SAAD DAHLAB UNIVERSITY OF BLIDA 1

Institute of Aeronautics and Space Studies

Third-year bachelor/ Aeronautical Structures

Course Material

Human Factors

by

Billel Boukert

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Objectives of this course: The Human Factors course in aviation engineering aims to teach students about human capabilities and limitations, which impact the performance of pilots and engineers and maintenance personnel in aviation systems. The program uses human error analysis to create safer environments, while developing aircraft systems and cockpit designs that users can operate comfortably. The program improves maintenance reliability through its study of fatigue and stress and workload factors. The program teaches human machine interface optimization, and decision-making skills, while students learn to work together through proper communication and teamwork practices.

By the end of this course, students should be able to:

- Understand the role of human factors in aviation engineering
- Identify human capabilities and limitations affecting performance
- Recognize and analyse sources of human error in aviation systems
- Apply strategies to improve safety and reduce risks
- Apply ergonomic principles to aircraft design and maintenance environments
- Evaluate human machine interaction in aviation systems
- Assess the impact of fatigue, stress, and workload on performance
- Demonstrate effective decision-making in operational contexts
- Improve communication and teamwork in aviation settings
- Apply human factors principles in design, maintenance, and operations

Key Words: Human Factors, Aviation Safety, Human Error, Ergonomics, Human–Machine Interaction, Situational Awareness, Decision-Making, Fatigue and Stress, Workload, Crew Resource Management, Maintenance Reliability, Aviation Systems Design

Contents

Introduction 1

Chapter I
The Basics of Physiology

Introdcion 4
I.1 The Atmosphere 5
I.1.a Composition 5
I.1.b Altitude 5
I.1.c The Physical Gas Laws 6
I.2 The Respiratory And Circulation Systems 7
I.2.a Functional Anatomy 7
I.2.b The Hypobaric Environment 9
I.2.c Hypoxia 11
I.2.d Susceptibility To Hypoxia 12
I.2.e Symptoms Of Hypoxia 12
I.2.f Stages Of Hypoxia 12
I.2.g Time Of Useful Consciousness 13
I.2.h Oxygen Systems 14
I.2.i Dilutor Demand 14
I.2.j Pressure Demand 14
I.2.k Pressure Demand Mask With Mask Mounted Regulator 14
I.2.l Continuous Flow Oxygen System 14
I.2.m Cabin Pressurisation 14
I.2.n Rapid Decompression 15
I.2.o Decompression Sickness 15
I.2.p Prevention And Treatment 16
I.2.q Hyperventilation 16
I.2.r Effects Of Acceleration 17

Chapter II
Man and the Environment

II.1 The Central And Peripheral Nervous System 19
II.1.a Central Nervous System 19
II.1.b Peripheral Nervous System 19
II.1.c The Autonomie Nervous (Vegetative) System 19
II.1.d Workings Of The Nervous System 20
II.2 Vision 20
II.2.a Functional Anatomy Of The Eye 20
II.2.b Physiology Of Vision 22
II.2.c The Visual Field-Scanning Techniques 23
II.2.d Binocular And Monocular Vision 25
II.2.e Depth Perception Monocular Cues 25
II.2.f Depth Perception Binocular Cues 26
II.2.g Night Vision 26
II.3 Hearing 27
II.3.a Functional Anatomy Of The Ear 27
II.3.b Flight Related Hazards To Hearing 28
II.3.c Effects Of Altitude Change 28
II.4 Integration Of Sensory Inputs 29
II.4.a Orientation 29
II.4.b Sensory Illusions And Spatial Disorientation 30
II.4.c Vestibular Illusions 30
II.4.d Visual Illusions 31
II.4.e Prevention Of Disorientation 34

Chapter III
Human Error and Reliability

III.1 Reliability Of Human Behaviour 37
III.2 Hypotheses Of Reality 37
III.3 Theory And Model Of Human Error 37
III.4 Error Generation 38
III.4.1 Ergonomies 39
III.4.2 Economics 41
III.4.3 Social Environment 41
III.5 Decision Making Concepts 42
III.5.1 Structure Phases 42
III.5.2 Limits 43
III.5.3 Risk Assessment 43
III.5.4 Practical Application Of Risk Management 44
III.6 Avoiding and Managing Errors 45
III.7 Safety Awareness 46
III.7.1 Risk Area Awareness 46
III.7.2 Error Proneness 47
III.7.3 Error Sources 47
III.7.4 Situational Awareness 48
III.8 coordination 49
III.8.1 Crew Briefings 49
III.8.2 Checklists 49
III.9 Cooperation 49
III.9.1 Group Dynamics 49
III.9.2 Leadership And Management Styles 51
III.9.3 Individual Duty And Role 52
III.9.4 Advantages And Disadvantages Of Team Work 52
III.10 Communication 52
III.10.1 Communication Models 53
III.11 Verbal And Non-Verbal Communication 55
III.12 Communication Barriers 55
III.13 Conflict Management 56

Chapter IV
Human Overload and Underload

IV.1 Arousal 57
IV.2 Stress 58
IV.2.1 Stressors 60
IV.2.2 Stress Overload 62
IV.2.3 Anxiety And Its Relationship To Stress 62
IV.2.4 Effects Of Stress 63
IV.2.5 Stress Management 63
IV.2.6 Coping Strategies 64
IV.3 Sleep and Fatigue 65
IV.3.1 Stages of Sleep 66
IV.3.2 Performance and Alertness 67
IV.3.3 Management of Fatigue 68
IV.3.4 Preventative Measures 69

CHAPTER V:
Maintenance Human Factors / Case Studies

Introduction 71
PART 1: BUILDING THE FOUNDATION OF MAINTENANCE HUMAN FACTORS, 1988 – 1999 72
V.1 Identifying Human Factors in the Maintenance and Inspection Work Domain 74
V.1.1 Focus on Training 74
V.1.2 Maintenance Accident Investigation 76
V.1.3 Organizational Factors and Safety Culture 77
V.1.4 Maintenance Error Analysis 78
V.1.5 Maintenance and the National Database 78
V.1.6 Maintenance Human Factors in Space Operations 79
V.1.7 Key Industry Guidance 81
PART 2: DEVELOPING METHODS AND TOOLS TO MEET NEW CHALLENGES (2000 – 2008) 81
V.2 NASA Aviation Safety Program: Maintenance Human Factors Task 82
V.2.1 Identification of Safety Needs 84
V.2.2 Development of Methods and Tools 87
V.2.3 Human Factors Interventions 87
V.2.4 Validation and Implementation of Products 88
V.2.5 Challenges For The Future 89

Conclusion
References

Introduction

Introduction

Human factors in aviation are involved in the study of human's capabilities, limitations, and behaviours, as well as the integration of that knowledge into the systems that we design for them to enhance safety, performance, and general well-being of the operators of the systems.

To operate an aircraft safely, a pilot must have an understanding of technical subjects such as aircraft engines, instruments, meteorology and navigation. To make the appropriate decisions for the safe operation of an aircraft, the pilot must exercise judgement. This is based on training, knowledge and experience, and an appreciation of all the factors which could influence the current situation, including human factors. Training in human factors is a requirement of the International Civil Aviation Organisation (ICAO).

There is an interface between flight crew, machine, systems, equipment and software, which come together in the airspace environment. Edwards, a psychologist, presented the concept at a technical symposium dealing with man and machine, in 1972. He described it as the SHEL concept.

Just as the aircraft structure, systems and software have structural and performance limitations, so the individual who makes up the liveware is subject to limitations of human performance. Some of these limitations will vary from day to day and between individuals, whereas other absolute limitations vary little between different people. Flying an aircraft is a psycho-motor skill which can be learned by applying theoretical knowledge during practical training. This comes more easily to an individual who possesses some basic aptitude, but constant reinforcement of the acquired psycho-motor skills is necessary throughout a flying career to maintain competence in the flying environment, the pilot has a duty of care to other crew members, passengers, other users of the airspace and to the general public. It is a legal requirement for the pilot to be fit to fly, whether flying professionally or for pleasure. Fitness is a complex interrelationship between physiological, psychological and emotional aspects of well-being.

It is important to remember that flight safety involves all those participating in aviation activity including management, the providers of support services (such as meteorological forecasting and flight planning), engineers and the regulatory authorities, not just the pilot. There must be an understanding of the potential conflict between resource availability, commercial considerations and the need to get the job done.

Thus it is essential for all those involved in aviation to be aware of human performance and limitations and how these may influence competence and flight safety. This requires an understanding of basic aviation physiology, health maintenance and basic aviation psychology.

The traditional flight training philosophy is based on knowledge, skill and experience. The development of psycho-motor proficiency leads to good handling skills, and is achieved by constant practice following demonstration by the instructor of the appropriate aircraft handling technique.

This has the objective of reducing human error by creating awareness of judgement and decision making, and the development of professionalism.

Assessment of competency must take account of all these factors. Professionalism suggests the involvement of learning or science, with an understanding of the broad issues and implications. Proficiency, on the other hand, implies expert dexterity in doing a task, but without consideration of the wider issues.

Travel by air is a safe means of transport. A one in a million risk of being killed or seriously injured requires five hours travel by air, compared with five minutes travel on a bicycle or 30 minutes in a car or on foot (UK 1994 statistics). Prior to 1960, the annual accident rate for scheduled air carriers was something over 60 per million departures. In the ten years to 1970, this rate improved dramatically to about one or two per million departures. Between 1980 and 1996, there were 621 global fatal accidents to jet and turboprop aeroplanes weighing more than 5,700 kg, resulting in 16,849 fatalities (source UK CAA CAP681).

The fatal accident rate for all North American and European operators during this period was 0.37 and 0.52 per million departures respectively, with JAA full member operators achieving 0.35 per million.

As a result of the increase in world air traffic, the annual number of fatal accidents increased globally by 32% during the period 1980-1996. If this growth in fatal accidents were to continue, by the year 2010 it is predicted there would be an annual average of 44 fatal accidents (almost one per week), assuming the same accident rate per million departures. However, over the period 1990-1996 the trend was decreasing.

Half of these 621 fatal accidents occurred during the approach and landing phases of flight, and in 41% of fatal accidents the most frequently identified causal factor was `Lack of positional awareness in the air'. The most frequently identified consequences were Collision with terrain/water/obstacle' and `Controlled flight into terrain', followed by `Loss of control in flight'.

Nearly 40% of all these fatal accidents involved aeroplanes which had not been fitted with currently available safety equipment, such as a ground proximity warning system (GPWS) or enhanced GPWS. In 88%, crew members were identified as a contributory causal factor, with 76% identifying crew as a primary causal factor. Only 11% of these fatal accidents to aeroplanes above 5,700 kg involved an aircraft primary causal factor.

In non-scheduled general aviation, the statistics are quoted as a fatal accident rate per 100,000 flying hours. For UK registered aeroplanes of 5700 kg and below, during the ten years prior to 1998, the average rate was 1.5, representing an average of twelve fatal light aeroplane accidents per year. The main causes, accounting for 86% of fatal accidents, were:

-continued flight into bad weather, including impact with high ground and loss of control in instrument meteorological conditions (IMC)
-loss of control in visual meteorological conditions (VMC), including stalling/spinning
-mid-air collision
-over-running short runway
-collision with ground obstacles during approach to land
-fuel exhaustion
-impaired pilot performance due to alcohol or drugs.

Monitoring accident statistics allows trends to be identified, which can lead to changes in training and regulatory requirements.

Improvements in technology, manufacturing standards, maintenance, operational procedures and training are responsible for much of the improvement in the accident rate since 1960. In the last 20 years, the proportion of accidents ascribed to human error has remained constant in excess of 70%.

However, it should be noted that `human error' does not imply `pilot error'. Equally, flight crew error cited as a causative factor should be often more properly viewed as the flight crew's inability to break the chain of events leading to the accident. Nonetheless, there has been a human failing at some stage.

Human error will occur, no matter how good the training nor how competent the individual. The designers of aircraft systems and those who develop operational procedures have to allow for this basic human limitation, and build in fail-safety. Trainers have to ensure that crew members understand the importance of monitoring their own actions and those of the rest of the crew, and to have the confidence to give and accept challenges. This underlies the principles of crew resource management (CRM); it is important to realise that these principles apply equally to the pilot of a small light aircraft as much as to the crew of a large passenger jet airliner.

The goal of most airlines is to achieve a profit from the safe carriage of passengers and/or cargo to and from destinations around the world. All the humans involved in this activity have needs, and for the passengers to arrive safely and punctually at their destination with their baggage, the airline must provide a serviceable and correctly equipped aircraft. This can be achieved only by having an efficient infra-structure in place, which meets the human needs of the airline employees and so contributes to flight safety. The same argument relating human needs to flight safety applies equally to air traffic control, engineering and all other support services. Everyone within the aviation industry contributes to flight safety.

CHAPTER I

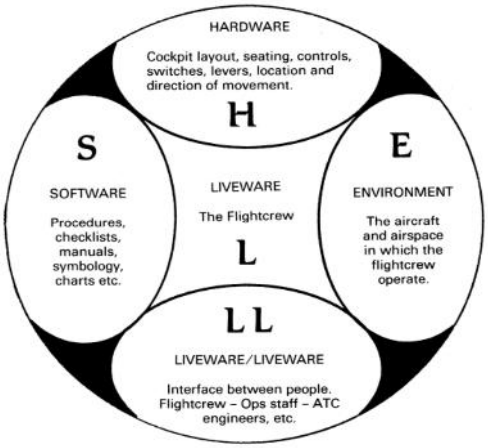
The Basics of Physiology

CHAPTER I:
The Basics of Physiology

Introduction

To operate an aircraft safely, a pilot must have an understanding of technical subjects such as aircraft engines, instruments, meteorology and navigation. To make the appropriate decisions for the safe operation of an aircraft, the pilot must exercise judgement. This is based on training, knowledge and experience, and an appreciation of all the factors which could influence the current situation, including human factors. Training in human factors is a requirement of the International Civil Aviation Organisation (ICAO).

There is an interface between flight crew, machine, systems, equipment and software, which come together in the airspace environment. Edwards, a psychologist, presented the concept at a technical symposium dealing with man and machine, in 1972. He
described it as the SHEL concept:



- **S** indicates the software - the procedures and rules which have to be followed, checklists, symbology, etc.
- **H** is the hardware - the aircraft, its systems and equipment
- **E** is the environment in which the man/machine system operates
- **L** is the liveware - the crew who operate the aircraft and interact with other personnel.

L sits at the centre of the SHEL, because the liveware interfaces with all the other components.

Just as the aircraft structure, systems and software have structural and performance limitations, so the individual who makes up the liveware is subject to limitations of human performance. Some of these limitations will vary from day to day and between individuals, whereas other absolute limitations vary little between different people.

Flying an aircraft is a psycho-motor skill which can be learned by applying theoretical knowledge during practical training. This comes more easily to an individual who possesses some basic aptitude, but constant reinforcement of the acquired psycho-motor skills is necessary throughout a flying career to maintain competence in the flying environment.

The normal working of the human body when in flight can be influenced by altitude, pressure, temperature, acceleration and changes in perception.

I.1 The Atmosphere

I.1.a Composition

The atmosphere surrounds the earth and forms an elastic layer of air consisting of a number of concentric shells. The inner shell is the troposphere which extends to an altitude of 30,000 ft at the poles and 60,000 ft at the equator. The atmospheric air is composed of a mixture of gases and water vapour. The most abundant gases are nitrogen (78%) and oxygen (21%), with the remaining 1% being argon, carbon dioxide, neon, hydrogen and ozone. These proportions are constant up to the tropopause (approximately 36,000 ft). In addition, the atmosphere contains solid particles such as dust and sea salt. These are important in the development of certain types of weather such as clouds, mist and fog because moisture condenses on these particles.

The pressure at sea level in the standard atmosphere is 760 millimetres of mercury (mmHg) (29.92 inches Hg, or 1013.2 millibars) and this falls to half at 18,000 ft, where the ambient temperature is about minus 20°e. Knowing the percentages of the main gases present in the atmosphere, it is possible to calculate the gas pressure, in mmHg, given the atmospheric pressure at an altitude.

Figure I.1 illustrates the reduction of atmospheric pressure with increasing altitude.

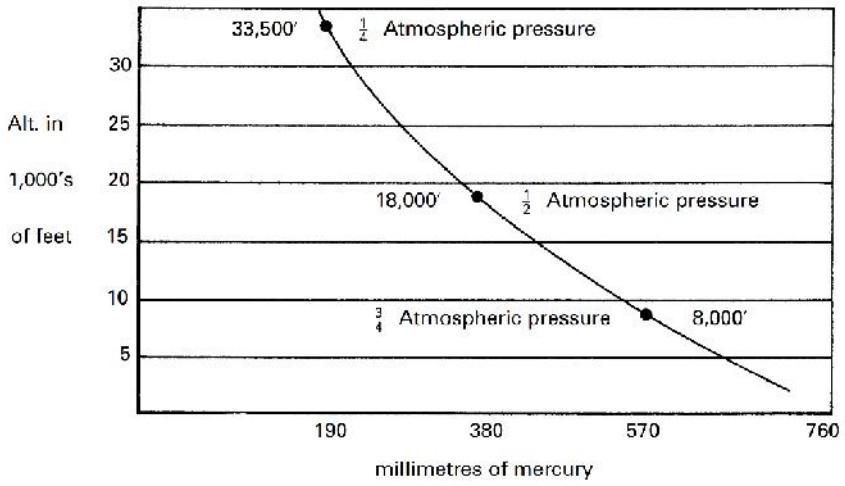


Figure I.1: illustrates the reduction of atmospheric pressure with increasing altitude.

I.1.b Altitude

Human physiology is influenced by the ambient pressure and composition of the atmosphere and the effects are related to altitude. Therefore, it is important to understand which datum is being used.

In aviation, altitude is defined as the elevation above mean sea level. Since atmospheric pressure varies at the surface of the earth, a forecast is made of the pressure (in millibars or inches Hg) in a given geographical area for the next hour, and this is referred to as the QNH. Thus, altitude is measured with reference to the QNH datum and is a measure of the vertical distance (in feet or metres) of an aircraft above mean sea level.

In aviation, height is a measure of the vertical distance of an aircraft above the airfield elevation. The atmospheric pressure is forecast at the airfield datum and this is referred to as the QFE. Thus, an aircraft altimeter set to this datum will indicate zero on the ground at the airfield, and not the altitude above mean sea level (unless the airfield happens to be at sea level).

Because of the continuously changing atmospheric pressure, and because at any one time the pressure varies at different points of the earth's surface, the standard atmospheric pressure (1013.2 mb or 29.92 in Hg) is used as the datum pressure for en-route flying above a certain altitude. This altitude is referred to as the transition altitude, above which vertical distance is referred to as a flight level (FL). The flight level is stated in 3 digits, representing hundreds of feet.

Thus, FL290 means that the aircraft altimeter indicates 29,000 ft above the standard pressure datum of 1013.2 mb, and ensures that appropriate vertical separation can be maintained between all aircraft flying in the vicinity. It does not mean that the aircraft is at an altitude of 29,000 ft above sea level (unless the surface atmospheric pressure at that point happens to be 1013 mb).

Finally, the cabin altitude refers to the pressure being maintained within the aircraft cabin. This depends upon the establishment of a pressure differential between the cabin interior and the outside atmosphere. In a pressurised aircraft this means that the effective altitude experienced by the aircraft occupants may well be different from the actual aircraft altitude.

With respect to the physiological effects of altitude, figures are based on the ICAO standard atmosphere, i.e., assuming a pressure of 760 mmHg at sea level, where the temperature is +15°C. The mean temperature lapse rate is a reduction of 1.98°C per 1,000 ft from sea level to 36,089 ft, above which it is a constant -56.5°C.

I.1.c The Physical Gas Laws

Since air is a mixture of gases which exert pressure, have measurable mass and can be compressed, it is subject to certain established laws governing reaction to changes in pressure, temperature, volume and density.

Boyle's law states that

'Providing the temperature is constant, the volume of a gas is inversely proportional to its pressure'.

This means that when the pressure increases, the volume decreases and conversely when the pressure decreases, the volume increases. Put another way, at a fixed temperature the pressure of the gas varies inversely with its volume. This is strictly correct only at moderate temperatures.

$$\frac{p1}{p2} = \frac{v2}{v1}, \text{ where } p = \text{pressure}, \ v = \text{volume}$$

Boyle's law explains some of the effects of altitude on the gas containing cavities of the human body during flight. For example, as altitude increases, the gas within the middle ear, sinuses and gastro-intestinal system will expand, sometimes with painful results.

