A question like 'how many people do you know who are afraid of flying?' suggest that the designer had not clearly defined the information he needed. Is he concerned with the number of people you have actually met or those you just know about ? And does he mean only those with a serious flight phobia? Is the questioner interested to know only those who will not fly because they are afraid? A question worded in such a vague way, and this is not uncommon, is worse than useless and is a waste of time an money. It can lead to false conclusions and the formulating of inappropriate policies.

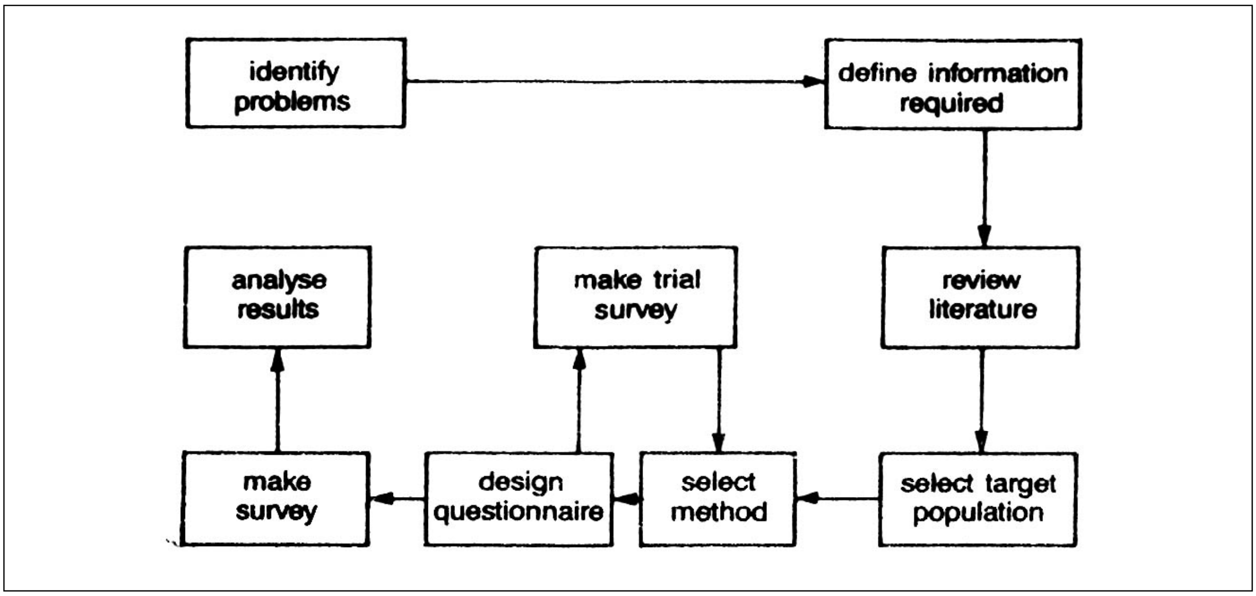


Fig. A model illustrating the process necessary for the design of an effective questionnaire.

Next in the preparatory sequence is a review of the relevant literature. This is needed to be certain of a full understanding of the subject under study and the technique involved in designing the particular kind of survey required. Excellent reference material is available to provide guidance on questionnaire design (e.g. Oppenheim, 1966; Sinclair, 1975). It is quite unjustifiable to repeat work already done or to design an ineffective or misleading survey simply as a result of neglecting to review the literature.

The next stage in the process is to define the target population, that is, those who are to give the answers. The survey could be to determine the quality of the public address system on board or in the departure hall of the terminal building. A decision will already have been made in the second step of the sequence on the information required. This may be to determine the technical quality of the equipment, the acoustics of the cabin or hall, or the quality of the contents of the messages broadcast. It is now necessary to establish who is to give the answers. Should it be only passengers or include crew and other staff. Of the broadcasts? And if on board, should it include all routes and day as well as night flights? And if crew are to be involved, should it include flight deck as well as cabin crew?

The choice of the survey method and the design of the questionnaire are the next items to be tackled. Guidance will be sought on whether it is preferable to have the survey conducted by personal interviews or whether the respondents will complete the forms themselves without assistance. The design of the questions and the selection of appropriate scales is critical to the effectiveness of the survey and these are discussed separately under the two following sub-headings.

With the questionnaire designed and the respondent selected, there is still one most important step necessary before the 'show is one the road'. A trial run, or as it is called in experimental work, a pilot study, must be carried out . This should preferably be done in three stages. Firstly, the document should be subject to criticism by one or more colleagues who have some experiences in questionnaires. After revision, it should then be given to a small group, say ten, of the population to be surveyed. This should be accompanied by a personal interview with the respondents to reveal any difficulties or ambiguities encountered. After further revision, it should then be submitted to a larger sample of the intended respondents to enable an assessment to be made of the until no further errors appear. For small surveys, the second and third stages may be combined. It would be most surprising if the feedback from the pilot study did not result in some modifications before the final printing of the questionnaires and initiation of the survey.

After completion of the survey, comes the analysis of results including an assessment of the implication of non-response. In order to do this effectively some input of expertise is needed from statistics, one of the disciplines upon which the technology of Human Factors frequently draws. This is both to assure a rational analysis of the results as well as arranging their presentation in the most meaningful way.

KEEPING UP-TO-DATE, CURRENCY

As discussed in Chapter 6, aircraft maintenance engineers undertake an approved course to obtain the knowledge and basic skills to enter the profession. This training is followed by instruction in more specific areas, such as maintenance of individual aircraft and specific systems (as discussed in Chapter 6, Section 4 on "Complex Systems"). However, the aviation industry is dynamic: operators change their aircraft, new aircraft types and variants are introduced, new aircraft maintenance practices are introduced. As a consequence, the engineer needs to keep his knowledge and skills up-to-date.

To maintain his currency, he must keep abreast of pertinent information relating to:

- new aircraft types or variants;
- new technologies and new aircraft systems;
- new tools and maintenance practices;
- modifications to current aircraft and systems he works on;

- revised maintenance procedures and practices.

Engineers are likely to keep up-to-date by:

- undertaking update courses;
- reading briefing material, memos and bulletins;
- studying maintenance manual amendments

Responsibility for maintaining currency lies with both the individual engineer and the maintenance organisation for which he works. The engineer should make it his business to keep up-to-date with changes in his profession (remembering that making assumptions can be dangerous). The organisation should provide the appropriate training and allow their staff time to undertake the training before working on a new aircraft type or variant. It should also make written information easily accessible to engineers and encourage them to read it. It is, of course, vital that those producing the information make it easy for engineers to understand (i.e. avoid ambiguity).

> Anecdotal evidence describes a case where a certain maintenance procedure was "proscribed" (i.e. prohibited) in a service bulletin. The technician reading this concluded that the procedure was "prescribed" (i.e. defined, laid down) and proceeded to perform the forbidden action.

From a human factors point of view, small changes to the technology or procedures concerning existing aircraft carry potentially the greatest risk. These do not usually warrant formal training and may merely be minor changes to the maintenance manual. Although there should be mechanisms in place to record all such changes, this presumes that the engineer will consult the updates. It is part of the engineer's individual responsibility to maintain his currency.

DISSEMINATION OF INFORMATION

As highlighted in the previous section, both the individual engineer and the organisation in which he works have a shared responsibility to keep abreast of new information. Good dissemination of information within an organisation forms part of its safety culture (Chapter 3, section 5). Typically, the maintenance organisation will be the sender and the individual engineer will be the recipient.

It was noted in Chapter 6, Section 1.1 "Planning", that an aircraft maintenance engineer or team of engineers need to plan the way work will be performed. Part of this process should be checking that all information relating to the task has been gathered and understood. This includes checking to see if there is any information highlighting a change associated with the task (e.g. the way something should be done, the tools to be used, the components or parts involved).

> It is imperative that engineers working remotely from the engineering base (e.g. on the line) familiarise themselves with new information (on notice boards, in maintenance manuals, etc.) on a regular basis.

There should normally be someone within the maintenance organisation with the responsibility for disseminating information. Supervisors can play an important role by ensuring that the engineers within their team have seen and understood any communicated information.

> Poor dissemination of information was judged to have been a contributory factor to the Eastern Airlines accident in 1983. The NTSB accident report stated:
>
> “On May 17, 1983, Eastern Air Lines issued a revised work card 7204 [master chip detector installation procedures, including the fitment of O-ring seals]. … the material was posted and all mechanics were expected to comply with the guidance. However, there was no supervisory follow-up to insure that mechanics and foremen were incorporating the training material into the work requirements… Use of binders and bulletin boards is not an effective means of controlling the dissemination of important work procedures, especially when there is no accountability system in place to enable supervisors to ensure that all mechanics had seen the applicable training and procedural information

Communication is an active process whereby both the organisation and engineer have to play their part.

■■■

CHAPTER 8
HUMAN ERROR

It has long been acknowledged that human performance is at times imperfect. Nearly two thousand years ago, the Roman philosopher Cicero cautioned “It is the nature of man to err”. It is an unequivocal fact that whenever men and women are involved in an activity, human error will occur at some point.

> In his book “Human Error” , Professor James Reason defines error as follows:
>
> “Error will be taken as a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency” .

It is clear that aircraft maintenance engineering depends on the competence of engineers. Many of the examples presented in Chapter 1 “Incidents Attributable to Human Factors / Human Error” and throughout the rest of this document highlight errors that aircraft maintenance engineers have made which have contributed to aircraft incidents or accidents.

In the past, aircraft components and systems were relatively unreliable. Modern aircraft by comparison are designed and manufactured to be highly reliable. As a consequence, it is more common nowadays to hear that an aviation incident or accident has been caused by “human error”.