Charles's law states that

'The volume of a fixed mass of gas held at a constant pressure varies directly with absolute temperature'.

A feature of gas expansion is that equal volumes of different gases expand by the same amount when heated to the same temperature. So provided the pressure remains constant, each degree centigrade rise in temperature will cause the gases to expand by 1/273 of the volume they would occupy at 0°C.

Another way of stating Charles's law is the volume of a fixed mass of a gas at constant pressure is directly proportional to its absolute temperature.

$$\frac{v1}{v2} = \frac{T1}{T2}, \text{ where } v = \text{volume, } T = \text{absolute temperature}$$

The gas laws of Boyle and Charles can be summarised by the equation:

pv/T = constant,

where p = pressure, v = volume, T = absolute temperature.

This is known as the gas equation, or General Gas Law, and it applies even when there is a change in all three variables, pressure, volume and temperature.

Dalton's law states that

'The total pressure of the gas mixture is equal to the sum of its partial pressures'.

This means that the proportion of oxygen remains 21% throughout the atmosphere, irrespective of the total atmospheric pressure at that level.

Henry's law states that

'At equilibrium the amount of gas dissolved in a liquid is proportional to the gas pressure'.

This means that the amount of gas in solution varies directly with the pressure of that gas. The relevance of this in aviation is that as altitude is increased and atmospheric pressure reduces, gases such as nitrogen will come out of solution in the body tissues. At high altitude this can lead to decompression sickness.

Fick's law states that

'The rate of gas diffusion through a tissue medium is proportional to the tissue area and the difference between the gas partial pressures on the two sides, and inversely proportional to the tissue thickness'.

This means that the transfer of gases, such as oxygen and carbon dioxide, through the alveolar membrane in the lungs depends on the area and thickness of the membrane, and the partial pressures of the gases in the blood and in the lung alveoli.

I.2 The Respiratory And Circulation Systems

I.2.a Functional Anatomy

The body tissues use oxygen to release energy to maintain life. The chemical reaction between oxygen and carbohydrate produces carbon dioxide, which is carried away from the tissues by the bloodstream to be excreted by the lungs and water. The utilisation of oxygen and production of carbon dioxide by the tissues is known as metabolism, which involves oxidation of carbohydrate from food to produce energy. This is respiration and it has three phases, each of which may be affected to some degree by flight:

(1) The exchange of gases between the body and the atmosphere
(2) The carriage of gases to and from the lungs and the site of oxidation (the tissue cells)
(3) The actual oxidation process in the cells, liberating energy.

Circulation is the term used to describe the passage of blood through the blood vessels (arteries, capillaries and veins). The arteries have elastic walls and carry oxygenated blood from the lungs via the heart's left atrium and left ventricle to the tissues. The vessels in the tissues are the capillaries which have very thin walls to allow diffusion of oxygen into the tissue cells and carbon dioxide out of the cells into the blood. The deoxygenated blood is carried in the veins back to the lungs via the right atrium and right ventricle of the heart. The veins do not have elastic walls and the contraction of adjacent body muscles assists the flow of blood through the veins. An adult body contains about six litres of blood. Just over half of this is plasma which is the liquid medium in which the blood cells are carried.

There are three kinds of blood cell, each with different functions.
Red blood cells (erythrocytes) contain haemoglobin which contains iron and is the major component of the red cells. This has a strong affinity for oxygen (and incidentally also for carbon monoxide, the affinity being 210 to 250 times greater than for oxygen). Anaemia is a condition in which the number of red blood cells is below normal and thus less oxygen can be carried from the lungs to the tissues. For this reason, it is recommended that flight crew engaged in regular flying do not donate blood. Red blood cells with their haemoglobin are manufactured in the bone marrow, and live for approximately 108 days. If an individual should decide to donate blood, a period of 24 hours should elapse before flying to ensure replenishment of the depleted red blood cells by the bone marrow. If bone marrow itself is donated, the minimum recommended time interval before flying is 48 hours to ensure recovery from the associated general anaesthetic.

The white blood cells consist of a number of types which have a range of functions. They engulf invading bacteria, they produce antibodies to resist attack by foreign invaders, they identify antigens and other foreign substances, they release anticoagulants and help combat inflammation, and they devour bacteria.

The remaining cells are platelets which are involved in blood coagulation.

Blood pressure in the body is maintained within close limits by pressoreceptors in the arterial walls. The normal blood pressure is in the region of 120/80mmHG, and this is controlled by variation in heart rate and tone of the arterial walls.

The effective volume of blood expelled by either ventricle per unit of time is the cardiac output. Thus cardiac output = stroke volume x heart rate, and the average for a healthy adult is 3.0 to 3.5 litres per minute.

Atmospheric air is breathed in through the nose, where it is filtered, moistened and warmed, and passes to the lungs via the trachea and appropriate bronchus. Each bronchus ends in a number of bronchioles which in turn end in the alveoli, millions of which form the lung tissue. The alveoli are thin-walled sacs (rather like balloons) which are surrounded by small thin-walled blood capillaries. The thin walls of the alveoli and capillaries allow gases such as oxygen and carbon dioxide to diffuse between atmospheric air in the alveoli and blood within the capillaries. The tissue boundary is the alveolar membrane.

During respiration, air is drawn into the lungs by the actions of the diaphragm and intercostal muscles; when these muscles relax, the process is reversed so the air is breathed out. This cycle occurs 12-15 times a minute at rest.

The volume of gas which can be held in the lungs at the end of a maximum inspiration is called total lung capacity. For a typical average healthy adult this is about 6.5 litres. During normal breathing the volume of gas in the lung is about half total lung capacity (3 to 3.5 litres). At the end of normal expiration, some gas remains in the lungs and this is called functional residual capacity and is about 3 litres.

The volume of gas expelled from the lungs during normal expiration is called the tidal volume, and is around 0.5 litres. After normal expiration it is possible to forcibly expel a further volume of gas, but even then, there will still be some gas remaining in the lungs. This is the residual volume and for a typical average healthy adult is about 1.5 litres. The difference between total lung capacity and the residual volume is called vital capacity, and in this example would be 5.0 litres (6.5-1.5).

The ventilation of the lungs is controlled so that the tensions of oxygen and carbon dioxide in the arterial blood are maintained within very close limits. The most important factors controlling the level of ventilation (breathing rate) are the amount of carbon dioxide, the acidity of the blood and the amount of oxygen present in the arterial blood. There are receptors in the respiratory centre of the brain which respond to the carbon dioxide tension and the acidity of the arterial blood. An increase in either of these leads to an increase in breathing rate. The absence of any breathing at all is termed apnoea, and the condition of 'sleep apnoea' can occur in some individuals when there is a cessation of breathing whilst asleep. It is of concern only when the period of apnoea exceeds one minute.

It is important to note that the most powerful stimulus to respiration is caused by an increase in carbon dioxide tension rather than a reduction in oxygen tension in the blood. Thus, the transfer of oxygen to the tissues is influenced by the presence of carbon dioxide.

I.2.b The Hypobaric Environment

The atmosphere is compressible and has mass. The air at the surface of the earth is supporting the mass of air above it and its molecules will therefore be pressed close together, causing the density of the air to be greatest at the surface. At sea level the partial pressure of oxygen is more than adequate to support normal living activities. With increasing altitude, there is a fall in atmospheric pressure together with a decrease in density and temperature. Fortunately, the relationship between the oxygen saturation of haemoglobin and oxygen tension minimises the effect of the reduction in partial pressure of oxygen. Ascent to an altitude of 10,000 ft produces a fall in the partial pressure of oxygen in the alveoli but only a slight fall in the percentage saturation of haemoglobin with oxygen. However, once altitude rises above 10,000 ft the percentage saturation of haemoglobin falls quickly and this results in the condition of hypoxia. In fact, above 8,000 ft the effects of lack of oxygen will begin to appear and a decrease in an individual's ability to perform complex tasks and a reduction in night vision can be measured.

Figure I.2 shows the oxygen dissociation curve of blood. The concentrations of physically dissolved and chemically combined oxygen are shown separately. The curve illustrated is the average for a fit young adult. The actual shape of the curve will be influenced by factors such as age, state of health, tobacco abuse and ambient temperature.

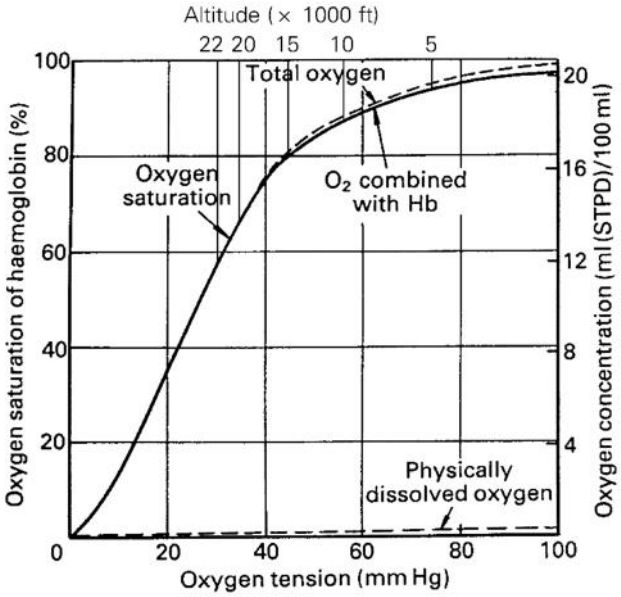


Figure I.2: The oxygen dissociation curve of blood.

At sea level the atmospheric pressure is 760 mmHg. The rate and depth of breathing is controlled by the metabolic demands of the tissues, and it has already been stated that the fundamental controlling factor is the partial pressure of carbon dioxide in the blood within the respiratory centre situated in the brain. It is extremely sensitive to small changes in the carbon dioxide tension in the blood, and continuously adjusts the breathing to maintain the tension at a normal level.

The composition of air in the alveoli of the lungs differs from that of atmospheric air due to constant diffusion of gases to and from the alveoli and the blood. Alveolar air includes water vapour and carbon dioxide generated by the body, which remains as a constant provided the respiratory rate remains constant and the body is at rest. The total pressure remains the same (760 mmHg at sea level) and so to accommodate the water vapour and carbon dioxide (40 mmHg and 47 mmHg respectively) the pressure of oxygen and nitrogen is reduced. Whereas the partial pressure of oxygen in the atmospheric air at sea level is 160 mmHg, the partial pressure of oxygen in the lung alveoli is 103 mmHg.

At 10,000 ft in the standard atmosphere, the total atmospheric pressure reduces to 523 mmHg. The pressures of carbon dioxide and water remain the same but the partial pressure of oxygen falls to 55 mmHg. This can be viewed as the critical oxygen tension below which a deterioration in performance is apparent.

Oxygen can be supplied through a mask in ever increasing concentration such that the inspired mixture has the correct amount of oxygen to maintain a pressure of 103 mmHg in the lung. It will be necessary for the proportion of oxygen to increase as altitude is increased and it can be calculated that the altitude at which the barometric pressure will equal the alveolar oxygen pressure of 103 mmHg, plus the pressure of water vapour and the pressure of alveolar carbon dioxide, is 33,700 ft at which altitude the barometric pressure is 190 mmHg. Thus, an individual breathing 100% oxygen at 33,700 ft has the same oxygen tension in the lung alveoli as breathing air at sea level.

Any ascent above 33,700 ft will lower the oxygen tension in the lung. The lung alveolar oxygen tension can fall to 55 mmHg before there is a deterioration in performance. Thus, the limiting altitude for breathing 100% oxygen is that where the alveolar pressure has fallen to 55 mmHg, which occurs at an altitude of 40,000 ft. A summary of lung partial pressures is given in Figure I.3, and of the body oxygen requirement in Figure I.4.

I.2.c Hypoxia

This can be defined quite simply as a lack of sufficient oxygen to meet the needs of the body tissues. Althought the brain is only 2% of the body weight it uses almost 20% of the total oxygen uptake and is very susceptible to reduction in oxygen partial pressure. Thus, the earliest effects of insufficient oxygen are the impairment of cerebral functions.

With an increase in altitude the air pressure decreases and above 10,000 ft there is insufficient oxygen available to maintain adequate cerebral function. There is wide variation between individuals so it is not possible to predict the exact altitude at which physical and mental impairment may occur. Another difficulty is that because of the very nature of hypoxia, the pilot becomes the poorest judge of when he or she is suffering from its insidious effects.

	Total pressure mm Hg	Oxygen mm Hg	Nitrogen mm Hg	Water vapour mm Hg	Carbon dioxide mm Hg
Sea level					
Atmosphere	760	160 (21%)	600	—	—
Alveoli	760	103 (14%)	570	47	40
10,000 ft					
Alveoli	523	55	381	47	40

Figure I.3: Alveolar partial pressures at sea level and 10,000 ft (from Dalton's law)

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	Atmospheric pressure mm Hg	Lung oxygen partial pressure mm Hg	Breathing gas
Sea level	760	103	Air
10,000 ft	523	55	Air
10,000 ft +	Reducing	103	Increasing oxygen concentration
33,700 ft	190	103	100% oxygen
33,700 ft +	Reducing	Falling	100% oxygen
40,000 ft	141	55	100% oxygen
40,000 ft +	Reducing	55 + *n*	100% oxygen under pressure *n*

Figure I.4: Summary of body oxygen requirement at altitude.

I.2.d Susceptibility To Hypoxia

The following factors increase an individual's susceptibility to hypoxia in flight:

• *Altitude* -the greater the altitude, the more rapid the onset
• *Time* -the longer the time of exposure, the greater the effect
• *Exercise* -exercise increases the demand for oxygen
• *Cold* -energy is required to generate heat to overcome low temperature, and this increases the demand for oxygen
• *Illness* -illness similarly increases the energy demands of the body
• *Fatigue* -fatigue lowers the threshold for hypoxia symptoms
•*Drugs / alcohol* -alcohol and drugs can depress brain function, thus reducing the tolerance of altitude
•*Smoking*- smoking produces carbon monoxide which binds to haemoglobin with a greater affinity than oxygen, thus reducing the amount of haemoglobin available for oxygen transport.

I.2.e Symptoms Of Hypoxia

A common early symptom of hypoxia is a personality change in which the normal inhibitory forces of common sense tend to be diminished, not unlike the intoxicating effect of alcohol. This progresses to impaired thinking and judgement, slowing reactions, mental and muscular incoordination, diminished vision and hearing, and impairment of memory. Eventually, there is loss of consciousness and ultimately, death.

The symptoms are insidious at first and slow to develop, but progressive and more marked at altitudes above 10,000 ft. In all cases night vision is impaired from approximately 5,000 ft upwards.

I.2.f Stages Of Hypoxia

All individuals who normally live around sea level will eventually show the general symptoms of hypoxia if exposed to altitude in excess of 10,000 ft, the time of useful consciousness being shown in Figure I.5. The stages of hypoxia can be classified by performance decrement, which is dependent upon altitude and the resulting oxygen saturation of the blood.

Indifferent stage -occurs when breathing air at altitude of 0 to 10,000ft, giving arterial oxygen saturation of 98 to 87%. Dark adaptation is adversely affected at altitudes as low as 5,000 ft, where visual sensitivity at night is reduced by approximately 10%. Performance of new tasks may be impaired, and a slight increase in heart and breathing rates occurs.

Altitude (ft)	Progressive decompression	Progressive decompression	Rapid decompression
	Seated at rest	Moderately active	Seated at rest
20,000	20 min	10 min	5 min
25,000	5 min	3 min	2 to 2.5 min
30,000	1.5 min	45 to 60 sec	60 sec
35,000	45 sec	30 sec	25 sec
40,000	25 sec	18 sec	12 to 15 sec
43,000	18 sec	12 sec	12 to 15 sec

Figure I.5: Times of useful consciousness.

Compensatory stage -occurs when breathing air at altitude of 10,000 to 15,000ft, giving arterial oxygen saturation of 87 to 80%. Cardiovascular and respiratory physiological responses provide some protection against hypoxia. Effects on the central nervous system become perceptible after a short period of time. These include drowsiness, decreased judgement and memory, and difficulty performing tasks requiring mental alertness or discrete motor movements. Short term memory loss can be detected from about 12,000 ft.

Disturbance stage -occurs when breathing air at altitude of 15,000 to 20,000ft, giving arterial oxygen saturation of 80 to 65%. Normal physiological mechanisms no longer offer protection against hypoxia. Effects include headache, dizziness, somnolence, air hunger, euphoria and fatigue.

Critical stage -occurs when breathing air at altitude of 20,000 to 23,000ft, giving an arterial oxygen saturation of 65 to 60%. Mental performance deteriorates and confusion or dizziness occurs within a few minutes. Total incapacitation with loss of consciousness rapidly follows with little or no warning.

I.2.g Time Of Useful Consciousness

The time of useful consciousness (TUC) is the maximum length of time during which an individual can carry out some purposeful activity following a loss of oxygen supply. Time of useful consciousness is also referred to as the effective performance time (EPT), which is defined as the length of time an individual is able to perform useful flying duties in an environment of inadequate oxygen. The use of EPT more accurately refers to critical (functional) performance than does TUC.

Figure I.5 shows the time of useful consciousness following the sudden loss of oxygen supply for a healthy individual at rest and moderately active, both for a progressive decompression and a rapid decompression.
Figure I.6 shows the effective performance time for a healthy individual at rest at various altitudes. The range of time indicates the variation due to individual endurance, experience, physical exertion, and whether a rapid decompression occurred or the supply was simply turned off at altitude (a progressive decompression).

Altitude (ft)	Effective performance time
18,000	20 to 30 min
22,000	10 min
25,000	3 to 5 min
28,000	2.5 to 3 min
30,000	1 to 2 min
35,000	0.5 to 1 min
40,000	15 to 20 sec
43,000	9 to 12 sec
50,000	9 to 12 sec

Figure I.6: Effective performance time.

I.2.h Oxygen Systems

For flight above 10,000 ft a supplementary oxygen supply must be available. The system may consist of a portable oxygen container and a mask, or a fixed installation with easily available masks fitted adjacent to the crew and passenger positions. There are various oxygen breathing systems available.

I.2.i Dilutor Demand

This is a flight crew oxygen system consisting of a close-fitting mask with a regulator that supplies a flow of oxygen according to cabin altitude. Regulators are designed to provide an appropriate proportion of oxygen and air, from a mix of 0% oxygen and 100% cabin air at cabin altitudes below 8,000 ft, gradually increasing the proportion of oxygen until, at approximately 33,000 ft, 100% oxygen and 0% cabin air is delivered. Oxygen is supplied only when the user inhales, reducing the amount of oxygen required.

I.2.j Pressure Demand

This is similar to dilutor demand equipment except that oxygen is automatically supplied under slight pressure at cabin altitudes above approximately 10,000 ft, with full pressure breathing above 38,000 ft.

I.2.k Pressure Demand Mask With Mask Mounted Regulator

This is a pressure demand mask with a regulator attached directly to the mask rather than mounted on the instrument panel or elsewhere within the flight deck. The mask mounted regulator eliminates the problem of a long hose which must be purged before oxygen is delivered to the mask.

I.2.l Continuous Flow Oxygen System

This oxygen system is typically provided for passengers. The passenger mask includes a re-breather bag which collects the user's exhaled air to be re-inhaled. The oxygen in the re-breather bag is replenished by a continuous flow of oxygen regulated as for dilutor demand regulated equipment. Because only a portion of the oxygen is consumed during each breath, the air in the re-breather bag remains highly saturated with oxygen and is drawn into the lungs at the beginning of inhalation. If the bag if depleted before the breath is completed, cabin air is used in the remainder of the inhalation.

I.2.m Cabin Pressurisation

For prolonged flight above 10,000 ft, the use of supplemental oxygen via a mask is both tiring and inefficient. An alternative method of maintaining an adequate partial pressure of oxygen is to pressurise the aircraft cabin to ensure the cabin altitude remains below 10,000 ft, irrespective of the actual altitude of the aircraft. The cabin air supply is provided by tapping bleed air from the aircraft engine or by using an independent compressor, and the pressure within the cabin is controlled by an outflow valve. Maintaining the cabin at sea level pressure would require an extremely strong (and thus heavy) fuselage structure which would adversely affect weight and hence fuel economy.

We have seen that normal healthy individuals can tolerate altitudes of up to 10,000 ft with no harmful effects. However, in the case of the elderly or individuals suffering from diseases of the respiratory or circulatory system, they are less able to tolerate the mild hypoxia at this altitude. Accordingly pressurised cabins are designed to maintain an altitude in the region of 6,000 ft which gives an effective compromise between the physiological needs of the crewmember or passenger and the economy needs of the aircraft operator.

I.2.n Rapid Decompression

If cabin pressure is suddenly lost during flight, pressure inside the aircraft will be forcefully equalised with outside air, with the cabin air being rapidly expelled. The magnitude and rate of this decompression, and the physiological effect on the occupants, will be determined by:

• the size of the cabin rupture or number of lost windows
• the altitude of the aircraft
• the amount of pressure differential between the cabin and the external environment
• the volume of the cabin
• the position of the rupture or lost window -the venturi effect can lead to a further increase in cabin altitude if cabin air is sucked out.

The larger the rupture and the smaller the cabin and the greater the pressure differential between the cabin and the outside air, the more rapid will be the rate of decompression. The term 'explosive decompression' is used to denote an extremely rapid loss of cabin pressure, although this is rare. However, when it does occur, a mist may form in the cabin due to the sudden change in temperature which can be incorrectly interpreted as smoke or fumes.

A sudden equalisation of pressure means a very strong blast of air outwards from the cabin opening. This may cause loose items or even persons to be sucked out. Therefore, when flying in a pressurised aircraft at high altitude it is advisable to keep seat belts fastened at all times when seated, which will also provide restraint if unexpected turbulence is encountered.

Within the body cavities free gases will expand and will be expelled where possible. If decompression is relatively slow, the body gases will escape without difficulty. The middle ear and the sinuses will be ventilated fairly easily because the higher pressure within the cavities forces open the Eustachian tube (which connects the middle ear to the back of the nose) and the sinus openings.

If the decompression is rapid, gases expanding inside the intestinal tract may cause some pain. However the intestine is normally capable of significant stretching, and serious injury is unlikely. The same applies to the lungs because the lung gas is usually expelled through the trachea with little resistance. Following decompression, the occupants will be exposed to hypoxia and the risk of decompression sickness. For this reason oxygen masks must be available at all times when flying pressurised aircraft.

I.2.o Decompression Sickness

In addition to the gases trapped in the body cavities, a considerable volume (primarily nitrogen) exists elsewhere within the body, not in its normal gaseous state but in solution.
As altitude increases this gas comes out of solution as bubbles and these can produce discomfort or pain around the joints or muscles -'the bends'.
Similar bubbles can form in the lung tissue, recognisable by a burning sensation or a stabbing pain in the chest, a cough and some difficulty in breathing -a condition known as 'the chokes'.

Bubbles affecting the nervous system can lead to difficulty in muscular co-ordination and this gives rise to the condition known as 'the staggers'.

Finally, bubbles can form in the skin and this gives an itching sensation known as 'the creeps', or formication. Decompression sickness seldom occurs below 25,000 ft and hardly ever below 18,000 ft, but this will vary with the individual and it is essential to descend to lower altitudes whenever the condition is suspected.

I.2.p Prevention and Treatment

Decompression sickness can be prevented by pre-breathing 100% oxygen before flight in order to 'wash out' nitrogen dissolved in body tissues. The length of time for pre-breathing depends upon the planned flight altitude. There is a risk of developing decompression sickness if flying within 12 or 24 hours of SCUBA diving, depending on the depth of the dive.

In the event of a rapid decompression at altitude, following the donning of masks and establishment of a supply of 100% oxygen, a rapid descent to below 25,000 ft and a slower descent to below 18,000 ft should prevent the development of decompression sickness.

Symptoms of decompression sickness in flight should be treated with 100% oxygen and the individual should be kept warm and still. Emergency post-flight treatment in a recompression chamber may be necessary on landing, and medical advice should be sought as soon as possible, preferably by radio communication prior to landing.

I.2.q Hyperventilation

Hyperventilation may be defined as breathing in excess of the metabolic needs of the body. One of the waste products of metabolism is carbon dioxide which is carried to the lungs in the bloodstream. The rate of breathing is controlled by the respiratory centre of the brain and this reacts to the amount of carbon dioxide in the bloodstream. For example, during physical activity the body cells use more oxygen and therefore more carbon dioxide is produced. This causes the respiratory centre to produce a faster rate of breathing. However, if a faster rate of breathing takes place without an increase in physical exertion, extra oxygen is not required so extra carbon dioxide is not produced. The excessive breathing removes carbon dioxide from the bloodstream faster than it is produced by metabolism leading to chemical changes within the blood. This is hyperventilation.

Causes of hyperventilation include:

- anxiety
- stress
- excitement
- motion sickness
- vibration
- heat
- acceleration (G' forces)
- pressure breathing
- hypoxia.

The symptoms associated with hyperventilation are:

- dizziness
- increased sensation of body heat
- tingling sensation in the fingers and toes
- increased heart rate
- nausea
- blurred vision.

In extreme cases, loss of consciousness can occur but when this happens the breathing rate slows and respiration becomes normal again and there is rapid recovery. The symptoms of hyperventilation are similar to those of hypoxia and it is important to be aware of how hyperventilation can be caused and the precautions to avoid it. Re-breathing air exhaled into a paper bag will slow the breathing rate and

stop hyperventilation, by restoring the normal acid-base balance (inhaling carbon dioxide increases blood acidity, which decreases the breathing rate). It can be avoided by understanding the signs and symptoms and maintaining a normal rate of respiration.

I.2.r Effects of Acceleration

Acceleration is the rate of change of velocity with time and occurs when the speed or direction of motion of a body alters. The magnitude (G) of an acceleration is expressed in multiples of the acceleration due to gravity (g), which is sensed as weight.

G = acceleration/g

The actual force of 1 G for an object is equivalent to the weight of that object. A person at rest is subject to the normal pull of gravity, i.e., 1 G, but if acceleration takes place in terms of speed or direction the G is increased. For example, if pulling out from a dive the pilot could experience 2 G or more, which is the equivalent of a person weighing 90 kg suddenly increasing apparent weight to 180 kg. So, the accelerated force is measured in G or multiples of the force of gravity.

In addition, acceleration may be described by the means by which it is produced, i.e. linear, radial or angular acceleration. The pilot's physiological response to this acceleration will be determined first by its magnitude and second by the duration and direction of its action. Duration is classified as either long (greater than 1 second) or short (1 second or less).

The body responds to inertial force, which by Newton's third law of motion is equal and opposite to the applied accelerative force. Thus, when pulling out of a dive, the headwards acceleration of the pilot produces a foot wards inertial force and this is referred to as + Gz.

Acceleration fore and aft (the horizontal plane) is referred to as Gx, whereas Gy is acceleration in the lateral plane (side to side). In normal aviation activity, acceleration is more likely to be encountered in the vertical plane (Gz). However short duration acceleration or deceleration, such as may occur in an accident, can affect any of the planes but particularly the horizontal. Tolerance to G forces depends on body orientation with respect to the direction of the applied force. Maximum human tolerance to acceleration is in the horizontal plane, and is in the order of 45 Gx.

The forces experienced with positive Gz result in a reduction in hydrostatic pressure within the blood vessels above the heart (i.e., supplying the brain) and an increase in hydrostatic pressure below the heart. The first symptom caused by increasing positive Gz is reduction in peripheral vision, followed by a narrowing of visual field and then if the G force continues beyond +2Gz, the condition known as 'grey out'. The cause of this phenomenon is that the pressure within the eye, the intraocular pressure, of 20 mmHg will abolish retinal blood flow once the arterial blood pressure falls below this value. If the G force reaches +4Gz the next stage will be a total loss of vision (black out) during which hearing and mental function are retained, and this will be followed by loss of consciousness (G¬LOC). G¬LOC may occur within 4 to 6 sec of rapid onset of +Gz.

Modern fighter aircraft are capable of sustaining accelerations of +8 to +10 Gz for periods up to 60 sec. These levels can be attained very quickly with the rapid onset reaching the limits of human tolerance.

Protection against the effects of +Gz can be assisted to some extent by using a reclining seat, which effectively reduces the distance, and hence the hydrostatic pressure, between the heart and the brain. Additional protection is given by wearing an anti G suit. This applies pressure to the lower limbs and abdomen during high G manoeuvres to prevent pooling of blood in the extremities and so enables the maintenance of hydrostatic pressure above the heart. Additional protection can be provided by the

use of positive pressure breathing during acceleration, which also assists in the maintenance of hydrostatic pressure.

The force of negative G is experienced during a rapid bunting manoeuvre or pushover and this results in the blood and the body organs being displaced towards the head. This increases blood pressure in the cranium and distends the small blood vessels of the face and the eyes. The face becomes flushed, with a sensation of fullness in the head and eyes ('red out').

Tolerance to G forces varies between individuals. Factors which decrease G tolerance include hypoxia, hyperventilation, and hypoglycaemia (low level of glucose in the blood). Alcohol and smoking also reduce G tolerance as do poor physical fitness and fatigue.

CHAPTER II
Man and the Environment

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Man and the Environment

The senses in man are sight, sound, touch, smell and taste. Human perception utilises information from all five sources, and it has been said that one can only perceive what one can conceive.

II.1 The Central and Peripheral Nervous System

The nervous system is the controlling and organising structure of the body, the seat of consciousness, memory and emotion. It is an information collecting system with massive storage capacity, able to relate new data to knowledge derived from past experience and thus achieve creativity. It is also highly responsive, reacting constantly to incoming stimuli by appropriate bodily movement so as to promote survival, well-being and adaptation to a constantly changing environment.
The nervous system has three main parts as shown below.

II.1.a Central Nervous System

This consists of the brain and spinal cord which effectively form a single organ, the spinal cord being the downward extension of the brain from the brain stem.
The brain is the processor of different sensory inputs, the origin of cognitive processes and the site of memory. It has a number of anatomically discrete areas, such as the cortex within which vision is processed and the cerebellum which is the area where balance and co-ordination are processed.

II.1.b Peripheral Nervous System

The nerves in this system link the various parts of the body to the central nervous system. There are 12 pairs of cranial nerves which run out from the brain and its stem and connect them to the sense organs and muscles of the head and neck. From the spinal cord, 31 pairs of spinal nerves pass out through the gaps between the bones of the spine (vertebrae). These are composite nerves containing fibres that activate muscles plus fibres that carry sensory information. The branches of these nerves extend throughout the body to the ends of the limbs.

II.1.c The Autonomie Nervous (Vegetative) System

This is concerned with the unconscious control of functions such as digestion, heartbeat, blood pressure, body temperature and sweating. Its component nerve cells lie in a chain of linked clumps, called ganglia, parallel to the spinal cord and just outside its bony canal. It also includes a certain number of direct connections between the ganglia and the brain.

The autonomic system is divided into sympathetic and parasympathetic systems. The sympathetic system is concerned with the body's response to stressful situations (the fight or flight response) and involves the cranial, thoracic, and upper lumbar nerves. The parasympathetic system acts on the body during sleep and involves the sacral (lower back) nerves and some cranial nerves. During periods of stress, it prolongs the body's mobilisation.

The sympathetic and parasympathetic nervous systems potentiate their effects via the release of hormones, controlled by feedback.
This is referred to as a self- regulated neurohormonal system.

II.1.d Workings of The Nervous System

The sense organs pass information to the brain via the nervous system. The sense organs are the eyes, ears, nose, the mouth taste receptors, and a range of specialised nerve endings (proprioceptive sensors) in the skin which respond to touch, pressure, pain, pin prick and temperature. The information is carried by the sensory and cranial nerves to the brain, where it is registered, stored and compared with previously stored data.

An appropriate response is facilitated by the motor nerves which cause muscles to contract or glands to secrete. Most muscles are voluntary (can be consciously controlled) but there are also many which contract involuntarily (without conscious control, or even awareness in some cases). Involuntary control is organised by the autonomic nervous system once information has been processed by the brain. A nerve impulse is triggered by a chemical reaction in the nerve tissue which initiates an electrical discharge along the nerve fibre. Thus, transmission of a nerve impulse is an electrochemical phenomenon, and electrical activity in the brain can be measured by the electroencephalogram (EEG). Sensory organs have a threshold below which they do not respond; for example, the eyes require a minimum light level for vision and the ears cannot hear sound below a certain pressure level.

The sensory threshold is different for different sensory organs and may vary in individuals from moment to moment. This is referred to as sensitivity and can be influenced by many factors such as the individual's arousal or by the nature of the environment surrounding the individual at that time.

Continuing stimulation can lead to a change in sensitivity and this is known as habituation. A reduction in sensitivity due to habituation may lead to reduced sensory awareness. This can have implications for flight safety, e.g. reduced visual sensitivity due to an unchanging visual scene flying at high altitude above cloud.

Adaptation occurs when the sensory response is modified as a result of continuous exposure to a situation, which may lead to a change in sensitivity. Examples include night vision adaptation, when the rods in the retina of the eye become more sensitive in the continuing absence of bright light, or aural adaptation when a continuous background noise ceases to be consciously perceived. Muscles which are normally under voluntary control may respond involuntarily and sometimes unconsciously to a stimulus; this is known as a reflex. Many reflex responses involve conscious awareness but they occur almost before we are aware of them.

One example is the reflex which makes an individual pull the hand away at once when it accidentally touches something very hot. The reflex is triggered by a sensory signal passing to the spinal cord, linking then to the cell bodies of the motor nerve fibres, and then passing to the various muscles causing them to contract. At the same time, pain messages pass up the spinal cord to the brain which is not involved in the reflex, except to memorise the danger situation. With forewarning, the brain can override the reflex and maintain the hand in contact with the hot source.

II.2 Vision

Of the five senses, vision is used and relied on most. However, it has limitations with which aircrew must be familiar.

II.2.a Functional Anatomy of The Eye

The eye is in many ways like a camera. Both have a shutter, diaphragm, lens and method of focusing within a container -in the eye this container is the eyeball.
The eyeball is moved by surrounding muscles and the lacrimal gland produces fluid (tears) to moisten the cornea. The eyelids act as protective shutters for the eyeballs.

Light passes through the transparent cornea, where most refraction (70 to 80%) occurs, before reaching the lens (Figure II.1). The pupil grows larger in conditions of reduced light and smaller when the light increases, thus ensuring the correct amount of light falls on the retina. The lens focuses the light on the retina.

Imperfect refraction of the light rays passing through the cornea and lens may lead to difficulty in focusing the image on the retina, causing a reduction in visual acuity. An increase in refractive power of the eye causes the image to be focused in front of the retina
(myopia), whereas a reduction in refractive power focuses the image beyond the retina (hypermetropia). Refractive errors can be corrected with suitable lenses.

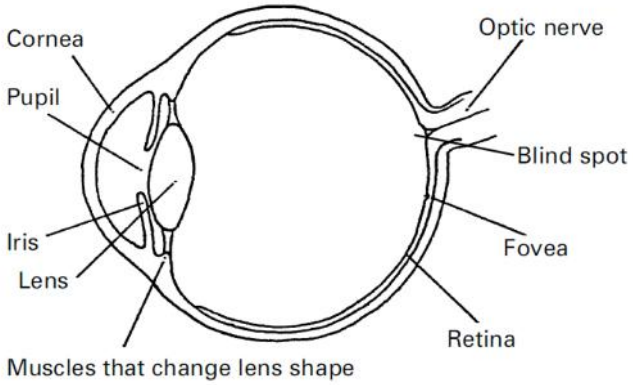


Figure. II.1: The eye (left eye seen from above).

Visual acuity is the capacity of the eye to resolve detail. To obtain the highest resolution, the target being observed must be focused on to the fovea. Visual acuity may be degraded by the shape of the eyeball, age, fatigue, alcohol, hypoxia and smoking. In an individual with normal eyesight, acuity at the fovea is 6/6 and the target subtends an angle on the retina of 5 minutes of arc.

The fovea is the region on the retina composed only of cone nerve endings, which are the visual nerve endings providing greatest acuity. Acuity diminishes rapidly after 2 to 3° from the centre of the fovea. At 5°, acuity has halved to 6/12, and at 25° it has decreased by a tenth to 6/60.

Visual field is the target area from which each retina can detect visual input. Anything lying outside the visual field of a retina will not be detected by that eye. Reduction in the visual field can be the first sign of the onset of certain pathological conditions, such as glaucoma (a rise in pressure in the anterior chamber of the eye).

Central vision is the perception by the brain from nerve inputs originating in the fovea. It gives best visual acuity.

Peripheral vision is the perception by the brain from nerve inputs originating from the areas of the retina away from the fovea. It is used for detecting movement.

Accommodation is the ability of the eye to alter its focal length. The speed and range of accommodation reduces with age, particularly in low light levels. The iris is the light adaption mechanism which caters for levels of illumination. The pupil grows larger in conditions of reduced light and smaller when the light level increases, ensuring the optimum amount of light falls on the retina. The adjustment range of the iris is 5:1.

II.2.b Physiology of Vision

The retina has special receptor cells which convert light energy into nerve impulses. These impulses pass to other cells in the retina before travelling along the optic nerve to the optic chiasma, which is the intersection of the two nerve tracts leading to either side of the brain. Information from both eyes is interpreted in the area of the brain known as the visual cortex. There are two types of nerve endings in the retina, cones and rods, differentiated by their construction and function.

The cones are located in the centre of the retina (fovea) and are used for day or high intensity light vision. There are a number of types of cone and they are involved with central vision to detect detail, perceive colour and identify faraway objects. They function poorly in dim light.

Some male individuals are deficient in the ability to perceive colour. This is due to a congenital absence of the cones sensitive to particular colours and is known as colour blindness. There are different degrees of colour blindness, the commonest affecting perception at the red-green end of the visual light spectrum, but it has no effect on visual acuity. Colour perception can be important for identifying navigation and signal lights (particularly at night), interpreting maps and charts, and interpreting electronic flight instrument displays. Perception of red and orange colour predominates in bright light whereas colours from the violet end of the spectrum predominate when light is dim. Colour becomes less distinct with distance.

The rods are located in the periphery of the retina, an area that is about 10,000 times more sensitive to light than the fovea. The rods are used in low light intensity by looking slightly to one side of objects rather than directly at them. Thus peripheral vision utilises the rods rather than the central cones.

This effect can be demonstrated at night by counting a group of faint lights in the distance when looking directly at them. Then by looking some 10° to one side it will be possible to see more lights.

A blind spot occurs in the central vision where the optic nerve enters the eye. This can be demonstrated by covering the left eye and using the right eye to focus on the image of the aeroplane in Figure II.2.

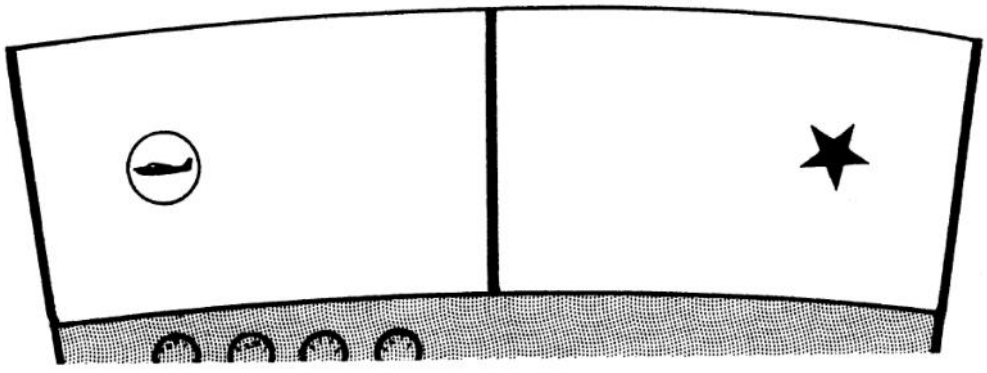


Figure II.2: Demonstration of visual blind spot.

Move the page slowly closer to the face and at some point the black star on the right will disappear as the image falls upon the blind spot. Although this does not occur when both eyes are used, the overlap of the two visual fields is imperfect because of the intrusion of facial features such as the nose.