The following quotation illustrates how aircraft maintenance engineers play a key role in keeping modern aircraft reliable:

> “Because civil aircraft are designed to fly safely for unlimited time provided defects are detected and repaired, safety becomes a matter of detection and repair rather than one of aircraft structure failure. In an ideal system, all defects which could affect flight safety will have been predicted in advance, located positively before they become dangerous, and eliminated by effective repair. In one sense, then, we have changed the safety system from one of physical defects in aircraft to one of errors in complex human-centred systems”

The rest of this chapter examines some of the various ways in which human error has been conceptualised. It then considers the likely types of error that occur during aircraft maintenance and the implications if these errors are not spotted and corrected. Finally, means of managing human error in aircraft maintenance are discussed.

ERROR MODELS AND THEORIES

To appreciate the types of error that it is possible to make, researchers have looked at human error in a number of ways and proposed various models and theories. These attempt to capture the nature of the error and its characteristics. To illustrate this, the following models and theories will be briefly highlighted:

- design- versus operator-induced errors;
- variable versus constant errors;

- reversible versus irreversible errors;
- slips, lapses and mistakes;
- skill-, rule- and knowledge-based behaviours and associated errors;
- the 'Swiss Cheese Model'.

Errors at the model interfaces

Each of the interfaces in the SHEL model has a potential of error where there is a mismatch between its components. For example:

— The interface between Liveware and Hardware (human and machine) is a frequent source of error: knobs and levers which are poorly located or lack of proper coding create mismatches at this interface.

— In the Liveware-Software interface, delays and errors may occur while seeking vital information from confusing, misleading or excessively cluttered documentation and charts.

— Errors associated with the Liveware-Environment interface are caused by environmental factors (noise, heat, lighting and vibration) and by the disturbance of biological rhythms in long-range flying resulting from irregular working/sleeping patterns.

— In the Liveware-Liveware interface, the focus is on the interaction between people because this process affects crew effectiveness. This interaction also includes leadership and command, and shortcomings at this interface reduce operational efficiency and cause misunderstandings and errors.

Error Rates

Having established that it is normal for man to err, it is reasonable to ask how often this is likely to occur; what error rates are considered normal. And a closely related though not identical question, how reliable is the human operator. In this respect, it should be remembered that man is a very flexible component, and if ergonomics has been properly applied to system design, he can serve to increase overall system reliability and not simply, through human error, decrease it.

On average, a person will make an error in dialling a telephone number on a round dial about once in 20 times. Performance is rather better with push-button selection. Many studies of human error rates during the performance of simple repetitive tasks have shown that errors can normally be expected to occur about once in 100 times or 10^{-2}. On the other hand, it has been demonstrated that under certain circumstances human reliability can improve by several orders of magnitude. An error rate of 1 in 1000 or 10^{-3} might be thought of as pretty good in most circumstances.

These are normal human error rates which are, so to speak, built into the human system. It is clear that they can vary widely depending on the task and many other factors such as fatigue, sleep loss and motivation. Nevertheless, this is the order of the problem we face in placing man into a complex man-machine system. It is clear that this kind of error rate, without some protective machinery, is quite unacceptable in a working environment in which the consequence of a single error can be disaster. While a direct comparison of the statistics would not be justifiable, it is worth recalling that the British Civil Aviation Authority (CAA) requirement for automatic landing equipment is that it shall not suffer a catastrophic failure more than once in 10 million landings or 10^{-7}.

As long ago as 1940, it was calculated that about 70% of aircraft accidents could be attributed to the performance of man (Meier Muller, 1940). A third (IATA, 1975) and human error remained the dominant theme (Fig. below).

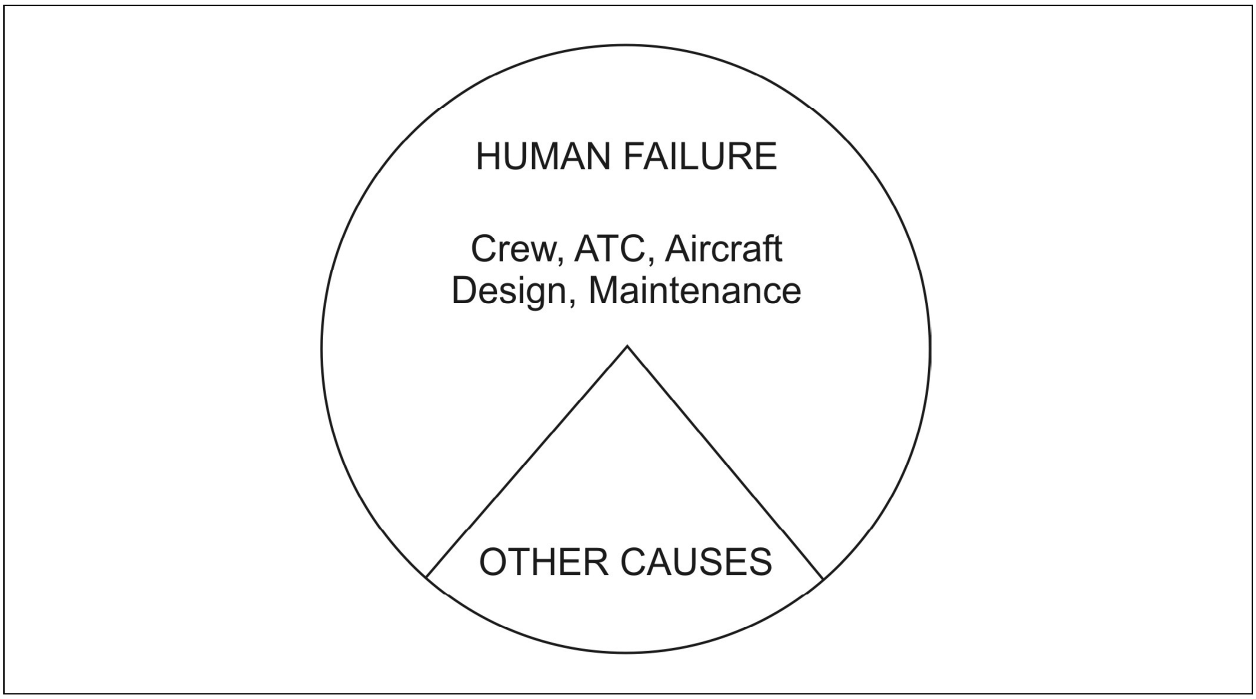


Fig. A diagram illustrating the dominant role played by human performance in civil aircraft accident (IATA, 1975)

This situation, however, is not unique to aviation; it has been estimated elsewhere that 80% – 90% of accidents are the result of human error (Draw, 1967).

Accident Proneness

The concept of accident proneness originated early in the 20th Century (Greenwood et al., 1964). Since then the concept, and even its definition, has been the subject of controversy and it will not be possible in the short space available here to cover the area in detail. It will be sufficient for our purpose to accept that accident proneness is the tendency of some people to have more accidents than others with equivalent risk exposure, for reasons beyond chance alone.

Having said that, it is necessary to examine the kind of distribution which might be expected from chance alone. This can be reduced from what is called the Poisson Distribution (Reichmann, 1961). As an example, if 100 people, then were distributed at random over a number of years amongst 100 people, then it might be expected that the apportionment of accidents would look something like this :

0 accident .... 37 people
1 accident .... 37 people
2 accidents .... 18 people
3 accidents .... 6 people
4 accidents .... 2 people

If the example were extended to cover 1000 accidents distributed amongst 1000 people, then three might be expected to have as many as five accidents. There would then be a powerful temptation to label these three victims as being accident prone with discriminatory action being taken against them. On the grounds of frequency alone, such action would be unjustified. Similar caution must also be applied when assessing an airline's relative safety on the basis of the very small sample of accidents occurring.

It is clear, then, that one person can have more accidents than another purely by chance. However, there are also other reasons for differences in the number of accidents experienced by individuals, which may be more controllable. One such reason may simply be one of exposure to risk. A pilot flying routinely in bad weather with poorly equipped aircraft and into inadequate airfields is exposed to more risk than one flying in a good climate with modern avionics on board an into airports with proper facilities.

In addition to pure chance an exposure, a third reason for variation in the individual's accident record could be that he possesses some innate characteristics which make him more liable to have accidents. Many have seen this as a more appropriate definition of accident proneness. There has been some evidence to suggest that those who have accidents at work also have them at home (Newbold, 1964). And also that there was a significant correlation between accidents in a simulated kitchen and road traffic accidents (Guilfor, 1973). Whether or not such an innate characteristic is not established.

It is likely that in any given period one person makes more errors than another for reasons other than chance, exposure or innate characteristics. One housewife may consistently break more glasses while washing the dishes than another, and this may result from an inherent awkwardness, lack of muscle coordination or simply carelessness. But the glass-breaking frequency may change on a short term basis with influences such as domestic or work stress, health variations, job satisfaction, or boredom.

It must be hoped that professional airline pilots with recognisable physiological, psychological or personality deficiencies which would make them congenital 'glass-breakers' will have been mostly filtered out as a result of screening techniques applied during selection and training. However, some no doubt will slip through this filtering process.

We are then left mainly with chance, exposure and short-term factors, that last frequently resulting from changes in motivation.

When examining these short-term factors it is still important to recognise that response to a particular stressful influence varies from one person to another. A life-change event (discussed in more detail in Chapter 4) which causes distress and performance degradation in one pilot may be taken in his stride by another, who, in his turn, may be vulnerable to a different form of stress.

In view of the lack of consistency and agreement in the use of the term accident proneness, it might be wise to discard it altogether as a concept and refer simply to individual differences in involvement in accidents. This allows all of the influencing elements to be considered equally without assuming a basis preeminence of any one and avoids the conceptual confusion which has plagued accident proneness.