A further point to remember is that some people who have perfect day vision may be myopic (near sighted) at night. Night myopia is little recognised, but can present a significant hazard because of the false confidence instilled by having good visual acuity by day. Night myopia occurs because of the way the eye differentially focuses the frequencies of different colours. Red and orange predominate by day and a lens, whether natural or artificial, which is easily capable of focusing these wavelengths will be less effective when focusing the colours from the violet end of the spectrum which prevail at night. In low light conditions, the lens of the eye has sufficient elasticity to focus the light from near objects but cannot focus properly on objects further away (near sightedness or myopia).

This can be compounded by the effects of increasing age. Ageing causes the elasticity of the lens to diminish, a condition known as presbyopia. In the case of a pilot who is already myopic and wears corrective spectacles, one of the effects of increasing age is that the daytime correction may be inadequate by night. Another effect of ageing is that the speed of accommodation reduces, especially in poor light. It is also worth remembering that mild hypoxia can impair visual acuity, which is particularly important during night flying.

II.2.c The Visual Field-Scanning Techniques

Scanning the sky for other aircraft is obviously important in avoiding mid-air collisions, particularly when flying under visual flight rules. Less than 10% of mid air collisions occur between aircraft approaching head on. Therefore, it is essential to develop and practise a scanning technique that allows the efficient monitoring of the surrounding air space as well as the cockpit instrumentation. A large aircraft such as a 747 can be seen quite easily when a few hundred metres away, but only when you are looking at it. Pilot workload will influence the time available for visual scanning and even when two pilots are employed, there will be moments when no one is looking outside. Lookout often becomes what is left of 'look in' time, so it is essential to arrange cockpit workload in a sensible manner to allow maximum time for looking out and scanning the sky.

Another point is the speed of today's jet aircraft, usually in the order of 500 knots for military aircraft and 250 knots in the lower levels for civil airliners. If the speed of closure between two aircraft is considered, it takes little calculation to appreciate that an aircraft which is 10 km away on an opposing heading will take but a few seconds to occupy your piece of airspace. For example, assuming a closure speed of 600 knots (which is 1 nm in 6 seconds) and a visibility of 6 nm, from the moment it is possible to spot the other aircraft there will be only 36 seconds before the aircraft meet. This might appear to give time to take avoiding action, but it is rare that an aircraft is spotted at the first possible moment. In fact trials have shown that the time interval between spotting another aircraft and taking avoiding action is around ten seconds. There are many reasons for this, including cockpit workload, position of the opposing aircraft during the scan period and its contrast with the surrounding environment. The time from visual input to recognition is approximately one second, and is referred to as the visual perception cascade. Figure II.3 shows a graphical representation of the changing size of an aircraft closing at 500 knots.

It is the relative movement of the two aircraft which is the most important aspect in visibility. Aircraft which move across the visual field will stimulate more of the peripheral nerve endings in the eyes and so are noticed sooner, but an aircraft which has relative movement to the observer is not usually a collision risk. It is when two aircraft are on constant headings, speeds and altitudes and are going to collide that there will be no relative movement between them and they will appear stationary from the cockpits. In this situation one of the most important cues (movement) is missing at a time when the greatest threat is being posed. Figure II.4 illustrates this constant bearing situation.
When above cloud, an aircraft approaching or converging from a distance which appears to be at the same altitude as the observer will pass below.

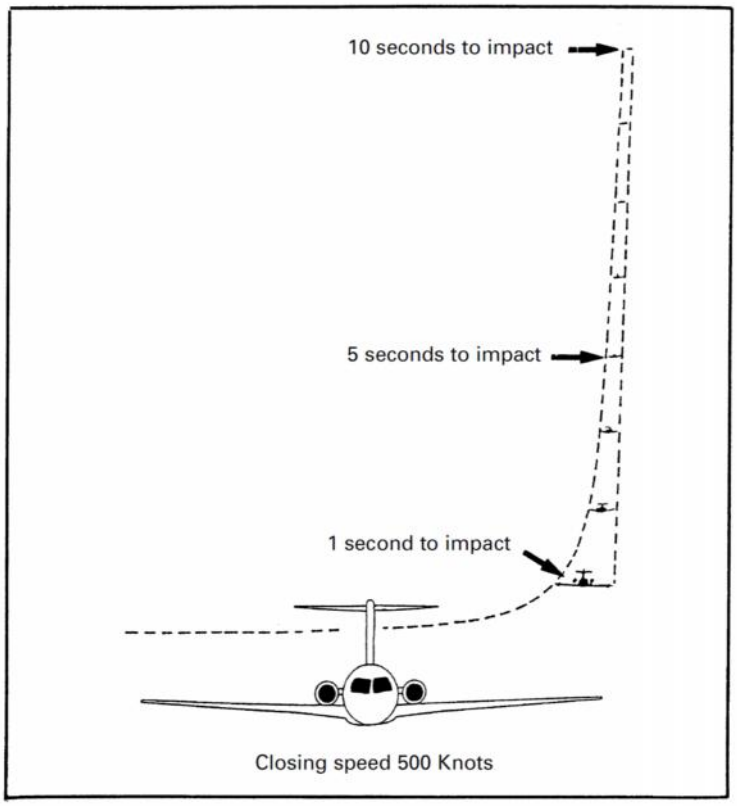


Figure II.3: The change in perceived size of an aircraft closing at 500 knots.

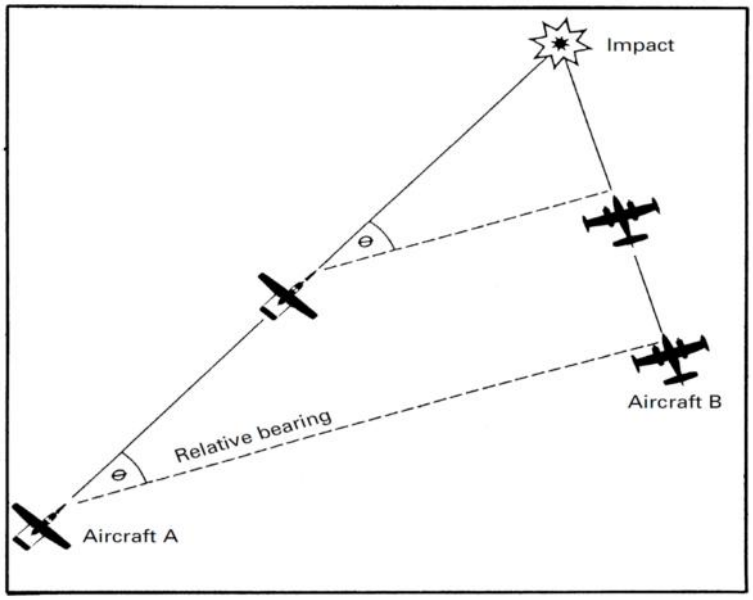


Figure. II.4: The constant relative bearing of two aircraft on collision course.

The best chance of avoiding mid-air collision is to maintain a constantly updated situational awareness of what is going on in the sky around you. Knowing where to look during the various phases of flight will considerably improve lookout. This particularly applies when entering an aerodrome traffic zone or flying close to ground-based navigation aids where one expects a greater concentration of traffic. In addition, the information available from radio calls made by other aircraft should be intelligently used to assess when extra vigilance is required and which areas of the sky to search.

When searching for a target, the eye cannot be moved continuously and smoothly. It moves in jerks with rests between them, the movement being known as saccades. The external world is sampled only during the rest phase, although the eye and brain integrate the information acquired in order to provide smooth perception of events. An eye movement/rest cycle (saccade cycle) takes about one third of a second, and this limits the detail which can be examined from the external world. The probability of detecting a conflicting aircraft can be maximised by making as many eye movements as possible and minimising the duration of the rests.

When searching the sky for other aircraft you should be aware of a condition known as 'empty field myopia'. This may occur when looking out of the cockpit at an empty sky. Because there is nothing at infinity on which to focus, the eye focuses at a point approximately between one and two metres away. This is aggravated by the windscreen frame and other parts of the aircraft structure which attract the focusing point in from infinity. As a result the eyes appear to search the surrounding area, but are in fact focused at a very close distance, so aircraft in the surrounding airspace may not be spotted. This can be alleviated to some extent by focusing on ground objects at frequent intervals, or in low visibility to focus on the wing tips from time to time. Having said that, most near miss incidents and mid-air collisions occur in conditions of good visibility and by day.

When developing a technique for effective visual scanning, it is necessary to perform a series of short, regularly spaced eye movements which bring successive areas of sky into the central (foveal) visual field. Scan from right to left or left to right, beginning a scan at the top of the visual field in front of you and then moving the eyes inward towards the bottom. Each movement should be 100 at the most, and each area should be observed for at least 1 second but not longer than 2 to 3 seconds. The alternating movement and stopping of the eyes during the scan is known as the saccade/rest cycle.

In low visibility, avoid looking directly at an object for more than 2 to 3 seconds (because it will bleach out). Instead, use the off centre viewing that consists of search movements of the eyes (100 above, below, or to either side) to locate an object, and small eye movements to keep the object in sight. Switching the eyes from one offset point to another every 2 to 3 seconds will enable the object to be detected in the peripheral field of vision.

Remember to move the body as well as the head to see around physical obstructions such as door and window posts.

II.2.d Binocular And Monocular Vision

The use of two eyes (binocular vision) is important in depth perception. This is the function of judging distance, both horizontal and vertical. However, binocular cues are only of importance when viewing objects close at hand. At greater distances, depth is perceived from information on relative object size, texture and brightness (monocular cues).

II.2.e Depth Perception Monocular Cues

• Size of the retinal image -comparison of the perceived object with size known from past experience
• Motion parallax -near objects appear to move against the observer's motion, whereas distant objects move in the same direction as the observer's motion
• Obscuration -nearer objects appear to cover distant objects (also known as interposition)
• Texture -visual detail of colour and texture lost at increasing distance
• Atmospheric perspective -distant objects appear bluer and hazier than near objects
• Linear perspective -parallel lines converge at a distance
• Apparent foreshortening -a circle appears as an ellipse when viewed at an angle.

II.2.f Depth Perception Binocular Cues

Generally used only for distances up to 200 metres.

• *Convergence* -the amount that the axes of the eyes converge to bring a visual target on to each fovea
• *Stereopsis* -the fusion of signals from slightly disparate retinal points, measured in seconds of arc of disparity
• *Accommodation* -if the eye observes a close object, the lens is thickened and the pupil becomes larger, while to focus on a more distant target, the lens flattens and the pupil becomes smaller.

An individual who has had only one functioning eye from childhood develops the ability to compensate. However, if an eye is lost at a later age it may take several months to develop adaptation to monocularity. During this adaptation period, an individual may experience hazy vision and occasional loss of balance, due to conflicting sensory information compared with past experience. A medical flight test is usually required to determine whether a person with monocular vision is acceptable on safety grounds.

II.2.g Night Vision

Night vision is derived from the rods in the retina and these are very sensitive to hypoxia, either as a result of low oxygen concentration in the ambient air or the presence of carbon monoxide from tobacco smoking or exhaust fumes. Night vision is also affected by age and alcohol.

Dark adaptation is the process by which the eyes adapt for optimal night visual acuity under conditions of low ambient illumination. The eyes require between 30 and 45 minutes to fully adapt to minimal lighting conditions. The lower the starting level of illumination, the more rapidly complete dark adaptation is achieved. To minimise the time necessary to achieve complete dark adaptation and to avoid losing it:

• avoid inhaling carbon monoxide from smoking or exhaust fumes
• adjust instrument and cockpit lighting to a level as low as possible
• avoid exposure to bright lights
• use supplemental oxygen when flying at night above 5,000 ft.

If dark adapted eyes are exposed to a bright light source, e.g., landing lights, for a period in excess of one second, night vision is temporarily impaired. Exposure to aircraft anticollision lights does not impair night vision adaptation because the intermittent flashes have a very short duration « 1 second).

In an attempt to preserve night adaptation, red light used to be used for cockpit illumination. However, it was found that with so many other sources of ambient light it made little practical difference. Also, the use of red light can obscure detail from topographical charts and airfield approach plates. The current standard is for white lighting, unless compatibility is required with night vision goggles when blue lighting is used. However, blue lighting leads to similar problems of interference with colour coded information on charts and plates. Thus, cockpits so equipped have the facility to switch back to white lighting when night vision goggles are not in use.

II.3 Hearing

II.3.a Functional Anatomy Of The Ear

The ear consists of three parts, the outer ear, the middle ear and the inner ear (Figure II.5).

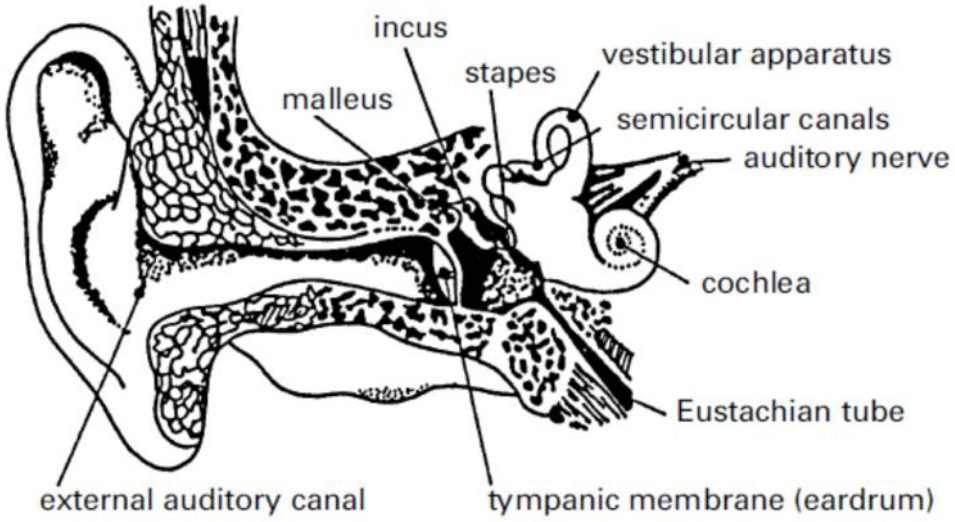


Figure II.5 : The ear.

The outer ear is composed of the ear flap (pinna) and the ear canal.
The middle ear contains the eardrum, the auditory ossicles (sound conducting bones) and the Eustachian (pharyngo-tympanic) tube.
The inner ear contains the cochlea (organ of hearing) and the balance mechanism.

The ear pinna collects sounds and directs them along the ear canal to the eardrum. Sounds, which are small fluctuations in air pressure, cause the drum to vibrate. For the drum to be sensitive to sound, the air in the middle ear must be at the same pressure as the air in the outer ear and this pressure is equalised by the Eustachian tube which connects the ear with the back of the throat. When climbing or descending in an aeroplane, a 'popping' sensation may be felt in the ears and is the result of uneven pressures being equalised between the outer and middle ear.

Sound pressure waves vibrate the eardrum (tympanic membrane) and these small vibrations are amplified by the three bones forming the ossicular chain. The third bone is shaped like a stirrup and this transmits the sound waves to the fluid (endolymph) contained within the cochlea. The sound pressure waves which move through the endolymph displace sensory hairs contained within the hearing organ (organ of Corti). Signals are transmitted to the brain via the auditory nerve and are perceived as sound. Different sound frequencies are detected by different groups of sensory hairs which explains why some forms of deafness lead to loss of the ability to perceive certain sound frequencies but not others.

The normal human ear can hear sound in the range of approximately 20 to 20,000 Hz. Normal conversation frequencies lie between 500 and 3,000 Hz, with the vowel frequencies between 500 and 2,000Hz, and the consonants between 1,000 and 2,000Hz.

II.3.b Flight Related Hazards To Hearing

It has been seen that hearing basically depends on two mechanisms. The first is the conduction system consisting of the eardrum and the bony ossicles to transmit the vibration and the second is the transducer system, the cochlea. Deafness affecting the first system is known as conductive deafness, whereas deafness affecting the cochlea or the nerve pathway connecting the cochlea to the brain is known as sensori-neural deafness.

Conductive deafness may arise in childhood from damage to the middle ear due to infection or trauma. Temporary conductive deafness can result from damage to the tympanic membrane, such as a perforation which can occur as a result of flying when suffering from an upper respiratory tract infection. Conductive deafness is often treatable with medication or surgery.

Sensori-neural deafness arising from damage to the cochlea or the nerve conduction system is usually irreversible. The hearing organ within the cochlea responds to vibrations but may be damaged by over stimulation in the form of loud and prolonged noise. Noise induced hearing loss (NIHL) may be temporary at first, but excessive and continuing exposure will lead to permanent damage and hearing loss.

Noise levels are measured using the decibel scale, which is a logarithmic scale relating to an arbitrary normal value of 0 dB. 0 dB is the sound pressure level experienced in a soundproofed environment such as a recording studio; 50 dB is the sound level experienced in the average office; 70 dB would be experienced during normal conversation and 100-120 dB would be the sound of a large jet aircraft taking off. Hearing may be damaged when exposed to noise energy in excess of 90 dB for prolonged periods. The damage is not only related to the loudness of the noise but also to the length of exposure and the frequency of the sound, i.e. it is the total noise energy which matters. Thus 90 dB experienced for 8 hours will be as damaging to the ear as 103 dB for 30 minutes.

The noise levels in the cockpit of some light aeroplanes can be high, and efficient noise cancelling headsets should be worn routinely.

One source of hazard to hearing in the cockpit is the use of excessive volume when listening through the radio headset. Although the noise level in most jet aircraft flight decks is below that which would cause hearing damage, the practice of leaving one ear uncovered while listening to radio telephone communications through the other ear can be hazardous to hearing. To enable the radio transmissions to be intelligible, it is necessary to increase the volume in the headset sufficiently to overcome the ambient noise being detected by the uncovered ear. This can lead to sound levels in the covered ear in excess of 90 dB which can cause hearing damage if the time of exposure is prolonged.

The airport ramp or apron area is noisy. In some cases, the noise on the ramp may well exceed 90 dB and hearing protection should be worn when performing pre-flight external checks. One of the effects of ageing is a reduction in the ability to hear high frequency sounds. This is known as presbycusis and is an irreversible part of the normal ageing process.

II.3.c Effects Of Altitude Change

Consistent with Boyle's law, the air in the cavity of the middle ear expands and contracts with changes in atmospheric pressure. During a change in altitude if the pressure in the ear is not readily equalised with the outside pressure, the drum is distended leading to inflammation with pain and temporary deafness. The Eustachian tube leads from middle ear to the back of the throat, so the middle ear communicates with the outside air and in normal conditions any difference between the middle ear and the outside atmosphere is equalised. The tube normally remains in a collapsed state, but it is briefly opened by swallowing or yawning.

When the air in the middle ear expands, as for example during a climb, a small bubble of air is forced out through the Eustachian tube at frequent intervals. Normally no difficulty should be experienced during the climb to higher altitudes because the pressure equalisation occurs automatically. During descent the situation is reversed. As the surrounding air pressure increases, the middle ear, which has accommodated to the reduced pressure at altitude, is at a lower pressure than the external ear canal. Consequently, the increase in pressure of the outside air forces the eardrum to bulge inward. This is much more difficult to relieve because air must now go back up the Eustachian tube to equalise the pressure between the inner ear and the outside atmosphere. The lower pressure in the Eustachian tube tends to collapse the tube rather than inflate it. This produces a sense of fullness, discomfort and even pain and temporary deafness.

Normally, ventilation of the middle ear during descent can be achieved by frequent swallowing or yawning, producing a contraction of the small throat muscles which briefly open up the Eustachian tube. When swallowing or yawning has no effect, the Valsalva manoeuvre can be performed. To do this, the mouth is closed, the nostrils pinched shut and then one should blow slowly and gently to build up pressure in the mouth and nose. It is important to ventilate the ears at frequent intervals during the descent, and if the ventilation becomes difficult the rate of descent should be decreased or even stopped at intervals to allow more time for the pressure to equalise.

Flying while suffering from a cold, catarrh or other upper respiratory infection is inadvisable because the tissue around the nasal end of the Eustachian tube will probably be swollen. This can cause the small orifice of the tube to be restricted or even closed, with resulting difficulty in equalising the pressure. If the pressure cannot be equalised, then there will be a risk of the eardrum becoming perforated; a perforation usually heals within six weeks but occasionally surgical intervention is

II.4 Integration Of Sensory Inputs

A stimulus must reach the sensory threshold before being registered by a particular sense.

II.4.a Orientation

Information from the body's sense organs -the eyes, the hearing and vestibular organs of the inner ear and the proprioceptive nerve endings in the skin, muscles and joints -is passed to the brain. The information is processed to determine orientation, i.e. the position of the body in space.