In particular, it allows full consideration to be given to shorter-term influences which may be a more fruitful approach in accident prevention.

Design-Versus Operator-Induced Errors

In aviation, emphasis is often placed upon the error(s) of the front line operators, who may include flight crew, air traffic controllers and aircraft maintenance engineers.

However, errors may have been made before an aircraft ever leaves the ground by aircraft designers. This may mean that, even if an aircraft is maintained and flown as it is designed to be, a flaw in its original design may lead to operational safety being compromised. Alternatively, flawed procedures put in place by airline, maintenance organisation or air traffic control management may also lead to operational problems.

It is common to find when investigating an incident or accident that more than one error has been made and often by more than one person. It may be that, only when a certain combination of errors arises and error 'defences' breached (see the 'Swiss Cheese Model') will safety be compromised.

Variable Versus Constant Errors

In his book "Human Error", Professor Reason discusses two types of human error: variable and constant. It can be seen in Figure below, that variable errors in (A) are random in nature, whereas the constant errors in (B) follow some kind of consistent, systematic (yet erroneous) pattern. The implication is that constant errors may be predicted and therefore controlled, whereas variable errors cannot be predicted and are much harder to deal with. If we know enough about the nature of the task, the environment it is performed in, the mechanisms governing performance, and the nature of the individual, we have a greater chance of predicting an error.

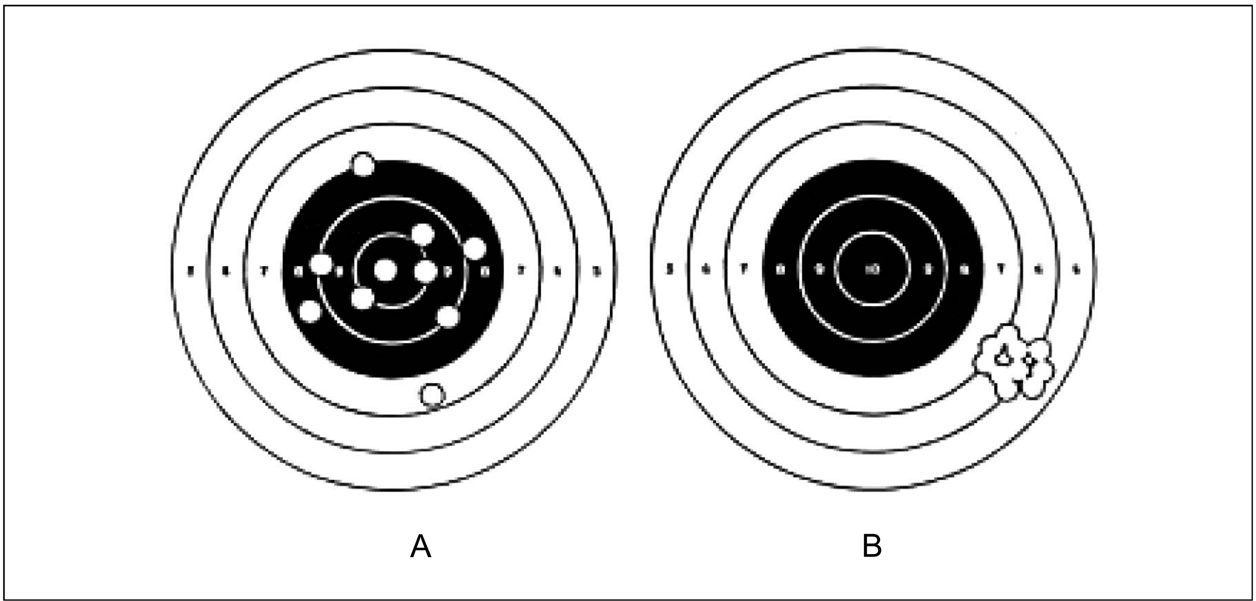


Fig. Variable versus Constant Errors.

Target patterns of 10 shots fired by two riflemen. Rifleman A's pattern exhibits no constant error, but large variable errors; rifleman B's pattern exhibit's a large constant error but small variable errors. The latter would, potentially, be easier to predict and to correct (e.g. by correctly aligning the rifle sight). Chapanis, 1951

However, it is rare to have enough information to permit accurate predictions; we can generally only predict along the lines of "re-assembly tasks are more likely to incur errors than dismantling tasks", or "an engineer is more likely to make an error at 3 a.m., after having worked 12 hours, than at 10 a.m. after having worked only 2 hours". It is possible to refine these predictions with more information, but there will always be random errors or elements which cannot be predicted.

Reversible Versus Irreversible Errors

Another way of categorising errors is to determine whether they are reversible or irreversible. The former can be recovered from, whereas the latter typically cannot be. For example, if a pilot miscalculates the fuel he should carry, he may have to divert to a closer airfield, but if he accidentally dumps his fuel, he may not have many options open to him.

A well designed system or procedure should mean that errors made by aircraft maintenance engineers are reversible. Thus, if an engineer installs a part incorrectly, it should be spotted and corrected before the aircraft is released back to service by supervisory procedures in place.

Slips, Lapses and Mistakes

Reason highlights the notion of 'intention' when considering the nature of error, asking the questions:

- Were the actions directed by some prior intention?
- Did the actions proceed as planned?
- Did they achieve their desired end?

Reason then suggests an error classification based upon the answers to these questions as shown in Figure below.

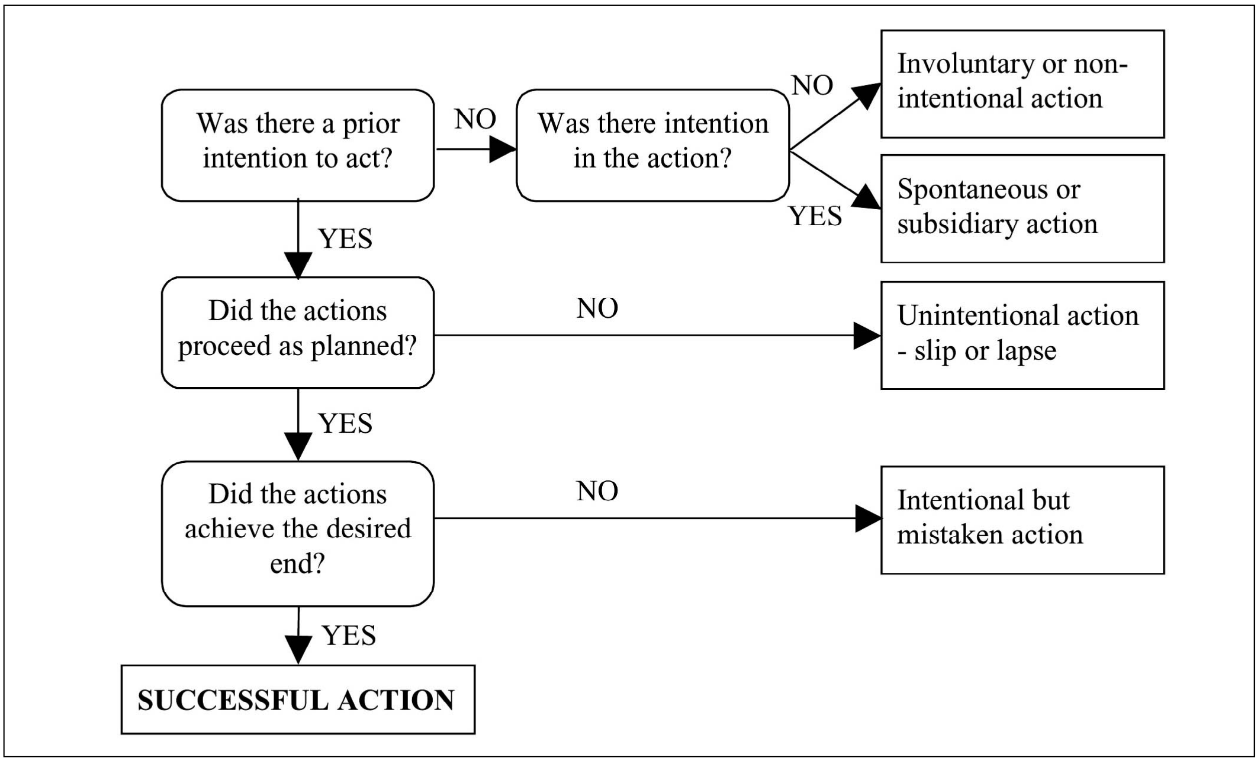


Fig. Error types based on intention.

The most well-known of these are slips, lapses and mistakes.

Slips can be thought of as actions not carried out as intended or planned, e.g. ‘transposing digits when copying out numbers, or misordering steps in a procedure.

Lapses are missed actions and omissions, i.e. when somebody has failed to do something due to lapses of memory and/or attention or because they have forgotten something, e.g. forgetting to replace an engine cowling.

Mistakes are a specific type of error brought about by a faulty plan/intention, i.e. somebody did something believing it to be correct when it was, in fact, wrong, e.g. an error of judgement such as mis-selection of bolts when fitting an aircraft windscreen.

Slips typically occur at the task execution stage, lapses at the storage (memory) stage and mistakes at the planning stage.

Violations sometimes appear to be human errors, but they differ from slips, lapses and mistakes because they are deliberate ‘illegal’ actions, i.e. somebody did something knowing it to be against the rules (e.g. deliberately failing to follow proper procedures). Aircraft maintenance engineers may consider that a violation is well-intentioned, i.e. ‘cutting corners’ to get a job done on time. However, procedures must be followed appropriately to help safeguard safety.

Skill-, Rule- and Knowledge-Based Behaviours and Associated Errors

The behaviour of aircraft maintenance engineers can be broken down into three distinct categories: skill-based, rule-based and knowledge-based behaviour.

Green et al define these:

“Skill-based behaviours are those that rely on stored routines or motor programmes that have been learned with practice and may be executed without conscious thought.

Rule-based behaviours are those for which a routine or procedure has been learned. The components of a rule-based behaviour may comprise a set of discrete skills.

Knowledge-based behaviours are those for which no procedure has been established. These require the [aircraft maintenance engineer] to evaluate information, and then use his knowledge and experience to formulate a plan for dealing with the situation.”

Each of these behaviour types have specific errors associated with them.

Examples of skill-based errors are action slips, environmental capture and reversion. Action slips as the name implies are the same as slips, i.e. an action not carried out as intended. The example given in Figure 24 may consist of an engineer realising he needs a certain wrench to complete a job but, because he is distracted by a colleague, picks up another set to the wrong torque and fails to notice that he has tightened the bolts incorrectly.

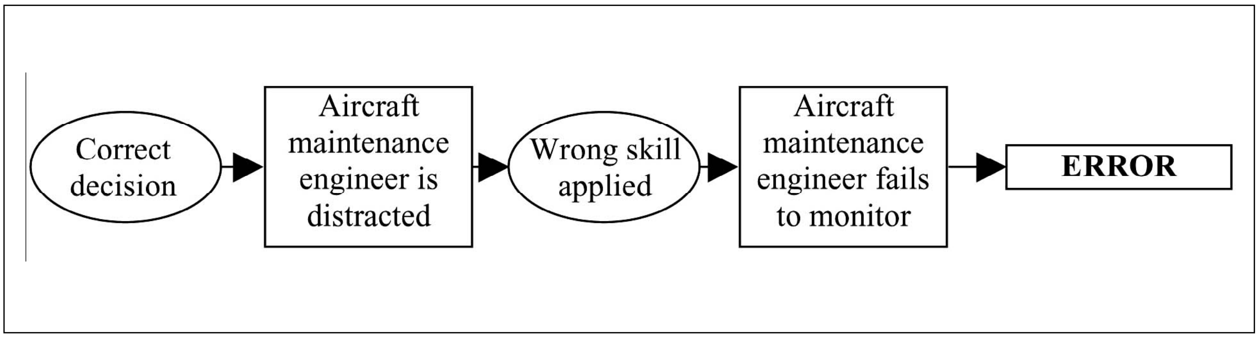


Fig. Example of an Action Slip

Environmental capture may occur when an engineer carries out a certain task very frequently in a certain location. Thus, an engineer used to carrying out a certain maintenance adjustment on an Airbus A300, may inadvertently carry out this adjustment on the next A300 he works on, even if it is not required (and he has not made a conscious decision to operate the skill).

Reversion can occur once a certain pattern of behaviour has been established, primarily because it can be very difficult to abandon or unlearn it when it is no longer appropriate. Thus, an engineer may accidentally carry out a procedure that he has used for years, even though it has been recently revised. This is more likely to happen when people are not concentrating or when they are in a stressful situation.

Rule-based behaviour is generally fairly robust and this is why the use of procedures and rules is emphasised in aircraft maintenance. However, errors here are related to the use of the wrong rule or procedure. For example, an engineer may misdiagnose a fault and thus apply the wrong procedure, thus not clearing the fault. Errors here are also sometimes due to faulty recall of procedures. For instance, not remembering the correct sequence when performing a procedure.

Errors at the knowledge-based performance level are related to incomplete or incorrect knowledge or interpreting the situation incorrectly. An example of this might be when an engineer attempts an unfamiliar repair task and assumes he can 'work it out'. Once he has set out in this way, he is likely to take more notice of things that suggest he is succeeding in his repair, while ignoring evidence to the contrary (known as confirmation bias).

The 'Swiss Cheese Model'

In his research, Reason has highlighted the concept of 'defences' against human error within an organisation, and has coined the notion of 'defences in depth'. Examples of defences are duplicate inspections, pilot pre-flight functional checks, etc., which help prevent to 'trap' human errors, reducing the likelihood of negative consequences. It is when these defences are weakened and breached that human errors can result in incidents or accidents. These defences have been portrayed diagramatically, as several slices of Swiss cheese (and hence the model has become known as Professor Reason's "Swiss cheese" model) (see Figure below).

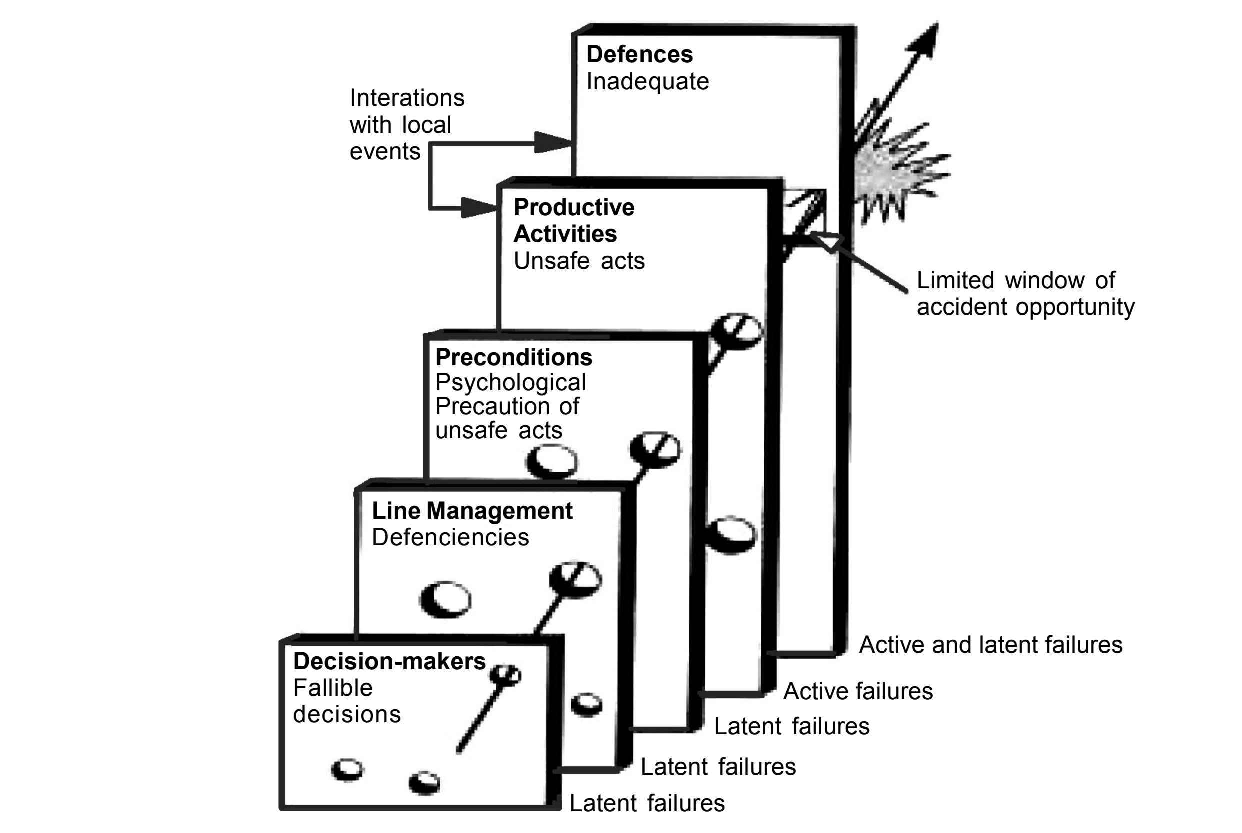


Fig. Reason's Swiss Cheese Model.

Some failures are latent, meaning that they have been made at some point in the past and lay dormant. This may be introduced at the time an aircraft was designed or may be associated with a management decision. Errors made by front line personnel, such as aircraft maintenance engineers, are 'active' failures. The more holes in a system's defences, the more likely it is that errors result in incidents or accidents, but it is only in certain circumstances, when all holes 'line up', that these occur. Usually, if an error has breached the engineering defences, it reaches the flight operations defences (e.g. in flight warning) and is detected and handled at this stage. However, occasionally in aviation, an error can breach all the defences (e.g. a pilot ignores an in flight warning, believing it to be a false alarm) and a catastrophic situation ensues.

Defences in aircraft maintenance engineering will be considered further in Section 4.

TYPES OF ERROR IN MAINTENANCE TASKS

THE CLASSIFICATION OF ERRORS

The need of

In order to describe a person we may say that he is a man of distinction, well-dressed, tall and honest. Similarly we may describe an error as being one of substitution, system-induced, random and reversible. By classifying people we are better able to identify them. Similarly with errors. There are many ways of doing this. Classifications may be in terms of source, as already discussed, cause, consequences or general nature. We will here simply review a few of the most common.ly used classification ters.

Design-induced and operator-induced

An error which occurs at the L – H or L – S interface may result from a faulure to design the Hardware or the Software properly taking into account the normal characteristics of the Liveware or the operator. This is often called a design-induced error as distinct from operator-induced.

As an example, there have been historically countless cases of confusion in handling theflaps and the gear controls on DC3 aircraft as they are in close proximity to each other and of comparable shape. Similar confusion between controls continues to be reported from time to time in the ASRS and CHIRP confidential reporting systems. Further examples of control and display designs which can induce errors arediscussed in Chapter 11.

An operator-induced error can be attributed directly to inadequate performance on the part of an individual reflecting, perhaps, deficient skill, motivation or vision. An error may be to some degree both design and operator-induced.

Sometimes a distinction is made between a design-induced error, referring the Hardware, and a system-induced error, referring to the Software.