The human body evolved in its natural terrestrial environment. However, flying takes the body away from its natural environment and conflicting information from the individual sensory organs may lead to disorientation, as a result of mismatch in sensory input and central processing.

The most important information comes from well-defined external visual cues, and if these are present, disorientation is uncommon. However, when a pilot attempts to fly without a visible horizon, such as in cloud, fog, precipitation or darkness, disorientation will occur unless attention is turned to the aircraft instruments.

Tests have shown that without adequate visual cues, control of the aircraft is lost within about 60 seconds of vision being lost in straight and level flight, and in an even shorter time if the aircraft is in a turn.

II.4.b Sensory Illusions And Spatial Disorientation

An illusion can be defined as a false impression or unreal vision formed when sensory information is misinterpreted by the brain. Spatial disorientation is a false perception of orientation of the aircraft, with respect to spatial references such as flight path and altitude, or reference to objects with respect to expected shape or size. These may occur when the sensory organs send conflicting information to the brain.

In the absence of powerful visual information, complex and interactive forces can create specific illusions. In the absence of external visual reference, e.g., flying in cloud, conditions of poor visibility or at night, the conflicting sensory information can be overcome by reference to the flight instruments. The information displayed has to be interpreted and integrated from the two-dimensional displays to give situational awareness in the four dimensions of flight. This is a skill which has to be learned and practised.

II.4.c Vestibular Illusions

II.4.c.1 Illusion of Level Flight (The Leans/Oculogyral Illusion)

In straight and level flight the fluid in the semi-circular canals of the ear is stationary and the hair detectors are not deflected. Any movement of the head, for example as a result of aircraft roll or pitch, will cause a reaction in the appropriate pair of canals and this is perceived as movement in the appropriate direction. The signal to the brain is the result of the sensory hairs being deflected by the relative movement of the fluid, but continuing the motion at a steady rate will allow the fluid to catch up with the aircraft and the hairs will revert to their original upright position.

This leads to a false perception that the aircraft is once again flying straight and level, a condition referred to as 'the leans'. If the attitude cannot be confirmed visually the pilot will assume the aircraft is level, but as the aircraft is continuing to turn there will be a tendency for the nose to lower, resulting in increased air speed. If the pilot now eases back on the elevator control to counter the increase in air speed, the turn will tend to steepen and the aircraft will descend. The result is a spiral dive.

II.4.c.2 The Illusion Of Turning In The Opposite Direction (Somatogyral Illusion)

Another illusion can occur when recovering to level flight after a turn. During the turn the fluid in the canal has stopped moving as a steady state is achieved. As the wings are levelled, the rolling motion stimulates motion of the fluid in the appropriate semi circular canals and the fluid continues to move after the canal itself has come to rest. This leads to a sensation of turning in the opposite direction, known as the somatogyral illusion. The pilot will therefore tend to bank the aircraft away from the falsely perceived turn.

II.4.c.3 Illusion Of Turning In A Different Axis

An abrupt head movement at a rate of 30 per second or more during a prolonged constant rate turn may set in motion the fluid in more than one pair of semi-circular canals, causing a strong sense of turning or accelerating in a different axis. This can lead to serious disorientation and is one form of the so-called Coriolis effect. The Coriolis effect is the illusion produced by the cross-coupled response arising from the stimulation of the semi-circular canals by the interaction of angular motion in two planes, the endolymph in the two canals being subjected to what is initially a very fast angular acceleration. The Coriolis or deviation force refers to the force exerted on a fluid subjected to rotation, and is used to explain the behaviour of the atmosphere near to the earth's surface. The mathematics are not necessary for an understanding of the cross-coupled endolymph response.

II.4.c.4 Illusion Of Tumbling Backwards (Somatogravic Illusion)

An abrupt change from climbing to level flight can cause excessive stimulation of the otolith which is the sensory organ for gravity and linear acceleration. This leads to the illusion of tumbling backwards, known as the 'somatogravic illusion', causing the pilot to move the elevator control forward to lower the nose. The result is to intensify the original false perception with respect to gravity.

II.4.c.5 Illusion Of Climbing

In a correctly balanced turn the acceleration tends to push the body into the aircraft seat, such as happens when an aircraft is being pulled into a climb or pulled out from a dive. If no visual reference is available this gravitational force may be interpreted as entering a climb and the pilot may react by moving the elevator control forward.

II.4.c.6 Illusion Of Diving

The positive G force perceived during a banked turn will be reduced when recovering to level flight. This reduction may be interpreted by the pilot as entering a dive and may lead to application of back pressure on the elevator control leading to a reduction in air speed.

II.4.c.7 Disorientation When Rotating

Severe disorientation and vertigo can occur if the aircraft is rolling and the pilot moves his or her head out of the plane of rotation; two sets of semi-circular canals are stimulated leading to the Coriolis effect. A harsh pull out of a dive while rolling will produce the same effect, typically when pulling out from a dive following a spin, before the rotation of the fluid in the semi-circular canal has ceased. If rotary motion occurs for a short period, e.g., during a spin, when it stops there will be a sensation of rotation in the opposite direction, due to the continuing rotation of the fluid. In the absence of good visual cues, it is possible for the pilot to respond to this false illusion by putting the aircraft into a spin in the opposite direction.

II.4.c.8 Vertigo

Vertigo is an illusory sensation of turning, although the term is often applied by pilots to any form of spatial disorientation. True vertigo is the ultimate sensation of spatial disorientation, in which the individual or his or her surroundings appear to whirl dizzily. It may be accompanied by nausea or vomiting and is a result of disturbance in the vestibular apparatus. It can be due to disease, in which case it is long lasting, but when it occurs in flight it is usually temporary lasting but a few seconds.

II.4.d Visual Illusions

Impulses from the sensory organs of the eye, the rods and cones in the retina, are conducted along the optic nerve to the brain for interpretation. The eye is very reliable for orientation as long as adequate reference points are available. However, in flight, objects seen from the air often look quite different from when seen on the ground thus causing difficulty in interpreting visual cues. The problems are compounded in conditions of poor visibility and visual illusions can lead to spatial disorientation or to landing errors.

II.4.d.1 Oculogravic Illusions

The oculogravic illusion can be considered as the visual component of the somatogravic illusion described above. When an aircraft accelerates and there is a backward rotation of the resultant force vector, the pilot may experience an illusion of pitch up. This may be accompanied by an apparent upward movement and displacement of objects, such as a line of lights, within the visual field.

II.4.d.2 Auto-Kinesis

In the dark a static light will appear to move when stared at for several seconds. The apparent movement will increase if the light source is allowed to become the prime focus of attention. To avoid the effects of this visual illusion, when flying at night it is important to shift the gaze so as not to stare at a single light source.

II.4.d.3 Illusion Of Level Flight (False Horizon)

In the absence of a clearly defined horizon, the pilot may mistakenly choose another line as a reference and, for example, may fly parallel to a sloping cloud bank instead of the earth's surface.

II.4.d.4 Approach And Landing Errors

The visual approach and landing of an aircraft requires the pilot to perceive and respond to a number of visual cues. When flying a 30 approach, the angle between the horizon and the visual impact point on the runway is also 30. Thus the approach is flown by the pilot using suitable control inputs to maintain a constant angle subtended at the horizon. When flying a large aircraft, the touchdown point will be short of the visual aiming point, and account needs to be taken of this when selecting the visual aiming point on the runway. The flow of visual texture in the peripheral visual field assists final judgement of height and speed.

Surface feature and atmospheric conditions can create illusions of incorrect height and distance from the runway threshold. Landing errors from these illusions can be avoided by anticipating them during approach and using all available landing aids such as approach angle guidance lights.

II.4.d.5 Ground Lighting Illusions

Lights along a straight path such as a road, and even lights on moving vehicles, can be mistaken for runway or approach lights. Bright runway and approach landing systems, especially where few lights illuminate the surrounding terrain, may create the illusion of there being less distance to the runway threshold. Flying over terrain which has few lights to provide height cues may lead to a lower-than-normal approach being flown.

II.4.d.6 Atmospheric Illusions

Atmospheric haze, mist or fog may lead to refraction of light. This can create an illusion of greater height or greater distance from the runway. When penetrating mist or fog, an illusion of pitching up can occur leading to the approach being steepened abruptly.
Rain on the windscreen may also lead to refraction of light, creating an illusion of greater height or distance from the runway. This can lead the pilot to make a shallower than normal approach. In addition, rain on the windscreen can give a blooming effect to the perception of runway lights. This gives the impression that the approach is faster and the runway is closer than it actually is.

II.4.d.7 Runway And Terrain Slope Illusion

An upsloping runway or terrain, or both, can create the illusion that the aircraft is at a higher altitude than it actually is and the runway looks shorter. This can lead to a lower-than-normal approach being flown. The runway or approach terrain which slopes down can have the opposite effect. This is shown in Figure II.7.

II.4.d.8 Runway Width Illusion

When approaching a runway that is narrower than usual, it may appear that the aircraft is higher than it actually is. This can lead to a low approach being flown. Conversely runways significantly wider than those normally used will give a pilot the impression of being lower than normal, increasing the risk of levelling out high and landing well beyond the runway threshold. This is shown in Figure II.8.

II.4.d.9 Featureless Terrain (Black Hole)

An absence of visible ground features, such as when approaching to land over water, darkened areas or terrain made featureless by snow, can create the illusion that the aircraft is at a higher altitude than is the case, leading to a low approach being flown.

When landing at night at an aerodrome with no surrounding lights, pilots face what has become known as the 'black hole'. This may lead to an excessively low approach being flown with the risk of undershooting the runway. The brain 'constructs' a view of reality utilising visual cues. If the runway edge lights are the only visible cue, there is nothing to provide the dimension of scale leading to false perception of distance and angle.

It is important to realise that visual illusions are the real perception at the time -'perception is reality'. They occur to pilots of all levels of skill and experience.

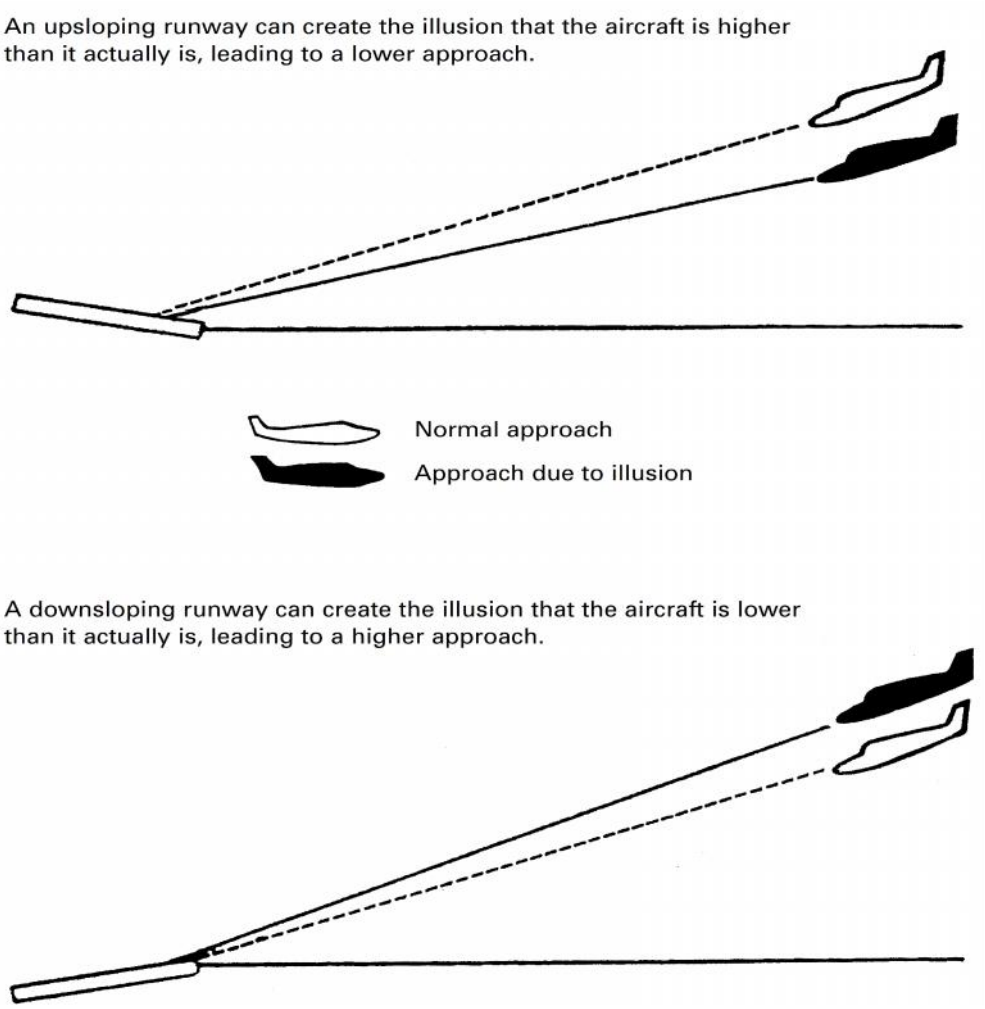


Figure II.7: Illusion created during approach caused by sloping runway.

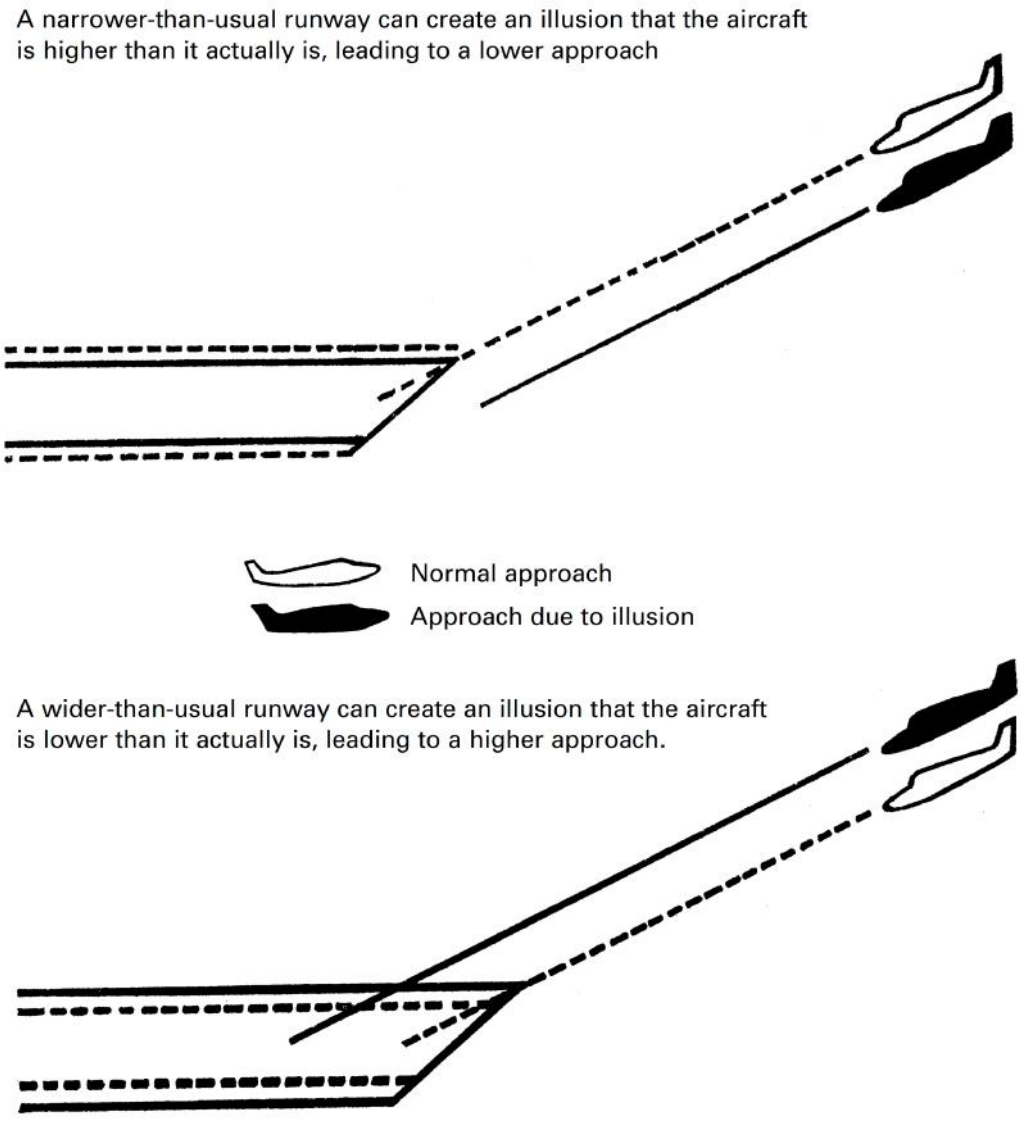


Figure II.8: Illusion during approach caused by change in runway width.

II.4.e Prevention Of Disorientation

The illusions arising from normal perceptions during flight can be suppressed by believing the aircraft instruments rather than physical sensations. Because instrument flying is an acquired skill, experience and continuing practice in instrument flying is necessary. Precautions to take:

• Never continue flying into deteriorating weather conditions unless suitably qualified in instrument flying.
• In poor visibility, do not attempt to mix instrument flying with visual flying; constant switching between the two sources of reference may in itself lead to disorientation.
• Never continue flying into dusk or darkness unless competent in the use of flight instruments.
• Avoid sudden head movements in flight, particularly when manoeuvring.
• Ensure that when outside visual references are used they are reliable fixed points on the earth's surface.
• Do not fly with a cold or when suffering from any other illness.
• Do not drink alcohol within 12 hours of take-off as its aftereffects make the semi-circular canals

more sensitive.
• Do not fly when tired or 'one degree under'.
• Maintain practice and proficiency in instrument flying.

If the pilot becomes disoriented when flying in visual meteorological conditions (VMe), a stabilising visual cue can be obtained by looking at the horizon. Disorientation during instrument flight (IMe) can result from conflict between physical sensations and the indications given by the instruments. In such a case, the instruments should be believed.

CHAPTER III
Human Error and Reliability

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Human Error and Reliability

An error can occur as an isolated incident or may form part of a chain of events.

The mis-selection of a radio frequency can be quickly identified and corrected and the flight safety result of such an isolated error is minimal. On the other hand, an error in the calculation of fuel flow early in a flight plan can set in chain a series of events with an eventual catastrophic outcome. An error chain can also be precipitated by an incorrect motor action such as mis-selection of a switch or control.

A pilot performing circuit training failed to raise the landing gear after take-off due to distraction during the after-take-off checks. In the pre-landing checks downwind, he operated the landing gear selector but failed to note that he had raised the gear instead of lowering it. On final approach, he expected to see three green indicator lights and failed to register that the lights were not illuminated. The wheels-up landing was the end of the error chain.

This is an example of environmental capture associated with skill-based behaviour.

Once skills have been learned and become automatic, they are established in the motor memory. Modification of these skills requires retraining, but the original skill cannot be erased. Under high workload or period of stress, reversion to the original skill may occur which is inappropriate to the current situation.

Human error in aviation is currently being addressed with two aims:

• to minimise the occurrence of errors by ensuring optimum matching of the components of the SHEL model with human characteristics (error resistance)

• to determine how to live with the errors which will inevitably remain as a result of human limitations (error tolerance).

Strategies employed include:

- more automation (e.g., enhanced ground proximity warning system -EGPWS)
- review of pilot performance monitored by the aircraft data recorder
- enhanced procedures for pilots to monitor aircraft automatic systems
- greater use of flight simulators
- improved automated warning devices.

III.1 Reliability Of Human Behaviour

Human error has long been a common and accepted element of behaviour, with examples occurring throughout history. However, this has not always been accepted in aviation. The expectation that training and adherence to standard operating procedures would remove any source of error has, on occasions, led to the establishment of a 'blame culture' rather than an acceptance that human error will inevitably occur.

Fortunately, the fallibility of human behaviour is now recognised and systems and procedures are designed to minimise the effect of human error, rather than to assume it will not happen.

Similar errors will have different outcomes in different situations. For example, putting sugar instead of salt on a plate of vegetables is of no serious consequence, whereas refuelling a piston - engine aircraft with kerosene instead of aviation gasoline could have catastrophic results.