Rather similar to these forms of classification is one which refers to situation-caused errors and contrasts these with what are described as human-caused errors. Some studies have pursued this grouping; one has reported two to four times as many situation - as human-caused errors (Kragt, 1978).

Random, systematic and sporadic

Another form of classification can be illustrated in the way rifle shots are distributed on a target (Figure below). When the shots appear to be scattered at ramdom across the target without any discernable pattern, this is called random error. Many factors may influence therange of this variability. A second kind of error is characterised by a small dispersion which is offset from the desired point. This is called sporadic error and this is said to exist when, after a routinely good performance, an isolated error occurs. Sporadic errors are very difficult to predict.

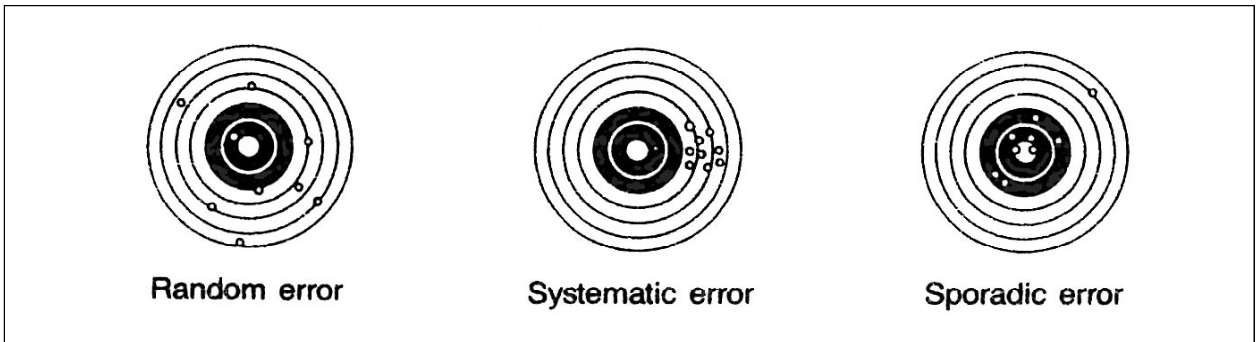


Fig. The classification of error as random, systematic and sporadic.

If we relate these three error types to the flying situation, we could say that the pilot whose landing touch-down point varies without a recognisable pattern is committing random errors. The one who consistently undershoots is demostrating a systematic error. While the one who normally lands the aircraft accurately, but then inexplicably makes a rare classification can, of course, be applied to the performance of other tasks, such as the stewardess making coffee or the mechanic carrying out maintenace work.

Omission, commission and sunbstitution

One of the most common errors recognised is failing to do something which ought to be done such as missing an item on a checklist. This is called an error of omission and introduces another way errors can be classified. An error of commission is doin something which ought not to be done, such as calling passengers to board the aircraft on the scheduled departure time when the flight has a one-hour technical delay. A third kind of error in this form of grouping is the error of substitution, which is takin action when it is required, but the wrong action. This kind of error has led to disaster on a number of occasions when a pilot closed down the wrong engine after an in-flight engine failure.

As aircraft maintenance engineers are human, errors in the industry are inevitable.

> Any maintenance task performed on an aircraft is an opportunity for human error to be introduced. Errors in aircraft maintenance engineering tend to take two specific forms:
>
> i. an error that results in a specific aircraft problem that was not there before the maintenance task was initiated;
>
> ii. an error that results in an unwanted or unsafe condition remaining undetected while performing a maintenance task designed to detect aircraft problems, i.e. something is missed.

Examples of errors highlighted in (i) in the box above are incorrect installation of line-replaceable units, failure to remove a protective cap from a hydraulic line before re-assembly or damaging an air duct used as a foothold while gaining access to perform a task. Examples of errors in (ii) are a structural crack unnoticed during a visual inspection task or a faulty avionics box that remains on the aircraft because incorrect diagnosis of the problem led to removal of the wrong box. The actual error type responsible can be any of those highlighted in the previous section of this document.

Errors During Regular and Less Frequent Maintenance Tasks

A large proportion of maintenance tasks are fairly routine, such as regular, periodic checks on aircraft. Thus, engineers will use a certain set of procedures relatively frequently and, as noted in the previous section, slips and lapses can occur when carrying out procedures in the busy hangar or line environment. Chapter 6, Section 2 “Repetitive Tasks” noted that engineers will often become so accustomed to doing a regular, often repeated task, that they will dispense with written guidance altogether. It would be unrealistic and unnecessarily time consuming to expect them to constantly refer to familiar guidance material. However, errors may occur if they do not keep up-to-date with any changes that occur to these frequently used procedures. These routine tasks are also prone to complacency, environmental capture and rule-based errors.

When undertaking less frequently performed tasks, there is the possibility of errors of judgement. If the engineer does not familiarise or refamiliarise himself properly with what needs to be done, he may mistakenly select the wrong procedure or parts.

Violation in Aircraft Maintenance

It is an unfortunate fact of life that violations occur in aviation maintenance. Most stem from a genuine desire to do a good job. Seldom are they acts of vandalism or sabotage. However. they represent a significant threat to safety as systems are designed assuming people will follow the procedures. There are four types of violations:

- Routine violations;
- Situational violations;
- Optimising violations;
- Exceptional violations.

Routine violations are things which have become 'the normal way of doing something' within the person's work group (e.g. a maintenance team). They can become routine for a number of reasons: engineers may believe that procedures may be over prescriptive and violate them to simplify a task (cutting corners), to save time and effort.

Situational violations occur due to the particular factors that exist at the time, such as time pressure, high workload, unworkable procedures, inadequate tooling, poor working conditions. These occur often when, in order to get the job done, engineers consider that a procedure cannot be followed.

Optimising violations involve breaking the rules for 'kicks'. These are often quite unrelated to the actual task. The person just uses the opportunity to satisfy a personal need.

Exceptional violations are typified by particular tasks or operating circumstances that make violations inevitable, no matter how well intentioned the engineer might be.

Examples of routine violations are not performing an engine run after a borescope inspection ("it never leaks"), or not changing the 'O' seals on the engine gearbox drive pad after a borescope inspection ("they are never damaged").

An example of a situational violation is an incident which occurred where the door of a B747 came open in-flight. An engineer with a tight deadline discovered that he needed a special jig to drill off a new door torque tube. The jig was not available, so the engineer decided to drill the holes by hand on a pillar drill. If he had complied with the maintenance manual he could not have done the job and the aircraft would have missed the service.

An example of an optimising violation would be an engineer who has to go across the airfield and drives there faster than permitted

Time pressure and high workload increase the likelihood of all types of violations occurring. People weigh up the perceived risks against the perceived benefits, unfortunately the actual risks can be much higher.

Errors Due to Individual Practices and Habits

Where procedures allow some leeway, aircraft maintenance engineers often develop their own strategies or preferred way of carrying out a task. Often, a 'good' rule or principle is one that has been used successfully in the past. These good rules become ‘rules of thumb’ that an engineer might adopt for day-to-day use. Problems occur when the rule or principle is wrongly applied. For example, aircraft pipe couplings are normally right hand threads but applying this ‘normally good rule’ to an oxygen pipe (having a different thread) could result in damage to the pipe. Also, there can be dangers in applying rules based on previous experience if, for example, design philosophy differs, as in the case of Airbus and Boeing. This may have been a factor in an A320 locked spoiler incident, where subtle differences between the operation of the spoilers on the A320 and those of the B767 (with which the engineers were more familiar) meant that actions which would have been appropriate on the B767 were inappropriate in the case of the A320.

In addition, engineers may pick up some ‘bad rules’, leading to bad habits during their working life, as a driver does after passing his driving test. An example of applying a bad rule is the British Rail technician in the Clapham train accident who had acquired the practice of bending back old wires rather than cutting them off and insulating them.

Errors Associated With Visual Inspection

There are also two particular types of error which are referred to particularly in the context of visual inspection, namely Type 1 errors and Type 2 errors. A Type 1 error occurs when a good item is incorrectly identified as faulty; a Type 2 error occurs when a faulty item is missed. Type 1 errors are not a safety concern per se, except that it means that resources are not being used most effectively, time being wasted on further investigation of items which are not genuine faults. Type 2 errors are of most concern since, if the fault (such as a crack) remains undetected, it can have serious consequences (as was the case in the Aloha accident, where cracks remained undetected).

Reason’s Study of Aviation Maintenance Engineering

Reason analysed the reports of 122 maintenance incidents occurring within a major airline over a 3 year period. He identified the main causes as being:

- Omissions (56%)
- Incorrect installation (30%)
- Wrong parts (8%)
- Other (6%)

It is likely that Reason’s findings are representative for the aircraft maintenance industry as a whole. Omissions can occur for a variety of reason, such as forgetting, deviation from a procedure (accidental or deliberate), or due to distraction. The B7372 double engine oil loss incident, in which the HP rotor drive covers were not refitted is an example of omission. Incorrect installation is unsurprising, as there is usually only one way in which something can be taken apart but many possible ways in which it can be reassembled. Reason illustrates this with a simple example of a bolt and several nuts (see Figure 26), asking the questions (a) how many ways can this be disassembled? (the answer being 1) and (b) how many ways can it be reassembled? (the answer being about 40,000, excluding errors of omission!).