Error rate will vary according to the task and can be influenced by many factors, such as fatigue, sleep loss and motivation. However, in an appropriately designed system, a human operator can enhance reliability by virtue of vigilance and the flexibility of human behaviour.

III.2 Hypotheses Of Reality

An important contributor to human error is the false hypothesis or mistaken assumption. Examples include taking off without air traffic control clearance, because something occurred to give the pilot the false assumption that he had been properly cleared, or landing at the wrong airport because of similar runway patterns.
The false hypothesis can be extremely resistant to correction. Evidence contradicting the false hypothesis is rejected until it becomes overwhelming, by which time it may be too late. Having made a decision based on a false hypothesis, the individual has a tendency to stick with the decision and seek information to confirm that decision, even to the extent of ignoring clear evidence that the decision is incorrect. This is known as confirmation bias. This has been seen in the cockpit voice recordings following accidents, revealing that doubts expressed by some crew members were overruled by the strength of the belief in the false hypothesis.

Situations when a false hypothesis is likely to occur include the following:

- When expectancy is high -typically after long experience of a situation and failing to appreciate that the situation is different on this occasion.
- When attention is diverted elsewhere -concentration on a particular problem can lead to false assumptions about other aspects of the flight.
- When it serves as a defence -human nature is to avoid anxiety, so a hypothesis may be based on avoiding the difficult true situation such as deteriorating weather.
- Following a period of high concentration -relaxation follows a stressful period and caution is set aside.
- The effects of motor memory -the operation of the wrong switch or control in a similar way to the correct one, perhaps leading to shutting down the wrong engine.

III.3 Theory And Model Of Human Error

Exercising a skill is a conscious decision normally made by the central decision maker as a result of information processing. The store of motor programmes appears able to utilise the sensory input and have access to the neural mechanisms controlling the motor output (muscles) without

necessarily referring to the central decision maker. This means that automatic skills (e.g., walking, some aspects of driving or flying) can occur at the same time as an activity requiring conscious control (e.g., holding a conversation).

However, if the usually automatic skill becomes demanding and requires conscious input, the single-channelled processing capacity of the central decision maker is utilised removing the spare capacity available for the other conscious task. This preoccupation may lead the pilot to make the correct initial decision, inadvertently exercise the wrong skill, but fail to monitor his or her activity, such that there is no awareness of the error which has been made.

Errors are more likely when the individual is preoccupied or tired (reducing central capacity), or when good conditions have reduced arousal leading to relaxation of vigilance and self-monitoring. Errors of skill rarely happen to trainees because they have to consciously think about what they are doing, unlike experienced pilots in whom so many skills have become automatic.

An error occurs because of a failure in processing. An active failure occurs when there is an absence of self-monitoring and a positive, though incorrect, action is taken. A latent failure is when there is the potential for error inherent in the planned action and the error occurs by virtue of omission. Thus a deliberate intended action can be inappropriate in a situation, giving rise to error, just as error can arise through the performance of an unintended action.

III.4 Error Generation

Error generation can be influenced by internal and external factors. Internal factors can be categorised as:

- improper technique
- overconfidence
- insufficient care
- inappropriate cognitive style.

The basic activity of a pilot follows a cycle of detection, diagnosis, decision and execution, and error can occur at any stage. The cognitive style of the individual may influence error generation, and the following patterns have been identified as leading to poor judgement:

- anti-authority -resents being told what to do
- impulsivity -reacts quickly without thinking through the consequences
- invulnerability -believes problems won't happen to him or her
- macho -belief in own ability to do the task
- external control -resignation and belief that the outcome cannot be influenced.

Recognition of these traits in oneself or other crew members should lead to a heightened awareness of the possibility of errors occurring.

External factors influencing error generation are:

- ergonomics
- economics
- social environment.

III.4.1 Ergonomies

The design of the flight deck or cockpit is necessarily a compromise between economics, the need to accommodate the range of flight crew shapes and sizes, and the positioning of the instruments and controls for optimum functional reach without compromising lookout and the operation of the aircraft.
The measurement of the human body is known as anthropometry. Anthropometric data are available for male and female populations from which statistical distributions and statistical properties, such as means and confidence limits, can be determined. In designing aircraft cockpits and flight decks, the 5% and 95% confidence limits are considered reasonable bounds, meaning that those who fall outside this range may not be accommodated in the design. The limits are also expressed as the 5th and 95th percentiles.

Key dimensions are measured, such as overall height, knee height and functional reach. Measurements are static (the individual not performing any function), dynamic (the individual simulating interaction with the cockpit environment) and contour (accurate operation of aircraft controls without inadvertent operation of others). An individual falling at one point on the distribution for one dimension (e.g., height) will not necessarily fall at the same point on the distribution for another dimension (e.g., functional reach).

The layout of the flight deck is designed to suit a population falling between the 5% confidence limit for females and the 95% limit for males, for key static, dynamic and contour measurements. This can give rise to problems due to the fact that different populations throughout the world are of different stature. Some compromise is inevitable.

The key reference point on the flight deck for the safe and efficient operation of the aircraft is the 'eye datum point' or 'design eye position'. When the pilot adjusts his or her seat to achieve this point, there should be optimum vision of controls and instrumentation and external visual reference without the need for excessive head movement. Sitting below the eye datum point decreases downward vision over the aircraft nose, and on the final stages of the landing approach sight of the undershoot is lost.

To accommodate the 5th to 95th percentile pilot population, the pilot seat must have a wide range of adjustment including up and down and tilt, as well as fore and aft. In addition to allowing the pilot to achieve the eye datum point, it must also provide comfortable support to enable the pilot to operate safely and efficiently without distraction from the seating. To reduce the possibility of backache, the lumbar support is designed to distribute spinal compression loads evenly over the intervertebral discs.

Great improvements have been made in modern instrument displays, including the development of digital instrumentation, but inevitably problems remain. The three-needle display altimeter is easily misinterpreted, and the potential for fatal error is enhanced by the fact that the needle indicating tens of thousands of feet is smaller than that indicating thousands, which in turn is smaller than that indicating hundreds of feet.

Studies comparing the three-pointer altimeter display with a digital display show a difficulty factor of 3:1 and an error rate of 20% over the digital. Although a small change in value is best displayed on a digital instrument, rate of change is best perceived on an analogue instrument (i.e., quantitative information is better suited to a digital display, while qualitative/comparative/rate information is more suited to an analogue display). Modern altimeters have a digital display plus a single needle indicating hundreds of feet, giving the advantages of both display types.

Digital altimeters require the availability of alternating electrical current (AC), so they cannot be used in simple light aircraft which have only a DC electrical system.

Figure III.1 illustrates a number of altimeters. Look at each for 5 seconds and interpret the indication.

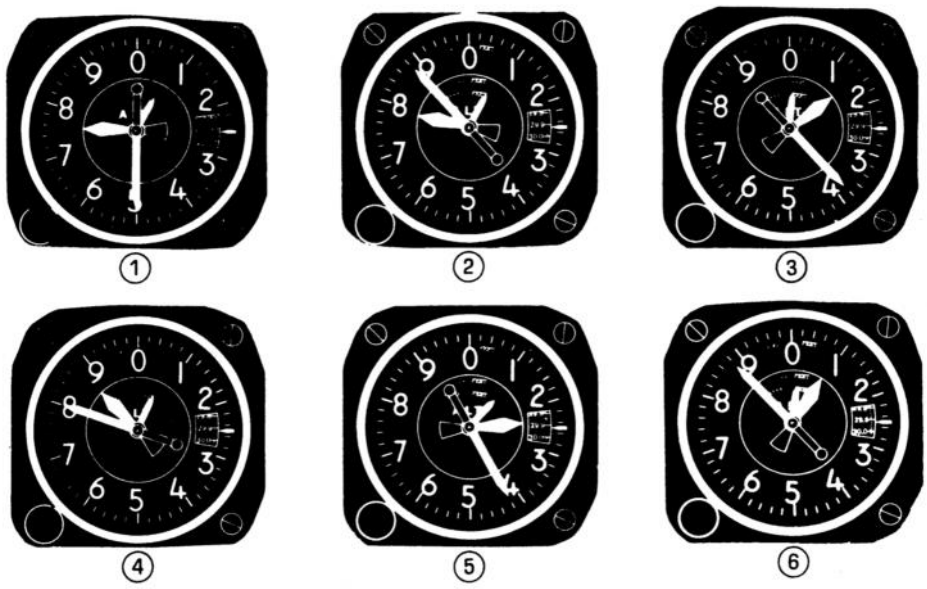


Figure III.1: Altimeters showing different heights for interpretation.

Answers to altimeter quiz : Altimeter readings: (1) 7,500 ft. (2) 7,880 ft. (3) 1,380 ft. (4) 8,800 ft. (5) 12,420 ft. (6) 880 ft.

The need to scan the flight instruments to gain four-dimensional situational awareness means that the pilot will only glance at the altimeter for a few seconds to monitor and correct any altitude deviation. However, the initial determination of altimeter reading requires more than a quick glance.

Standardisation exists for some aspects of instrument displays, but there is some variation between manufacturers, and standards have evolved with time. For example, the control knob used to set the pressure sub-scale on the altimeter is turned clockwise to increase the reading on some types of altimeters, but turned counter clockwise to achieve the same result in other types.

When developing 'glass cockpits', one manufacturer in Europe decided that the higher values for the linear speed scale should be placed at the top of the screen, whereas another manufacturer in the USA concluded that the higher values should be placed at the bottom of the scale. There were sound arguments for both, but eventually the European solution was adopted as the standard, but not before the potential for error and confusion had arisen.

Errors can arise from mis selection of controls. There have been a number of instances where the landing gear has been raised rather than the flaps after landing, despite the landing gear selector control being shaped like a wheel and the flap control like a flap. This is an example of a false hypothesis not being influenced by a tactile cue, which is insufficiently strong to overcome the mind set leading to the erroneous selection.

Despite the potential for error, there is currently no requirement for objective evaluation of the human engineering (ergonomic) acceptability of instrumentation, and no mechanism for international standardisation. This is clearly an undesirable state of affairs, but pilots must remain vigilant to this source of error particularly under high work load.

Nonetheless, the importance of standardisation in the design of aircraft controls to reduce error generation is being increasingly recognised. For example:

- a handle or knob used to open a valve should always be designed to rotate in an anticlockwise direction
- cockpit warnings should alert the flight crew but not startle them. Aural warnings are better for gaining attention, but visual warnings are better for leading the pilot to the correct location of the problem
- where a colour change is used to indicate a change of state, it should be accompanied by a change of caption or location.

III.4.2 Economics

The driving force in civil air operations is commercial pressure. It is obvious that to remain in business, an operator must make a profit. Similarly, the private pilot is under pressure to fly as cheaply as possible or to cut corners to reduce chargeable air time. There are continuing pressures on utilisation of aircraft and equipment, and on productivity of flight and ground personnel.

In the 1950s the flight crew of a long-range airliner included two pilots, a flight navigator, a flight engineer and a radio operator. The crew now consists only of two pilots, the roles of navigator, radio operator and more recently the flight engineer having been supplanted by developing technology.

The driving force for the technological development has been cost reduction; a microprocessor is cheaper than a human crew member. It is also more efficient at performing the routine tasks, but only when under the control of a human being. Similarly, the evolution of electronic flight instrument displays has been driven as much by the fact that a liquid crystal display is cheaper to build and maintain than a complex analogue mechanical instrument, as by the multifunctional capacity of the electronic display.

In themselves, these developments should not lead to an increase in error. However, the pilot now has a range of functional tasks to perform and there are fewer crew members to monitor and cross check his or her actions. Commercial pressures require long working hours, which can lead to fatigue and reduced vigilance increasing the possibility of error.

III.4.3 Social Environment

The task of the crew on a flight deck is to work together safely and effectively. This is influenced by the role or job of the individual crew members, the status and experience of the individuals, and their personalities.

The function of having more than one pilot on the flight deck is to reduce workload by task sharing, to produce consensus decision making, and to ensure crosschecking of actions to minimise error.

Suffice it to say at this point that the organisation and dynamics of the flight crew group can have a significant influence on error generation, with pressure exerted by the group upon the individual to conform to social norms, comply with direct requests, or obey authority.

III.5 Decision Making Concepts

Although the human has a vast capacity for sensing information, the decision-making stage of the process consists of just one single channel, being time shared between the different inputs. While one piece of information is being processed, the others are held temporarily in the short-term memory store, from where they are retrieved at the appropriate time. The storage and retrieval operation can be affected by many factors and this gives a source of potential error.

Because of its limited capacity, the decision-making channel is vulnerable to overload. The consequent load shedding may be poorly managed and can result in important information being discarded or not used. Under high workload or stress, concentration on a single stimulus may occur with other important inputs being ignored. When this applies to visual sensation, it is known as perceptual tunnelling.

Thus it can be seen that the decision-making process has two major components. The rational part involves conscious thought and choice, whereas the intuitive part of the process utilises long-term memory stores.
Decision making is a step-by-step scientific process which is sometimes referred to as the judgement concept. The stages in making a decision are:

- diagnosis and definition of objective
- collection of information
- assessment of risk
- development and evaluation of options
- decision of appropriate course of action
- implementation
- review and evaluation of consequences
- feedback.

The four stages of information processing are:

- sensing
- perception
- decision making
- motor action (response).

Once the action has been taken there is feedback to ensure the efficient operation of the system. Inadequate or inappropriate feedback can interfere with the processing system, leading to errors.

Decision making is the capability to properly choose responses in complex situations where several reactions are possible. It is a major component of situational awareness, airmanship and good flying judgement. It is thought to be naturally developed through experience, but there is some evidence that situational awareness, judgement and decision-making skills can be improved through structured training.

III.5.1 Structure Phases

Decision making is concerned with problem solving behaviour which is based only partially on knowledge and skills. The structure phases are:

- considering the choice of alternatives (gathering information)
- taking the appropriate decision despite uncertainty (considering alternatives)

- using available information (such as instrumentation and situational awareness) to reach a decision and form the appropriate judgement (positive decision).

III.5.2 Limits

The efficiency of decision making is limited by a number of factors. These include the individual's mental model of the particular situation, the application of heuristic methods of problem solving (proceeding by trial and error to discover the solution), assessment of probabilities and the ability to recognise personal limits of workload. All these are influenced by individual personality factors such as flexibility, creativity and social style (such as dominance).

III.5.3 Risk Assessment

In 1901, Wilbur Wright stated: 'If you are looking for perfect safety, you will do well to sit on a fence and watch the birds'. But it is known that the fence will not collapse only by assessing its condition before it is sat upon, and even then the assessment may be wrong.

Risk is a normal part of daily life, and its assessment is a fundamental part of human behaviour. Risk has to be recognised, the alternatives weighed up and a balanced conclusion reached. In aviation, risk cannot be completely avoided but the penalties of taking unnecessary risks can be very high. Before a risk can be assessed it must first be recognised, but failure of recognition sows the seeds of a hazardous situation. Because human behaviour varies widely between individuals and situations, there is no simple formula for learning how to recognise degrees of risk.

Indeed, the human is not good at assessing risk. Essentially one can recognise two types of risk:

- objective -this is external risk, the assessment of which is not influenced by the human being
- subjective -this is internal risk, which is coloured by the training and experience of the individual.

Flying training involves the development of motor skills plus the ability to make good decisions. In the early stages of learning it is logical to concentrate on motor skills and simple judgement, such as correctly positioning the aircraft in the traffic pattern, using the flying controls and throttle to achieve the correct flight path and speed, and judging the height of the aircraft during the landing flare.

The development of more complex judgements based on multiple factors occurs later in training because motor skills are developed by handling items which can be seen, felt and moved, whereas cognitive judgements and decisions are more abstract, using intelligence, awareness and experience. The four basic elements involved in the development of judgement are also involved in risk assessment:

- the pilot
- the aircraft
- environmental conditions
- available time.

III.5.3.a The Pilot

Judgement can be clouded by high stress levels which can affect pilot performance during flight. Stress is covered, but the four basic stressors are:

- *Physical* -conditions associated with the pilot's immediate environment affecting physical well-being, such as temperature, noise, or vibration.
- *Physiological* -the pilot's physical condition in relation to factors such as fatigue or hunger.
- *Psychological* -the influence of emotion, workload and the need to make decisions.
- *Sociological* -emotional stresses arising away from the flying environment, such as marital problems or job pressures.

The positive capabilities in an individual's decision-making process are:

- creativity
- innovativity
- adaptability

The negative human capabilities, potentially giving rise to error are:

- false mental model
- incorrect motor programme
- lack of feedback.

III.5.3.b The Aircraft

Risk factors associated with the aircraft include its condition and suitability for the intended flight. The level of installed equipment and appropriate fuel calculations must all be taken into account during risk assessment.

III.5.3.c Environmental Conditions

The environment is a wide-ranging risk element. It includes the prevailing and anticipated weather, and the regulations governing the operation of the aircraft within the airspace system.

III.5.3.d Time

Time is a constraining influence on the other three elements involved in risk assessment. When time is perceived to be short, impulsive or inappropriate decisions are more likely to be made. Lack of time does not just add to risk but multiplies it, and the shorter the time available the more likely it is that risks will be increased. The stress factor increases linearly as the deadline approaches.

Risk assessment is a continuing process during the planning and execution of a flight. The four elements of judgement development can be additive and accumulate, and a continuous analysis is required to enable reduction or removal of increasing risk factors by taking positive and correct decisions at an early stage. There are two main components in balancing risk:

- Intellectual -using existing knowledge, although this may not always be correct or sufficient to enable efficient information processing.
- Motivational -the individual's attitude towards risk and how it is affected by other influences such as the need to get home or peer pressure.

III.5.4 Practical Application Of Risk Management

Managing risk involves good judgement and decision making, which is the result of appropriate thought processes. The following are examples of inappropriate thought processes leading to poor risk management.

- Many general aviation pilots take care to ensure a cover is fitted to the pitot head when a light aircraft is parked, and yet do not fit a cover to the fuel vent which is equally vulnerable to the ingress of insects and debris.
- Pre take off power checks may be performed with one fuel tank selected, and the selection is changed for take-off. This leads to the situation of full power being demanded at a critical time from a fuel system which has not been checked at high flow.

It is not only low time general aviation pilots who find themselves in situations for which they appear to lack the necessary understanding. The following example is of an accident in 1974 to a Boeing 727 in the USA.

The aircraft crashed 12 minutes after departure from New York. At 16,000 ft (the altitude at which icing was encountered) the airspeed fell and the anti- stall stick shaker activated at a high nose attitude of 30° pitch. The indicated airspeed was 412 knots whereas the actual airspeed was 165 knots. The aircraft entered a stall and spin and was destroyed, killing all on board. The erroneous airspeed was the result of a blockage in the pitot heads caused by icing, because the crew had overlooked the need to activate the pitot head heaters. The crew incorrectly diagnosed the stall warnings as Mach buffet (which occurs at high airspeed) and proceeded to raise the aircraft nose to reduce airspeed, leading to the fatal stall and spin.

The crew's situational awareness was flawed, and incorrect thought processing led to the wrong diagnosis. This was an error of com mission using rule based behaviour. Risk management often involves making rapid choices, based on available information and knowledge.

A VFR pilot faced with deteriorating weather ahead may have to make a rapid choice between continuing, diverting, or returning to the airfield of departure. Considerations in the decision making process include time, money, inconvenience, perceived danger, and social or peer pressure. In the heat of the moment, even the concept of diversion may become confused -does it mean diverting track around the weather or does it mean diverting to an alternate airfield?

A quickly detected, correctly diagnosed engine fire, followed by an appropriate decision to shut down the affected engine, can be nullified by a slip in performing the required action leading to a shutdown of the good engine.

Errors in formulating the correct plan of action are referred to as mistakes, whereas errors in the execution of a plan are referred to as slips. However, the outcome is the same with the execution of an incorrect action, leading to a minor incident or a catastrophic accident depending on the circumstances.

A slip does not satisfy the operator's intent, although the intent was correct. Conversely a fault satisfies the operator's intent, but in this case the intent itself was incorrect.

III.6 Avoiding and Managing Errors

All human beings are prone to make errors. Human error is a fact of life and cannot be removed totally by training. It is therefore important to incorporate backups and fail-safe procedures in safety critical areas in an attempt to overcome the results or the possibility of human error, and avoid the development of false hypotheses. This concept must also be accepted in others. It is not helpful to flight safety to engender a culture of blame when an individual makes an error; rather it should be accepted as a normal human limitation and every effort should be made to learn from the error in an attempt to avoid repetition.