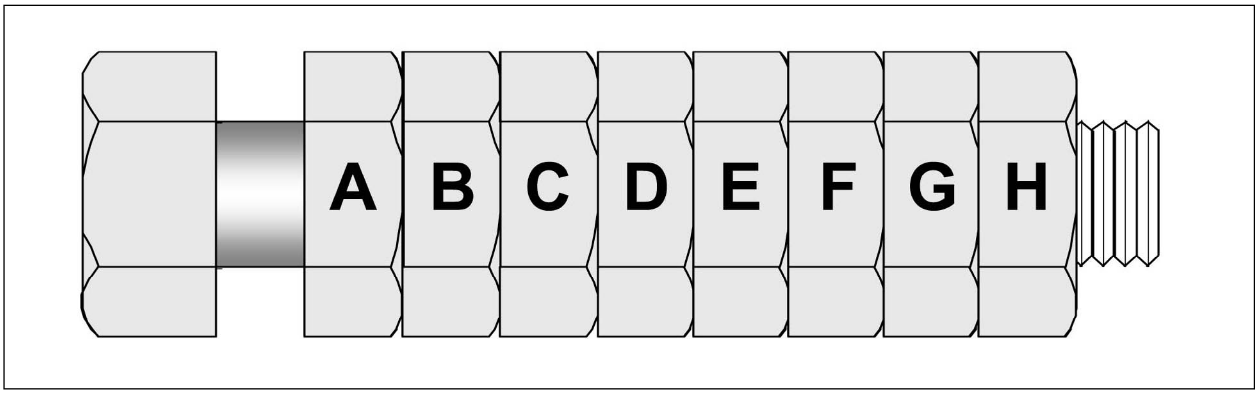


Fig. Reason's Bolt and Nuts Example. Source: Reason, 1997

In the BAC1-111 accident in June 1990, the error was fitting the wrong bolts to the windscreen. This illustrates well the category of 'wrong parts'.

Human error in maintenance usually manifests itself as an unintended aircraft discrepancy (physical degradation or failure) attributable to the actions or non-actions of the aircraft maintenance technician (AMT). The word "attributable" is used because human error in maintenance can take two basic forms. In the first case, the error results in a specific aircraft discrepancy that was not there before the maintenance task was initiated. Any maintenance task performed on an aircraft is an opportunity for human error which may result in an unwanted aircraft discrepancy. Examples include incorrect installation of line-replaceable units or failure to remove a protective cap from a hydraulic line before reassembly or damaging an air duct used as a foothold while gaining access to perform a task (among other failures, these examples also illustrate mismatches in the L-H interface of the SHEL model). The second type of error results in an unwanted or unsafe condition being undetected while performing a scheduled or unscheduled maintenance task designed to detect aircraft degradation. Examples include a structural crack unnoticed during a visual inspection task or a faulty avionics box that remains on the aircraft because incorrect diagnosis of the problem led to removal of the wrong box. These errors may have been caused by latent failures, such as deficient training, poor allocation of resources and maintenance tools, time-pressures, etc. They may also have been caused by poor ergonomic design of tools (L-H flawed interface), incomplete documentation or manuals (L-S interface flaw), etc.

Several widely publicized accidents have had human errors in maintenance as a contributing factor. The American Airlines DC-10 accident in Chicago in 1979 resulted from an engine change procedure where the pylon and engine were removed and installed as a unit rather than separately. This unapproved procedure (a latent failure, probably with L-H and L-S mismatch involved) resulted in failure of the pylon structure which became evident when one of the wing-mounted engines and its pylon separated from the aircraft at take-off. The resulting damage to hydraulic systems caused the retraction of the left wing outboard leading edge slats and subsequent loss of control. In 1985, a Japan Airlines Boeing 747 suffered a rap decompression in flight when an improperly repaired rear pressure bulkhead failed (a latent failure, probably with L-H and L-S mismatch involved). The subsequent overpressurization of the empennage and expansion of shockwave due to the explosive breakage of the spherical pressure bulkhead caused control system failure and the destruction of the aircraft with great loss of life. In April 1988, an Aloha Airlines Boeing 737 suffered a structural failure of the upper fuselage. Eventually the aircraft was landed with the loss of only one life. This accident was attributed to improper maintenance practices (latent failures) that allowed structural deterioration to go undetected.

In a detailed analysis of 93 major world-wide accidents which occurred between 1959 and 1983, it was revealed that maintenance and inspection were factors in 12% of the accidents. The analysis proposes the following significant causes of accidents and their presence in percentages:

Cause of Accident	**Presence (%)**
pilot deviation from standard procedures	33
inadequate cross-check by second pilot	26
design faults	13
maintenance and inspection deficiencies	12
absence of approach guidance	10
captain ignored crew inputs	10
air traffic control error/failure	09
improper crew response during abnormal conditions	09
insufficient or incorrect weather information	08
runway hazards	07
improper decision to land	06
air traffic control/flight crew communication deficiencies	06

In some accidents, where the error was attributed to maintenance and inspection, the error itself was a primary causal factor of the accident whereas, in other cases, the maintenance discrepancy was just one link in a chain of events that led to the accident.

The United Kingdom Civil Aviation Authority (UK CAA) has published a listing of frequently recurring maintenance discrepancies. According to this listing, the leading maintenance problems in order of occurrence are:

incorrect installation of components
fitting of wrong parts
electrical wiring discrepancies (including cross-connections)
loose objects (tools, etc.) left in aircraft
inadequate lubrication
cowlings, access panels and fairings not secured
landing gear ground lock pins not removed before departure.

An analysis of 122 documented occurrences involving Human Factors errors with likely engineering relevance, occurring in the 1989-1991 time period in one airline, revealed that the main categories of maintenance error were:

Maintenance error categories	Percentage
omissions	56
incorrect installations	30
wrong parts	08
other	06

The majority of items often omitted are fastenings left undone or incomplete. The following example illustrates this point:

> An aircraft experienced vibration problems with the right engine for two weeks. The engineers had looked at the problem and, believing that it was the pneumatics, had swapped the pressure-regulating valves. However, just to be on the safe side, they sent an aircraft maintenance technician along to monitor the engine readings on a flight from Amsterdam to Kos carrying a full load of tourists. Departure was uneventful except for a brief rise on the vibration indicator of the right engine at about 130 knots. On cruise, the vibration indicator was bouncing up and down between 1.2 and 1.3, still within the normal range. However, there was a feeling of unfamiliar and strange vibrations. Ninety minutes into the flight, the vibration indicator registered 1.5, just below the amber range. Fifteen minutes later, the indicator was bouncing up into the amber range. The crew reverted to manual throttle control and descended to FL 290, slowly closing the throttle. The right engine vibration indicator suddenly shot up to 5.2 and a dull tremor shook the aircraft. Then the readings returned to the normal range and the vibration disappeared. The Captain, however, decided to declare an emergency and land in Athens where he felt he could get technical support that would not be available at Kos. With the engine now at idle thrust, the engine readings went back to the normal range and, as a result, the Captain decided to leave it well alone and not shut it down. On landing, the crew noticed some metal particles around the engine and discolouration on the blades that looked like oil.

When the report concerning the engine came out a few days later, it read:

> "... that the cause of the loose disc was the nuts being fitted only 'finger tight' to the LP1 (low pressure) and LP2 disc bolts and not being torqued up allowing axial movement in and out of the curvature, causing heavy rubs and out of balance. The nuts became successively loose allowing the bolts to come free until only the residual four remained."

The engine had been in for overhaul before the operator took delivery of the aircraft. There are 36 nuts and bolts that hold the LP1 and LP2 discs together. Apparently the technician working on them had finger tightened them and then decided to go to lunch. On his return he forgot to torque them as he had intended to do before he left for lunch. All but four of the bolts had fallen out and the remaining bolts only had 1/4 of an inch of thread left. Only the residual thrust held the engine together. Had the crew elected to shut the engine down, the consequences would probably have been catastrophic.

Incorrect installation of components and lack of proper inspection and quality control represent the most frequently recurring maintenance errors. Examples abound. Consider the following occurrences:

- On 5 May 1983, Eastern Airlines Flight 855, a Lockheed L-1011 aircraft, departed Miami International Airport en route to Nassau, the Bahamas. A short time after take-off, the low oil pressure light for No. 2 engine illuminated. The crew shut down the engine as a precautionary measure and the pilot decided to return to Miami. Shortly thereafter the remaining two engines failed following a zero oil pressure indication on both engines. Attempts were made to restart all three engines. Twenty-two miles from Miami, descending through 4 000 ft, the crew was able to restart the No. 2 engine and made a one-engine landing with the No. 2 engine producing considerable smoke. It was found that all three master chip detector assemblies had been installed without O-ring seals.

- On 10 June 1990, a BAC 1-11 aircraft (British Airways Flight 5390) departed Birmingham International Airport for Malaga, Spain, with 81 passengers, four cabin and two flight crew. The co-pilot was the pilot flying during the take-off and, once established in the climb, the pilot-in-command handled the aircraft in accordance with the operator's normal operating procedures. At this stage both pilots released their shoulder harnesses and the pilot-in-command loosened his lap-strap. As the aircraft was climbing through 17 300 feet pressure altitude, there was a loud bang and the fuselage filled with condensation mist indicating that a rapid decompression had occurred. A cockpit windscreen had blown out and the pilot-in-command was partially sucked out of his windscreen aperture. The flight deck door blew onto the flight deck where it lay across the radio and navigation console. The co-pilot immediately regained control of the aircraft and initiated a rapid descent to FL 110. The cabin crew tried to pull the pilot-in-command back into the aircraft but the effect of the slipstream prevented them from succeeding. They held him by the ankles until the aircraft landed. The investigation revealed that the accident occurred because a replacement windscreen had been fitted with the wrong bolts.
- On 11 September 1991, Continental Express Flight 2574, an Embraer 120, departed Laredo International Airport, Texas, en route to Houston Intercontinental Airport. The aircraft experienced a sudden structural breakup in flight and crashed, killing all 13 persons on board. The investigation revealed that the accident occurred because the attaching screws on top of the left side leading edge of the horizontal stabilizer were removed and not reattached, leaving the leading edge/de-ice boot assembly secured to the horizontal stabilizer by only the bottom attachment screws.