Despite improvements in training and operational procedures, errors will continue to occur. Error can be managed as follows:

- *avoidance* -recognition of human traits and weakness can lead to the development of strategies and operating techniques to avoid error generation
- *trapping* -having identified an error, its effect can be minimised by isolating or trapping the activity affected by the error
- *mitigating* -the consequences of the error can be reduced by taking action to prevent the development of an error chain.

The development of error is influenced by awareness, and this has three levels:

- *perception* -the receipt and interpretation of sensory input, such as sight and sound
- *comprehension* -this is having an understanding of the current situation
- *projection* -this is utilising the knowledge of the current situation to look ahead and understand how this will influence the next stage of events, including the consequences of any course of action.

To manage error successfully, the crew on a flight deck must utilise the following team skills:

- *briefing* -this is to identify potential problems
- *preparation* -this is planning for the expected sequence of events and making contingencies for the unexpected; it is sometimes referred to as 'staying ahead of the aircraft'
- *workload* -establishing and maintaining priorities helps individual members of the crew to avoid overload.

The same principles apply to single pilot operation, and self-discipline is necessary to ensure that these stages are followed.

III.7 Safety Awareness

III.7.1 Risk Area Awareness

The areas of greatest risk in flying are take off, final descent and landing. Figures for accidents to corporate aircraft in the USA show that 27% of accidents occur during the final descent (which comprises 2% of total flight time), 20% occur during landing (1% of flight time), and 13% during take-off (1% of flight time).Thus 60% of the accidents occur during the4% of time spent near the ground. Similar statistics are observed when examining the accident reports from other countries and in other areas of aviation activity.

For all sectors of aviation, the comparatively few accidents occurring during the cruise phase of flight frequently involve controlled flight into terrain (CFIT). This is an accident which occurs when an apparently serviceable aircraft is flown by a healthy crew into ground (often covered by cloud) (see Figure III.2).

In all these areas of risk, accidents occur as a result of lack of skill, judgement, poor decision making, or a false perception of situational awareness.



Figure III.2: Controlled flight into terrain (CFIT).

III.7.2 Error Proneness

Certain personality characteristics appear to be associated with increased likelihood of accident involvement, although there is no such thing as a single clearly defined accident-prone personality.

Accidents are sometimes found to be associated with aggressive, anti-social, or non-conforming behaviour. It has also been suggested that the neurotic extrovert is at greater risk of accident involvement than the stable introvert, although other studies show that introverts are more likely to be involved.

Different personality characteristics are likely to predispose individuals towards different types of error, so the identification of an error prone personality is difficult.

Different individuals react in different ways to high workload, fatigue and stress. There are individual variations in mental processing capacity, and it is important for an individual to identify when he or she is reaching the limit of capacity, and thus becoming prone to error.

III.7.3 Error Sources

There are many sources of error in operating an aircraft, mostly due to failure in human processing or behaviour. It is incumbent on all members of a crew to be alert for error generated intrinsically in the aircraft, or extrinsically in the air traffic or engineering environments. Crosschecking and monitoring of the actions and behaviour of other individuals is an important aspect of maintaining flight safety.

In 1983, Rouse, a cybernetics engineer developed an error classification scheme. This sets out six categories of behaviour needed to accomplish a specific task; examples are given of where error may occur.

(1) Observation of system

- misinterpretation of correct readings
- failure to observe variables

(2) Choice of hypothesis

- hypothesis inconsistent with observations
- choice of irrelevant hypothesis

(3) Testing of hypothesis

- wrong conclusion reached
- correct conclusion rejected

(4) Choice of goal

- insufficiently specified
- counter productive

(5) Choice of procedure

- would achieve incorrect goal
- procedure not chosen

(6) Execution of procedure

- required step omitted
- steps executed in wrong order.

Thus, opportunities for error arise at all stages of the activity cycle, and such a scheme is useful when evaluating errors which may occur using new technology.

III.7.4 Situational Awareness

Situational awareness is when perception matches reality. It is the state of knowing where the aircraft is, where it has been and where it is going in terms of the four dimensions of flight (the fourth dimension being time).

This requires an understanding of the limitations of oneself, the aircraft and its associated equipment and requires a continuing update of the associated risks.

Situational awareness is developed by processing the information available and using the resulting perception to develop a four-dimensional mental model. It is based on perception -when this matches reality, one is situationally aware.

In flight, information is derived from the flight and performance instruments, and from radio transmissions made by other aircraft and air traffic control. Each instrument can give only limited information, e.g., air speed, direction, altitude, rate of climb, aircraft attitude etc. To gain true situational awareness, it is necessary to mentally integrate this visual and aural information to build the four-dimensional picture.

This process can never become fully automatic and always requires some conscious effort of thought. This process is therefore vulnerable during overload of the information processing system, such as might occur during high workload or when the pilot's wellbeing is below par.

III.8 coordination

The presence of more than one crew member in a cockpit or on a flight deck constitutes a team or a multicrew. An awareness and understanding of the human factors influencing the working of the team will enhance performance and flight safety.

The crew must have a leader, whose personality, behaviour and management style will inevitably impact on the team dynamics. Similarly, the personalities and behaviour of the other team members will influence the team performance.

Effective co-ordination will depend upon effective co-operation and communication between the team members. This will differ between the flight training phase and the commercial flight operation. During training there is an expectation of error as skills are developed, whereas in commercial flight operation the monitoring and cross-checking function is a confirmation of expected and mutually understood actions.

III.8.1 Crew Briefings

The purpose of crew briefings is to ensure that each member of the crew understands the responsibilities of each individual; this ensures that any unbriefed action during the flight can be rapidly questioned. Crew briefings should be held before every flight and given when required in response to situations occurring during the flight. To be effective, briefings should be short and contain less than ten ideas.

III.8.2 Checklists

Checklists are also known as flight reference cards (FRCs) or quick reference handbooks (QRHs). The purpose of a checklist is to enable the crew to carry out a procedure in a well-defined and orderly manner, ensuring that all the necessary actions are completed by challenge, response and visual cross-checking. Checklists should be readily to hand on the flight deck and easy to use. They should be of a suitable size for stowage and easy handling, and should utilise cross-referenced indexing, colour coding of pages by topic and dividing pages with protruding index tabs. Bold, upper case and italic text may be useful in conveying emphasis, but text in normal font is faster and easier to read.

Interruption of checks by external sources, such as a radio call, can lead to actions being missed. Another source of error in using routine checklists habitually, is that the response may become automatic rather than diligent. There is a danger that familiarity with the aircraft and its systems can lead to rapid dismissal of checklist items, and pilots must guard against this tendency. Pilots of single crew aeroplanes must take particular care in the absence of a colleague to cross-check actions.

III.9 Cooperation

Cooperation is defined as action taken as part of an overall strategy. Co-action is defined as action coincident with, but independent from, an overall strategy.

III.9.1 Group Dynamics

The occupants of an aircraft cockpit or the crew on the flight deck of a commercial airliner make up an identifiable group. A functional group is a collection of individuals with different personalities and social backgrounds, working together to achieve the same outcome. In a professional flight crew, the group members will have experienced similar training and will have similar knowledge of operating procedures and standards, although there will be variations in individual experience

levels. Their task is to work together safely and effectively. This can be enhanced by crew resource management (CRM) training.

Multi crew co-operation (MCC) training takes the elements of CRM a stage further. It puts flight crew members into a practical scenario where they learn to work together as a team, applying the psychological principles of CRM to ensure the safe and efficient operation of a multi-crew aircraft.

In any group, consideration has to be given to individual needs as well as to the needs of the group. In a professional flight crew the roles are normally well defined and understood, whereas in recreational flying there may be more opportunity for conflict and confusion as a result of different personality traits not being moderated by standardised procedures.

The purpose of having a crew on the flight deck is to reduce workload by enabling tasks to be shared. It may also enable better quality decisions to be made than would be made by one individual. Although the decision made by a group will generally be of better quality than the average decisions made by the members of the group, it will never improve upon the problem solving ability of the ablest member of the group. Synergy is the term used to describe the state where the group performance is compared with individual performance. Communication and co-operation are important elements in the achievement of good synergy. Considering a two-pilot crew, good synergy is when1+1= >2, and poor synergy is when1+1= <2.

Cohesion is the ability of the group to work together to achieve a task. However, when there is too much cohesion thinking as a group can have negative results.

The dynamics of the group will be affected by a number of variables, including the role or job of each individual, the status of the individuals, and their personalities. Other factors include con-formity, compliance, risky shift and group duration.

III.9.1.a Conformity

This refers to those occasions when an individual changes his or her behaviour towards the group norm. It can be influenced by social pressure within the group, and by the size of the opposing majority (the optimum number being just four).

III.9.1.b Compliance

This refers to the likelihood of an individual's accession to the request or actions of another member in the group. It is influenced by the type or magnitude of a request which has been made previously. Thus compliance with a large or unreasonable request is more likely if it has been preceded by an even more unreasonable request. This suggests that processing the request includes some form of comparative analysis. It will also be influenced by the status of the individual making the request.

III.9.1.c Risky Shift

It can be shown that if the individual members of a group already hold an opinion about a particular course of action, the opinion of the group as a whole will be even stronger. This is a form of polarisation, and can lead to decision making which is insufficiently tempered by consideration of the attendant risks in a situation.

III.9.1.d Group Duration

The dynamics and behaviour of a group will be influenced by the length of time for which that group remains in existence. It is common for military crews to be 'constituted' which means that the group of individuals will stay together until separated by posting off the squadron. Thus, they become very familiar with the ways in which individual group members work and behave.

On the other hand, the group members of a civilian airline crew may never have flown together, nor even previously met, before being required to function as an efficient and effective team. Thus, the importance of adherence to standard operating procedures, to ensure that all members of the team know the role and actions to be expected of the others.

III.9.2 Leadership And Management Styles

For a group to work most effectively it must have a recognised leader and be a team which is prepared to follow that leader. A good leader will have the respect of the people with whom he or she works, including the other members of the flight crew, immediate managers and members of the supporting operating team. To develop a good team, the leader will delegate responsibilities when appropriate and consider the opinions of other team members, freely admitting when any mistake is made. Followership is the ability of an individual to effectively support a recognised leader by being a good team player. The best leaders also have the ability to act as good followers.

The pilot in command of the aircraft is the captain, and he or she will be leader of the flight deck group by virtue of status. A leader may be 'task oriented' (goal directed, G) or 'relationship oriented' (person directed, P), or may combine elements of both depending on individual personality.

This integration of task and relationship orientation was first proposed by Blake and Mouton in 1964, and is known as Blake and Mouton's grid theory. It is based on the concept that leaders vary on an arbitrary scale from 1 to 9 in their concern for people (relationships) and their concern for getting things done (tasks). A grid can be constructed using 'goal/task' as the y axis and 'people' as the X axis, and this gives rise to five main styles of leadership:

(1) *Authority-obedience* (9 on the Goal scale, 1 on the People scale -9,1 or G+) -dictates how a job should be done. This individual would show maximum concern for task completion with a minimum concern for people. The leadership style may be dominant, opinionated, aggressive and stubborn. This leader would run an authoritarian cockpit.

(2*) 'Country Club' management* (1,9 or P+) -gets everybody talking at the expense of getting the job done. This type of leader would show maximum concern for people, even at the expense of achieving results. The leadership style would be practical, trusting, friendly and accommodating, but would not voice qualms.

(3) *Impoverished management* (1,1 or P-G-) -no interest in the task or the people. An individual with this style is putting forward only the least effort to remain within an organisation, with minimum concern for tasks or people. The way the cockpit was managed would be 'laissez faire', implying a complete abstention from interference with individual action. This is potentially a dangerous situation.

(4) *Company Man* (5,5 or P+/-G+/-) -goes along to get along. An individual with this leadership style just maintains the middle line, avoiding conflict, which results in conforming with the status quo.

(5) *Team management* (9,9 or P+G+) -goal and people centred. This leader integrates concern for the task and concern for people at a high level, and achieves the goal through the participation, involvement and commitment of all those who can contribute. This would lead to a synergistic cockpit. However, there can be a danger of paternalism when the leader expresses a strong concern for the wellbeing of followers, but fails to consider their contributions to the task being completed.

The ideal leader will have a style which combines the extremes of either orientation (P+G+) and will be confident and relaxed, communicate and involve others, accept criticism, and be technically competent. Powers of command will be exercised in a way which gains the respect and commitment of all crew members, generating an atmosphere in which all members of the team feel that they are actively and positively contributing to the achievement of the goal.

III.9.3 Individual Duty And Role

In a single pilot operation, as in most recreational flying and much general aviation, the duty and role of the pilot is clear. However, in the case of the crew on a flight deck, the individual roles of the crew members will influence interpersonal behaviour.

The role of the pilot will depend upon whether he or she is the nominated handling pilot for the particular sector of the flight. The captain retains command and ultimate responsibility for the conduct of the flight, but duties are shared. In general, the handling pilot is concerned with the physical control of the aircraft, while the non- handling pilot is responsible for communication with air traffic control, actioning checklist items, and monitoring the actions of the handling pilot. It is common practice for these roles to alternate between the pilots on consecutive flight sectors.

The monitoring role can be difficult, particularly if the non handling pilot is junior or less experienced than the handling pilot. There has to be an understanding and acceptance by both pilots that it is entirely in order for the non handling pilot to question the actions of the other and, if necessary, take over control. This acceptance will be facilitated by appropriate behaviour and leadership style.

III.9.4 Advantages And Disadvantages Of Team Work

III.9.4.a Advantages

- a decision arrived at by a group is likely to be better quality than that derived by an individual
- flight safety should be enhanced
- workload is reduced by sharing
- work stress should be reduced.

III.9.4.b Disadvantages

- personality clashes
- time taken to reach committee decision
- conformity
- risky shift.

III.10 Communication

The human state is such that communication is an integral part of interaction. This led Paul Watzlawick, a human factors communication expert, to state his first axiom of communication which is 'one cannot not communicate'. However, interpersonal communication is not without problems.

In a survey of 119 fatal accidents, the primary cause was given as inadequate communication in 41%. In any communication there must be a transmitter, a message, and a receiver. It is important that the receiver has time and space in which to interpret the message and respond accordingly.

Thus, it is the quality and not the quantity of communication which matters most on a busy flight deck.
Implicit communication is where various interpretations may be derived from the information conveyed. Explicit communication, on the other hand, is where the message is detailed with exact information and there is no ambiguity in interpretation of the message.

Because aviation is an international activity, in which participants are of different cultures and nationalities, it is important to use a universal professional language containing simple unambiguous words with well understood meaning. Any message used must be simple and explicit, and under international agreement this is based on English language technical or operational words and phrases ('aviation English'). It is important to avoid colloquial idiom during communication and to use standard phraseology.
Examples of misunderstanding during communication on the flight deck include:

(1) Captain: 'Take off power.' First officer reduced power.
(2) Captain: 'Feather four.' First officer: 'All at once?'.
(3) Captain: 'Feather one.' First officer: 'Which one?'.
(4) Captain: 'Cheer up!' First officer raised the gear.
(5) Captain: 'Yaw damper.' First officer: 'My damper.'
(6) Air Traffic Controller: 'Say present heading.' First officer: 'Present heading.'

III.10.1 Communication Models

During aural communication, an individual only actually listens to about a third of what is heard. This is because of the existence of the 'attention loop' -the first part of the communication is listened to, the information is evaluated, and a plan of action is formulated. This all takes mental processing time, which means that elements of the message can be missed, or the listener may drop out of the attention loop for a short time.

Communication serves many functions in daily life, examples being:

- instrumental function -the object is to obtain something, such as a ticket purchase
- informative function -discover or explain something
- ritual function -part of a ceremony such as a wedding
- persuasive function -to modify an attitude or behaviour pattern.

The persuasive function of communication can be important in the flight deck environment and has three basic parts.

III.10.1.a The Originator

The originator must have credibility, which comprises expertise and trustworthiness. It is also important for the originator to believe in the validity of the message.

III.10.1.b The Message

The effectiveness of a message is influenced both by its content and by the manner in which it is presented.

Consideration of the content includes deciding on whether or not the message should contain both sides of the argument. If the receiver is already in broad agreement with the position being advocated, a one sided argument may be more persuasive by reinforcing existing attitudes. On the other hand, if there is no existing agreement, putting both sides of the case may be more effective.

Putting the positive arguments first is known as a primacy effect, whereas putting the more persuasive argument second is known as a recency effect. The way questions are phrased can also influence communication. There are three types: implicit (open), explicit (closed) and leading question.

III.10.1.c The Receiver

The final element in persuasive communication is the receiver. It has been suggested that a message modifying an individual's perception of an objective, rather than modifying his or her attitude towards it, may be more effective.

III.10.1.d Berlo's Communication Model

The model by Berlo, a human factors communication expert, proposes that communication has four components, which are:

Source	Communication skills
	Knowledge
	Social system
	Culture
	Attitudes
Message	Elements
	Structure
	Content
	Treatment
	Code
Channel	Seeing
	Hearing
	Touching
	Smelling
	Taste
Receiver	Communication skills
	Knowledge
	Social system
	Culture
	Attitudes

It can be seen that the communication elements are identical for the source (originator) and the receiver, and that the channels of communication utilise all the human sensory pathways.

III.10.1.e Schulz Von Thun's Communication Model

Schulz von Thun, a German professor, proposes that there are four aspects of a verbal message which can be visualised on four sides of a rectangle:

(1) *Informational aspect* -level of facts.
(2) *Relational aspect* -level where one is telling something about the relationship between oneself and the other person.
(3) *Appellative aspect* -level where one tells the other person what to do.
(4) *Self-disclosure aspect* -level where one tells something about oneself.

These levels apply as much to the receiver as to the originator, and von Thun calls this the four ears of an individual. The fact that the originator and the receiver may weigh the levels differently if

they are not explicitly expressed can become crucial.

An aircraft is taxying at a major airport and approaches a red stop bar. The captain says, 'The stop bar is red'. This statement can be analysed in terms of the four levels:

(1*) Informational aspect* -'The stop bar is red'.
(2) *Relational aspect* -'I am in the position to tell you these things, and you have to listen carefully' or 'You are in a position to help me out of my confusion'.
(3) *Appelative aspect* -'Stop!' or 'Tell me why the stop bar is red'.
(4*) Self-disclosure aspect* -'I've seen the red stop bar and I have to tell you this' or 'I am wondering why the stop bar is red'.

It is necessary to have a context, given by nonverbal cues, to know how the different levels should be interpreted. In normal communication it is not important to analyse all messages on all levels. However, if problems arise, it is possible to move the message to the informational level of fact and redirect it to the speaker for clarification. From this it can be seen that the receiver is more critical than the transmitter, and the relational aspect tends to be most dominant.

III.11 Verbal And Non-Verbal Communication

Verbal communication is the use of words and language to give and receive information. Language is inextricably linked with the cognitive or thinking processes as well as with communication. Interpersonal relationships are influenced by the manner of speech as well as by the content. The manner, or paralanguage, includes voice pitch, word stress, timing and pauses. This can cause difficulties when communicating in a language which is not native to the speaker, such as may occur in the use of English as the international aviation language.

Nonverbal communication is also known as body language. This involves communication using eye contact, facial expression, touch, body orientation and posture, hand and head movement, and physical separation ('personal space').

III.12 Communication Barriers

One study of the importance attached to each communication method on how the sense of the message being received is picked up, showed that words were 7%, the way the words were said 38%, and body language 55%.

The flight deck environment inhibits these normal means of communication, particularly by restricting the use of nonverbal cues or body language. Thus communication between crew members has to be transmitted verbally, particularly at times of high workload or stress. However, during overload the verbal communication may not be processed (heard but not listened to) and vital information may be missed. Communication may also be inhibited by an individual's personal style. Interruptions, and the ease with which one person gives way to the other, are indicative of dominance in a relationship.

An authoritarian individual is dogmatic and assertive, and communication from subordinates can be inhibited. Alternatively, a paternalistic style leads to frustration among the crew who feel that they are able to contribute little to the effective conduct of the operation, since they are not listened to. Perversely, the paternalistic individual believes that he is trying his best for the crew, and thus two-way communication is ineffective.
Effective communication is a skill which can be learned, but requires practice.

III.13 Conflict Management

Conflict can arise because of inappropriate behaviour by other members of the group.