IMPLICATIONS OF ERRORS (I.E. ACCIDENTS)

In the worst cases, human errors in aviation maintenance can and do cause aircraft accidents. However, as portrayed in Figure below, accidents are the observable manifestations of error. Like an iceberg which has most of its mass beneath the water line, the majority of errors do not result in actual accidents.

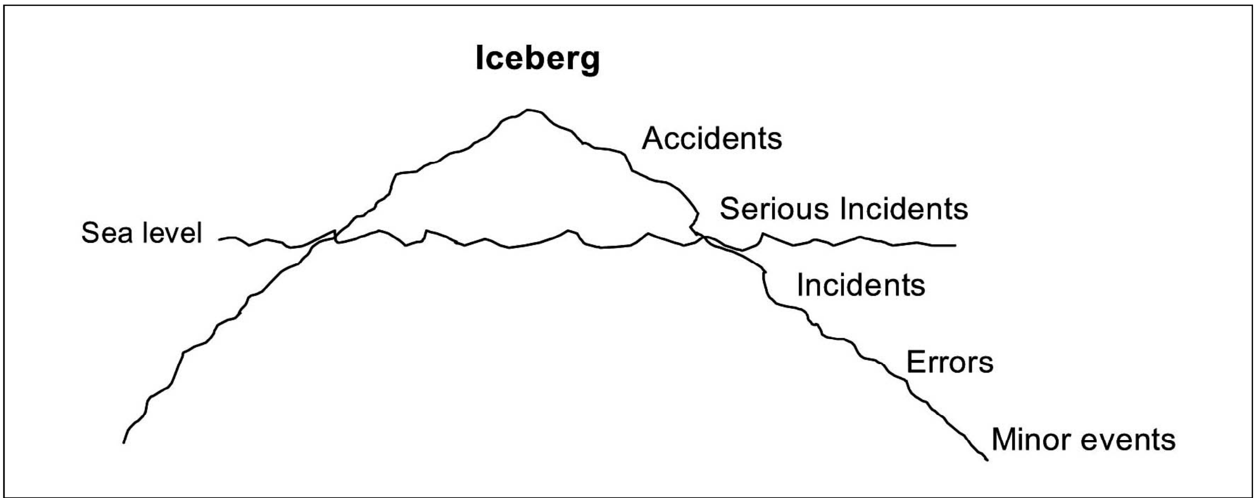


Fig. The "Iceberg Model" of Accidents

Thankfully, most errors made by aircraft maintenance engineers do not have catastrophic results. This does not mean that this might not be the result should they occur again.

Errors that do not cause accidents but still cause a problem are known as incidents. This subject was introduced at the beginning of this document in Chapter 1, Section 2 “Incidents Attributable To Human Factors / Human Error”, which gave examples of aviation incidents relating to aircraft maintenance errors. Some incidents are more high profile than others, such as errors causing significant in-flight events that, fortuitously, or because of the skills of the pilot, did not become accidents. Other incidents are more mundane and do not become serious because of defences built into the maintenance system. However, all incidents are significant to the aircraft maintenance industry, as they may warn of a potential future accident should the error occur in different circumstances. As a consequence, all maintenance incidents have to be reported to the UK Civil Aviation Authority Mandatory Occurrence Reporting Scheme (MORS). These data are used to disclose trends and, where necessary, implement action to reduce the likelihood or criticality of further errors. In the UK, the Confidential Human Factors Incident Reporting Programme (CHIRP) scheme provides an alternative reporting mechanism for individuals who want to report safety concerns and incidents confidentially.

It is likely that the greatest proportion of errors made by aircraft maintenance engineers are spotted almost immediately they are made and corrected. The engineer may detect his own error, or it may be picked up by colleagues, supervisors or quality control. In these cases, the engineer involved should (it is hoped) learn from his error and therefore (it is hoped) be less likely to make the same error again.

> It is vital that aircraft maintenance engineers learn from their own errors and from the errors made by others in the industry. These powerful and persuasive lessons are the positive aspects of human error.

When an error occurs in the maintenance system of an airline, the engineer who last worked on the aircraft is usually considered to be ‘at fault’. The engineer may be reprimanded, given remedial training or simply told not to make the same error again. However, blame does not necessarily act as a positive force in aircraft maintenance: it can discourage engineers from ‘coming clean’ about their errors. They may cover up a mistake or not report an incident. It may also be unfair to blame the engineer if the error results from a failure or weakness inherent in the system which the engineer has accidentally discovered (for example, a latent failure such as a poor procedure drawn up by an aircraft manufacturer - possibly an exceptional violation).

The UK Civil Aviation Authority has stressed in Airworthiness Notice No. 71 (Issue 1, 20 March 2000) that it “seeks to provide an environment in which errors may be openly investigated in order that the contributing factors and root causes of maintenance errors can be addressed”. To facilitate this, it is considered that an unpremeditated or inadvertent lapse should not incur any punitive action, but a breach of professionalism may do so (e.g. where an engineer causes deliberate harm or damage, has been involved previously in similar lapses, attempted to hide their lapse or part in a mishap, etc.).

AVOIDING AND MANAGING ERRORS

Whilst the aircraft maintenance engineering industry should always strive towards ensuring that errors do not occur in the first place, it will never be possible to eradicate them totally. Therefore all maintenance organisations should aim to ‘manage’ errors.

Error management seeks to:
- prevent errors from occurring;
- eliminate or mitigate the bad effects of errors

Reason refers to the two components of error management as: (i) error containment and (ii) error reduction.

To prevent errors from occurring, it is necessary to predict where they are most likely to occur and then to put in place preventative measures. Incident reporting schemes (such as MORS) do this for the industry as a whole. Within a maintenance organisation, data on errors, incidents and accidents should be captured with a Safety Management System (SMS), which should provide mechanisms for identifying potential weak spots and error-prone activities or situations. Output from this should guide local training, company procedures, the introduction of new defences, or the modification of existing defences.

According to Reason1, error management includes measure to:

- minimise the error liability of the individual or the team;
- reduce the error vulnerability of particular tasks or task elements;
- discover, assess and then eliminate error-producing (and violation-producing) factors within the workplace;
- diagnose organisational factors that create error-producing factors within the individual, the team, the task or the workplace;
- enhance error detection;
- increase the error tolerance of the workplace or system;
- make latent conditions more visible to those who operate and manage the system;
- improve the organisation's intrinsic resistance to human fallibility.

It would be very difficult to list all means by which errors might be prevented or minimised in aircraft maintenance. In effect, the whole of this document discusses mechanisms for this, from ensuring that individuals are fit and alert, to making sure that the hangar lighting is adequate.

One of the things likely to be most effective in preventing error is to make sure that engineers follow procedures. This can be effected by ensuring that the procedures are correct and usable, that the means of presentation of the information is user friendly and appropriate to the task and context, that engineers are encouraged to follow procedures and not to cut corners.

Ultimately, maintenance organisations have to compromise between implementing measures to prevent, reduce or detect errors, and making a profit. Some measures cost little (such as renewing light bulbs in the hangar); others cost a lot (such as employing extra staff to spread workload). Incidents tend to result in short term error mitigation measures but if an organisation has no incidents for a long time (or has them but does not know about them or appreciate their significance), there is a danger of complacency setting in and cost reduction strategies eroding the defences against error. Reason1 refers to this as "the unrocked boat" (Figure below).

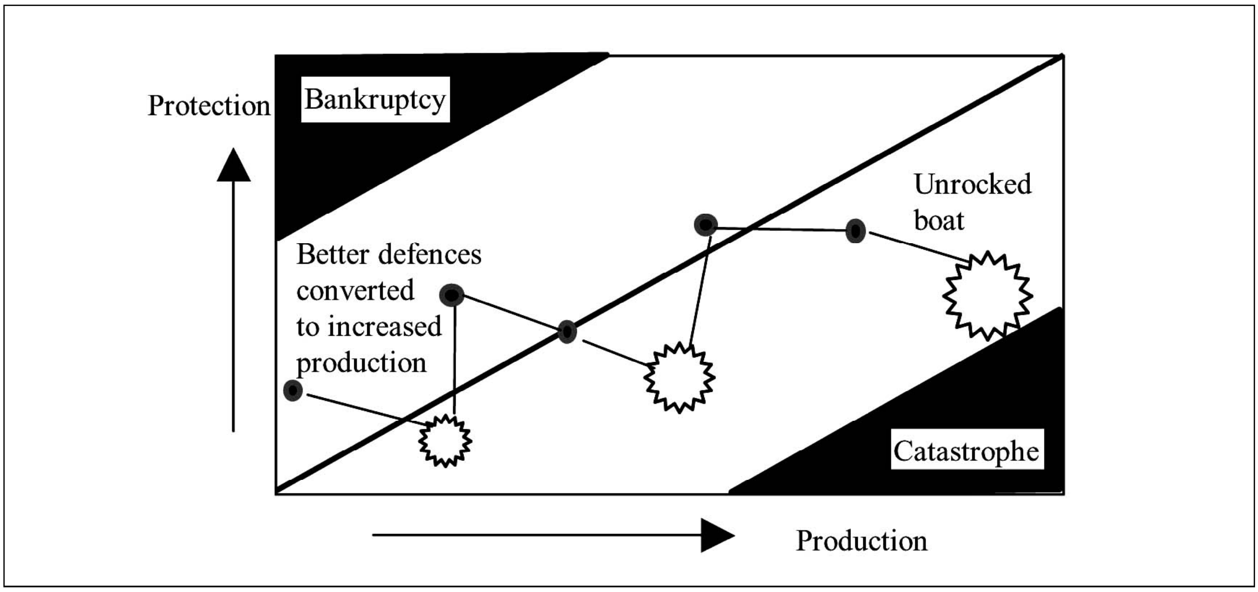


Fig. The lifespan of a hypothetical organisation through the production - protection space. Reason, 1997

It is important that organisations balance profit and costs, and try to ensure that the defences which are put in place are the most cost-effective in terms of trapping errors and preventing catastrophic outcomes.

Ultimately, it is the responsibility of each and every aircraft maintenance engineer to take every possible care in his work and be vigilant for error (see Chapter 3, Section 1). On the whole, aircraft maintenance engineers are very conscious of the importance of their work and typically expend considerable effort to prevent injuries, prevent damage, and to keep the aircraft they work on safe.

The two-pronged attack

Having established that man has a task to fulfill and having acquired some understanding of the nature of human error, the stage is now set to examine how this challenge to safety and efficiency can best be met. This involves a two-pronged attack.

Firstly, and as the initial prong of the attack, it is necessary to minimise the occurrence of errors. One way to tackle this is by ensuring a high level of staff competence through optimising selection, training and checking. It is important to recall here that a test or check establishes only how a person performs under the test or check conditions and does not say too much about how he will perform when not under supervision and when working in a non-test environment. Personality, attitudes and motivation play a vitally important role here. In tightening the selection process and increasing training and checking, there are clear economic limits. A point is reached where diminishing returns make further investment in this direction impractical.

It would obviously be an attraction solution if we could eliminate human error altogether but, as Cicero pointed out in his wisdom, errors are a normal part of human behaviour. Their total removal is an unrealistic dream. However restrictive is the staff selection process and however much in invested in training and checking, there will still be residual errors. The second prong of the attack, then, is to reduce the consequences of these remaining errors. In safety, we are primarily concerned with the consequences of error rather than the error itself, so this strategy is of the utmost relevance.

Throughout aviation history the emphasis has been on the refinement of man with the objective that errors will be totally avoided. It has been a commonly held philosophy that a person carrying as much responsibility as an airline pilot should not make mistakes. Even errors of judgement, as distinct from discrete errors involving incorrect procedures, usually suffer severe penalties from the authorities. That is, if the pilot should be lucky enough to survive. This is in contrast to attitudes elsewhere, such as in the medical profession, which is more tolerant of human error amongst its members than is the aviation community. A medical authority has said that 'physicians and surgeons often flinch from even identifying error in clinical practice, let alone recording it, presumably because they themselves hold... that error arises either from their or their colleagues' ignorance or ineptitude' (Gorowitz et al., 1976). When a protective blanket enshrouds human error, programmes to meet their challenge as applied in aviation and outlined in this chapter are effectively block. Such programmes cannot function without a recognition that errors are a part of normal human behaviour and that to conceal them is to encourage their repetition and all the consequences which follow.

The illusion that it is possible to achieve error-free operation has been a convenient concept in simplifying accident investigations and the allocation of blame but has tended to discourage proper attention to the second prong of the attack – living with errors but reducing their consequences.

From the discussion earlier in this chapter on the sources and classification of errors, many of the steps which should be taken to control them will be self-evident. Nevertheless, it may be worthwhile to review these steps referring to the sources and classification terms already quoted and within the general framework of the two-pronged attack.

■■■

CHAPTER 9
HAZARDS IN THE WORKPLACE

Hazards in the workplace tend to be a health and safety issue, relating to the protection of individuals at work. All workplaces have hazards and aircraft maintenance engineering is no exception. Health and safety is somewhat separate from human factors and this chapter therefore gives only a very brief overview of the issues relating the aircraft maintenance engineering.

RECOGNISING AND AVOIDING HAZARDS

Potential Hazards in Aircraft Maintenance Engineering

There are may potential hazards in the aircraft maintenance industry and it is impossible to list them all here. However, a thorough health and safety appraisal will reveal the hazards. Physical hazards may include:

- very bright lights (e.g. from welding);
- very loud sounds (sudden or continuous);
- confined or enclosed areas;
- working at significant heights;
- noxious substances (liquids, fumes, etc.);
- excessive temperature (i.e. too cold or too hot);
- moving equipment, moving vehicles and vibration.

Many of these have been addressed earlier in this document (e.g. Chapter 5 “Physical Environment”).

Relevant Legislation and the Maintenance Organisation’s Responsibilities

The UK Health and Safety Executive (HSE) have responsibility for overseeing safety in the workplace. The Health and Safety at Work Act 1974 and accompanying Regulations are the relevant legislation and the HSE produce publications and leaflets summarising various aspects. The Health and Safety at Work Act 1974 places a responsibility on employers to produce a written statement of general policy with respect to the Health and Safety at Work of its employees. The employer is also obliged to bring to the notice of all its employees this policy together with the organisation and arrangements in force for carrying out that policy. Thus, in an aircraft maintenance organisation, the health and safety policy might include statements applicable to the organisation such as the need to:

- Carry out assessments of work including inspections to determine Health and Safety risks;
- Provide safe working practices and procedures for plant, machinery, work equipment, materials and substances;

- Inform employees and other persons including temporary workers of any risk;
- Provide suitable training and/or instruction to meet any Health and Safety risks;
- Develop and introduce practices and procedures to reduce risks to Health and Safety including the provision of special protective devices and personal protective equipment;
- Provide for the welfare of employees;
- Discuss with and consult employee representatives on Health and Safety matters.

Maintenance organisations should appoint someone with health and safety responsibilities.

In brief, a maintenance organisation has a duty under health and safety legislation to:

- identify hazards in the workplace;
- remove them where possible;
- mitigate the risks to employees.

If hazards cannot be removed from the workplace, employees should be made aware that they exist and how to avoid them. This can be effected through training and warning signs. To be effective, warnings signs must:

- clearly identify the hazard(s);
- describe the danger (i.e. electric shock, radiation, etc);
- inform employees what to do or not to do.

The sign must attract an engineer's attention, it must be visible and it must be understandable to the people it is aimed at. Additionally, in the maintenance industry, it must be durable enough to remain effective, often for years, in areas where dust and the elements can be present.

Positive recommendations are more effective than negative ones. For example, the statement "Stay behind yellow line on floor" is better than "Do not come near this equipment". Warning signs should contain a single word indicating the degree of risk associated with the hazard: DANGER denotes that the hazard is immediate and could cause grave, irreversible damage or injury. CAUTION indicates a hazard of lesser magnitude. The sign should also detail how to avoid or manage the risk. CAUTION signs are generally yellow and black. DANGER signs use red, black and white.

Engineer's Individual Responsibilities

The legislation notes that every individual in a workplace also has health and safety responsibilities.

Every aircraft maintenance engineer should be aware that he can influence the safety of those with whom he works.

Thus, in an aircraft maintenance organisation, the health and safety policy might include statements applicable to engineers such as the need to:

- Take reasonable care of the health and safety of themselves and others who may be affected by their acts or omissions at work;
- Co-operate with the maintenance organisation to ensure that statutory requirements concerning health and safety at work are met;
- Work in accordance with any safety instruction and/or training received;
- Inform their supervisor or management of work situations that represent an immediate or potential danger to health and safety at work and any shortcomings in protection arrangements;
- Not interfere intentionally or recklessly with, nor misuse, anything provided in the interests of health and safety.

The attitude of an individual engineer, team or maintenance organisation (i.e. organisational culture) can have a significant impact on health and safety. Individuals who display an anti-authority attitude, are impulsive, or reckless are a danger in aircraft maintenance.

Safety In the Working Environment

Engineers should ensure that they keep the working environment safe. Clutter, rubbish, etc. is not only a nuisance to others, but can constitute a danger (e.g. a trip hazard, fire hazard, etc.). In addition, engineers should be careful when working on the line not to leave objects when a job has been completed. Foreign Object Damage (FOD) is a risk to aircraft operating at an airfield.

Safety When Working On Aircraft

Before operating or working on aircraft system, an engineer should carry out clearance checks around moveable surfaces (e.g. flying controls, landing gear, flaps, etc.). Deactivation procedures should be followed (e.g. pull circuit breakers, isolate valves, disconnect power, etc.). Notification of deactivation through the provision of adequate placard in key locations is essential to inform others of system status.

Dealing With Emergencies

Careful handling of health and safety in the maintenance environment should serve to minimise risks. However, should health and safety problems occur, all personnel should know as far as reasonably practical how to deal with emergency situations.

Emergencies may include:

- An injury to oneself or to a colleague;
- A situation that is inherently dangerous, which has the potential to cause injury (such as the escape of a noxious substance, or a fire).

Appropriate guidance and training should be provided by the maintenance organisation. The organisation should also provide procedures and facilities for dealing with emergency situations and these must be adequately communicated to all personnel. Maintenance organisations should appoint and train one or more first aiders.

The basic actions in an emergency are to:

- Stay calm and assess the situation
    - Observe what has happened;
    - Look for dangers to oneself and others;
    - Never put oneself at risk.
- Make the area safe
    - Protect any casualties from further danger;
    - Remove the danger if it is safe to do so (i.e. switching off an electrical current if an electrocution has occurred);
    - Be aware of ones own limitations (e.g. do not fight a fire unless it is practical to do so).
- Assess all casualties to the best of ones abilities (especially if one is a qualified first aider)
- Call for help
    - Summon help from those nearby if it is safe for them to become involved;
    - Call for local emergency equipment (e.g. fire extinguisher);
    - Call for emergency services (ambulance or fire brigade, etc.).
    - Provide assistance as far as one feels competent to.

Emergency drills are of great value in potentially dangerous environments. Aircraft maintenance engineers should take part in these wherever possible. Knowledge of what to do in an emergency can save lives.

■■■