An intrapersonal conflict is conflict within oneself, such as knowing what should be done in a situation and not wanting to do it. An interpersonal conflict, on the other hand, is conflict between two or more people.

If a conflict is destructive with no constructive solution, what started as a small difference of opinion can escalate into a major confrontation involving other crew members and affecting flight safety.

The avoidance of conflict, and its solution when it occurs, can be assisted by the use of good communication practice:

- *inquiry* -ideas should be elicited and opinions taken from all crew members, with the leader avoiding giving an indication of his or her own ideas or opinion at the outset
- *active listening* -the ideas and opinions of all group members should be solicited, and any expressions of doubt should be encouraged
- *advocacy* -deal in evidence and not prejudice
- *feedback* -check to ensure the solution fits the scenario, reconfiguring if required
- *metacommunication* -use all channels of communication, including body language, facial expression, gestures, tone and pitch of voice, but avoid emotion
- *negotiation* -reach a solution by discussion with both sides
- *arbitration* -arrive at a solution acceptable to both sides, by using an independent uninvolved individual.

CHAPTER IV
Human Overload and Underload

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IV.1 Arousal

An individual's arousal is the preparedness for performing any task. It is the degree of activation or alertness of the part of the brain known as the cortex.
Arousal and performance are related by an inverted U-shaped curve (known as the Yerkes-Dodson curve, or Yerkes-Dodson law) as shown in Figure IV.1. It can be considered that deep sleep forms one end of the arousal axis while sheer panic forms the other end, both of which result in poor performance. The optimum arousal for maximum performance is somewhere in between.
Many things will affect arousal; these include the individual's well-being, level of stress, mental overload, underload, etc.

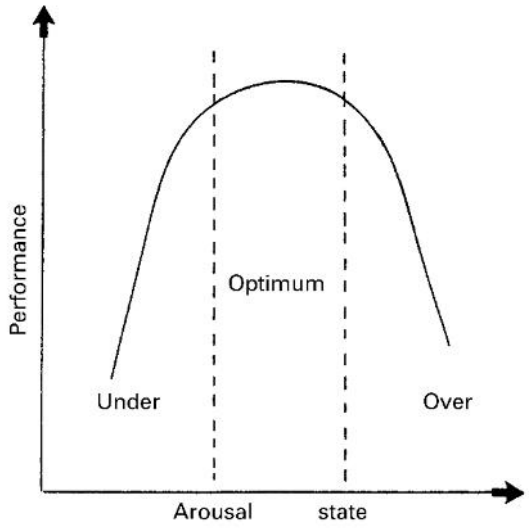


Figure IV.1: The Yerkes-Dodson curve.

Other factors affecting the Yerkes-Dodson curve include the degree of difficulty of the task being performed, training and familiarity. The optimum level of arousal is inversely related to the difficulty of the task.

Although stress will influence the arousal state, the relationship between stress levels and performance is not a simple inverted U shaped curve.
It is important to understand that under-arousal can have as much effect on performance as can over-arousal.

An example of under-arousal can be seen when flying in good weather in the cruise phase of flight where simple tasks take more effort than normal to complete. It is helpful to keep occupied with small 'housekeeping' tasks to try to maintain the arousal level in the area for optimum performance, so ensuring the best response in the event of an unexpected problem developing. Another example of under-arousal affecting performance can be seen when an approach to land is made in perfect

weather conditions to a runway with which the pilot is very familiar, particularly when tired at the end of a long sector. Unless the handling pilot consciously raises his or her arousal level, an unexpectedly poor landing can occur.

IV.2 Stress

Stress is the response to unfavourable environmental conditions, referred to as stressors, and describes how a body reacts to demands placed upon it. Stress applied to an airframe or power plant which exceeds the designed load factor leads to weakening or failure of the component affected. In the same way if excessive demands are placed on an individual, it is possible to exceed the individual's capacity to meet them. This results in a deterioration in the individual's ability to cope with the situation.

One model of stress is shown in Figure IV.2. This illustrates how stress can develop when an individual's perceived ability to perform a given task does not meet the demand. This gives rise to physiological (physical) and psychological (mental) responses which can affect the individual's performance. Physical stress occurs when external conditions either put a strain on the homeostatic mechanisms of the body or are so extreme as to nullify them. Mental stress occurs when the perceived demand exceeds the perceived ability.

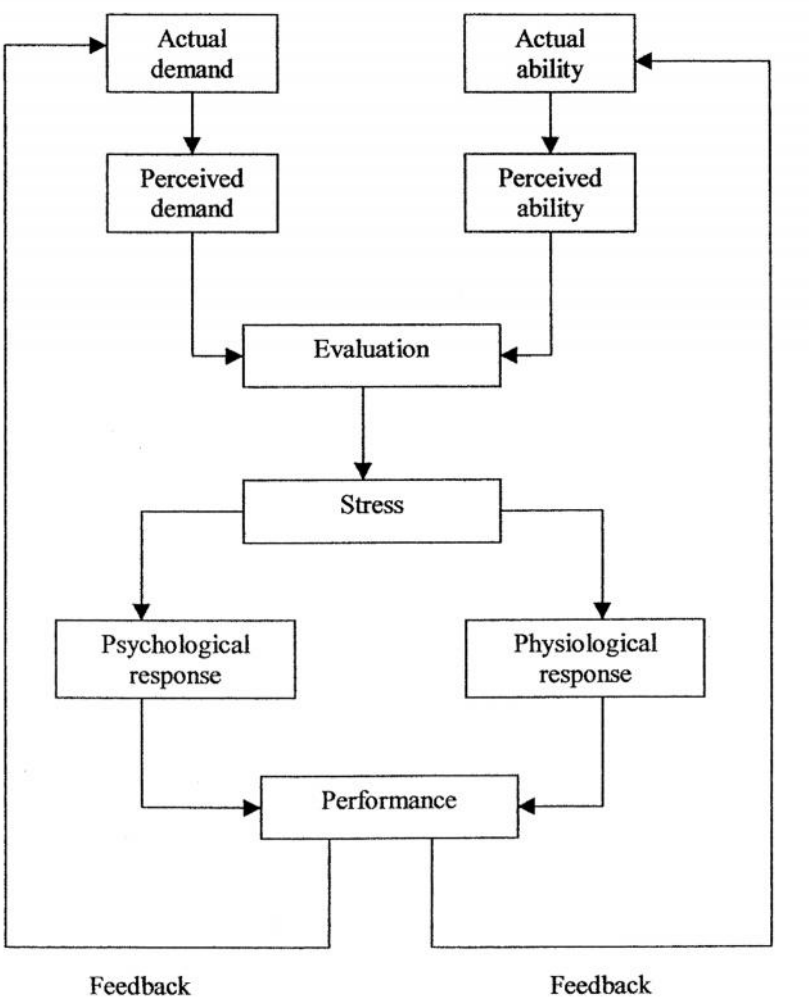


Figure IV.2: Model of stress.

An individual can be likened in some ways to a bucket in that he or she has only a certain capacity. Once that capacity is exceeded, the bucket will overflow and will hold no more. Just as buckets come in different shapes and sizes, so different individuals have different capacities and abilities to cope.

Stress on a human being can be defined as:

- the body's non-specific response to demands placed upon it, whether these demands are pleasant or unpleasant
- an unresolved pressure, strain or force acting upon the individual's mental or physical systems which, if continued, will cause damage to those systems.

Thus, continued stress can create physical symptoms such as insomnia, loss of appetite, headache, irritability, etc. The stimulus for stress is known as a stressor which is the force producing a change in the self-regulating balance between the individual's internal and external environment.

This stimulus will demand a response which may be psychological or physiological. Thus, we see that the stressor is the stimulus and the stress is the response to it.

Stress is an inescapable part of human life. It is impossible to live without experiencing some degree of stress, whether at home, during our work role or at leisure. Further, an optimum amount of stress is necessary for an individual to function efficiently and perform a given task such as flying an aeroplane.

Selye described two forms of stress. The first is 'eustress', which is associated with a feeling of increased energy and ability to deal with the stressor. It can be considered to be 'good stress' which stimulates and adapts the body. The second is 'distress', when the individual feels that events are out of control and there is an inability to cope. This is 'bad stress'.

Stress can be acute or chronic:

- acute stress is something sudden and unexpected such as an engine fire or losing one's wallet;
- chronic stress is something that continues for a long period of time such as financial difficulties or inter-personal relationship problems.

The response to acute stress takes three stages, known as Selye's general adaptation syndrome (GAS).

(1) Alarm reaction (psychological)
In the alarm stage the body recognises the stressor and prepares for fight or flight by the release of hormones (adrenaline and corticosteroids). These hormones increase the heart beat and the rate of breathing, raise the blood sugar level, increase perspiration, and slow digestion. Depending on the degree of danger recognised, the alarm reaction may result in a burst of energy, greater muscular strength, heightened hearing and vision. This is the 'fight or flight' response produced by the sympathetic system of the autonomic nervous system (ANS).

(2) Resistance (psychosomatic)
In the resistance stage the body attempts to repair any damage caused by the stress, enabling it to adapt to sustained or chronic stressors such as extreme cold, hard physical labour or personal worries. If the stress continues over a long period, the body will attempt to maintain its arousal state of readiness by activating the parasympathetic system of the autonomic nervous system. This prolongs mobilisation, giving time to find a solution and restore the body when the perceived threat has passed.

(3) Exhaustion (somatic)
Exhaustion is short-lived and affects those parts of the body which have been involved in the resistance stage. If the combination of resistance and exhaustion continues without relief over a long period, physical symptoms may develop such as raised blood pressure, headaches or indigestion.

IV.2.1 Stressors

The total stress which can be imposed on the individual can be considered as from four sources.

(1) Environmental (physical)
These stressors are related to normal events which may occur during flying operations.
They may occur singly or collectively, and can be created by noise, vibration, heat, lack of oxygen, presence of carbon monoxide, the onset of fatigue, etc. Others are directly related to the tasks involved in flying, and the degree of stress will vary from flight to flight, and for different stages of the flight.

The potential main environmental sources of stress on the flight deck are:

- Temperature 20°C -comfortable temperature for most people in normal clothing >30°C - increased heart rate, blood pressure and sweating
  <15°C -discomfort,loss of feeling in hands, poor control of fine muscle movement

- Vibration Different parts of the body show a natural resonance at different periods of vibration. For example, the natural resonance of the eyeball is 30-40 Hz, and the skull is 1-4 Hz. Effects of vibration include:
  1-4 Hz -interference with breathing, neck pain
  4-10 Hz -chest and abdominal pain
  8-12 Hz -backache
  10-20 Hz -headache, eyestrain, throat pain, speech difficulty, muscle tension
  30-40 Hz -interference with vision

- Noise > 80 dB -task performance may be impaired
  > 90 dB -measurable impairment of task performance However, it has been shown that in some situations performance of vigilance tasks can actually be better in high noise levels than in low levels. This is because noise increases arousal and can move the individual into the optimum performance area of the Yerkes Dodson inverted U curve.

- Humidity 40-60% -normal
  < 20% -minor discomfort, such as skin, eye, nose, throat dryness

- Glare UV radiation from sunlight can cause visual fatigue.

(2) Life (psychological)
These stressors include causes such as emotional, domestic, social and financial.
These are associated with events in everyday life. They are wide ranging and may include such factors as domestic and financial pressures which most of us face on a recurring basis. Family arguments, death of a close relative, inability to pay bills, lifestyle and personal activities, smoking or drinking to excess and other factors which may affect physical and mental health, all contribute to life stress which is part of everyday living. These can add significantly to the operational stressors which are part of flying activities.

Stress can also arise from physiological factors such as hunger, thirst, pain, lack of sleep and fatigue.

There have been many attempts to quantify the stress effect of life or domestic events. Once such scheme scores stress by totalling points, as follows:

Death of a spouse or partner	100
Divorce	73
Marital separation	65
Death of a close family member	63
Personal injury or illness	53
Loss of job	47
Retirement	45
Pregnancy	40
Sexual problems	40
Son or daughter leaving home	29
Change of residence	20
Bank loan or credit card debt	17
Vacation	13
Minor law violation	11

The cumulative points score gives an indication of life stress:

< 60 - Free of life stress
60-80 - Normal life stress
80-100 - High life stress
> 100 - Under serious life stress

(3) Reactive
These are the body's physical or mental response to situations which arise in everyday life, as well as those which arise when operating an aircraft. They stem from the body's reaction to a specific event. Examples in aviation are encountering wind shear on finals or running short of fuel.

(4) Organisational
Stress can arise from within the company or organisation for which an individual works. Certain organisational conditions have been identified as potential stressors. These include:

- poor communication
- role conflict or ambiguity
- workload and autonomy
- relationships with others
- lack of career development
- pay inequality
- bureaucratic processes.

Organisational stress in the aviation industry can affect flight safety. It can be avoided when the company is proactive in giving attention to the listed factors and provides support for employees.
A major stressor for pilots in modern aviation is insufficient hands-on flying.

IV.2.2 Stress Overload

Stress factors or stressors are cumulative and additive. Each individual has a personal stress limit and if this is exceeded, stress overload occurs which can result in an inability to handle even moderate workload. This personal stress limit varies with different people, as it is affected by an individual's physiological and psychological characteristics. For example, some individuals have the ability to switch off and relax, thus reducing the effects of stressors. Others are not so well equipped and the stress level increases to an unacceptable degree. When it happens to individuals working in a safety related environment, such as pilots, air traffic controllers or aircraft engineers, it can have serious effects in terms of flight safety.

It is common for an individual to believe that admitting to suffering from pressure is an admission of failure of ability to meet the demands of the job. It has long been an accepted culture in aviation that flight crew and others should be able to cope with any pressure or any situation, and training is directed at developing this capability in the individual -the 'can do' attitude.

Too often an individual, or his or her managers, will fail to recognise or to accept the emerging existence of stress-related symptoms. Denial is common, in a misguided attempt to maintain self-esteem. Once the symptoms are apparent, behavioural changes such as aggression or alcohol dependence may have become established. Such behaviour may lead to disciplinary action, which could have been avoided by early recognition of the developing situation and appropriate intervention and support.

IV.2.3 Anxiety And Its Relationship To Stress

Anxiety creates worry, and in turn any form of worry may lead to stress. Imaginary stress is sometimes referred to as anxiety. Anxiety may be produced by an individual knowing that he or she has no control over specific effects, or that he or she lacks the knowledge to handle such events. It is particularly prevalent in people who, for one reason or another, are lacking in self-confidence. It can be changed by increasing knowledge and gaining greater proficiency in operating an aircraft, which requires more time devoted to study and flight training.

Attitudes and general mental state have a direct influence on an individual's well-being. Psychological and emotional factors such as fear, anger, frustration, worry and anxiety may, over a long period of time, begin to affect the physical aspects of an individual's state of well-being.

Stress and anxiety are an inevitable part of human life and in small amounts they are necessary to achieve optimum performance. It is nature's way of keeping an individual keyed up for a task, by helping concentration and making recognition of danger easier. On the other hand excessive stress levels lead to excessive anxiety and it is important that individuals are able to recognise this.

IV.2.4 Effects Of Stress

Individuals respond in different ways to high stress loads. Apart from the effects on behaviour, such as aggression, irritability, dogmatism and frustration, various psychological mechanisms may come into play in an attempt to cope with the situation. They include the following:

- *Omission* -completely omitting a particular action, such as forgetting to lower the landing gear during an approach with high workload and additional distractions.
- *Error* -incorrect response to a given stimulus, such as switching off the anti-collision beacon instead of the electric fuel pump.
- *Queuing* -sequentially delaying necessary actions in an inappropriate order of attention priority, such as failing to action a checklist while dealing with complicated air traffic control instructions.
- *Filtering* -rejection of certain tasks because of overload, such as not identifying the navigation aids when setting up for an instrument approach.
- *Approximation* -making approximations in technique in an attempt to cope with all the tasks required in a short term interval, such as accepting inaccuracies while flying an ILS approach.
- *Coning of attention* -with increasing stress, the attention scan closes in to a smaller field of awareness. This can lead to inability to integrate the available information, and may be seen in the breakdown of the instrument scan during high workload activity in instrument flying conditions.
- *Regression* -under stress, behaviour may regress to the earliest learnt, such as operating a control or selector in a manner which would have been appropriate to the previous type of aircraft flown but not the current one.
- *Escape* -the ultimate response to extreme levels of stress is to give up or freeze.

In addition to the psychological effects of stress, physical effects may occur which vary from one individual to another. Stress is often perceived by the brain as some form of threat, and indeed, if you are being chased by a sabre toothed tiger who fancies you for dinner, it is a reasonable assumption on the part of the brain.

The 'fight or flight' response has already been mentioned in which the primitive automatic responses for handling threatening situations come into play. Adrenaline is released, causing a rise in blood pressure, an increase in heart rate, deeper and more rapid breathing and an increase in tone of the larger muscle groups. Hormones known as corticosteroids are also released, making available stored sugars for increased energy use. The body is now ready for fight or flight (escape). Unfortunately, this is often an inappropriate response and, because the situation has to be handled by mental rather than physical effort, the excess adrenaline can result in muscle tremor, incoordination, excessive sweating, and, in extreme cases, mental confusion and dizziness.
The effects of continuing stress or overload have already been mentioned. Performance can therefore be severely compromised in many ways by high levels of stress. It is important to realise that stress is cumulative and the effects of stress from one situation can be transferred to a different situation.
The break point occurs when, if the stress continues, performance is degraded.

IV.2.5 Stress Management

As we have seen, a certain amount of stress is unavoidable and indeed in certain conditions, it may be beneficial in raising arousal and hence improving performance. However, stress overload can reduce performance and it is helpful to consider ways of dealing with stress and reducing its effects.
The first step in reducing stress is to recognise when one is approaching the normal stress limit; inevitably this is a personal evaluation based on an understanding of one's own personality and

capacity.

In determining fitness to fly, the psychological and emotional part of well-being must be considered in addition to the physical. Flying training engenders self-confidence and a strong desire to complete the task in hand. It can be difficult therefore to recognise and admit that one may indeed be approaching the limit.

The maintenance of physical well-being can assist in developing resistance to stress.

Actions to deal with stress include the following:

- Recognise the factors which are combining to cause the stress. Assess your own situation to see which of these factors is present.
- Deal with those factors which can be removed. Some can be handled just by recognising them for what they are and mentally putting them aside.
- If stress is being produced by overload, pause to organise a list of priorities. Do not allow low priority problems to influence you when you are not intending to deal with them. In flight, follow standard operating procedures and use checklists with which you are familiar.
- Manage your time. It helps to develop a cycle of activity, apportioning time to each item.
- When appropriate delegate duties and learn to offload.
- Involve other people in your problems. Communicating and avoiding isolation is an effective way of lowering the level of stressors.
- In situations of acute stress, learn to recognise what is occurring. Learn to 'let go' and to mentally and physically relax. It may help to consciously relax your muscles whenever you feel tense or stressed.
- If the situation allows, take a short break for refreshment or relaxation. In flight, hand over control to another crew member when this is possible.
- Physical fitness seems to make some people more stress resistant. Eating regular balanced meals and indulging in physical activity several times a week promotes general health.
- Be positive and tackle responsibilities and problems as they occur. Avoid the tendency to put things off in the hope they will go away.
- Development of an appropriate sense of humour can be an excellent way of avoiding emotional stress.
- Recognise your own limitations and avoid overcommitment.

Finally, remember that clear thinking, free from emotional or physical worries is essential for flight planning and the safe conduct of a flight. Accidents and incidents in flight often occur because the requirements of the task exceed the pilot's capabilities, and this is more likely to occur when the effects of life stresses reduce the capacity to cope.

IV.2.6 Coping Strategies

Coping is the process in which the individual either adjusts to the perceived demands of a situation or changes the situation itself.

Some of the strategies appear to be carried out subconsciously, and it is only when they are unsuccessful that the stressor is noticed. Individuals vary in their ability to cope.
Three coping strategies can be defined as follows.

IV.2.6.a Action Coping

In this strategy the individual takes some action to reduce the stress either by removing the problem or altering the situation so that it becomes less demanding. The extreme is when the individual

removes himself from the situation, for example by changing jobs or getting divorced.

IV.2.6.b Cognitive Coping

This coping strategy is used when the situation cannot be changed. It involves reducing the emotional and physiological impact of the stress. This may be done by rationalisation or emotional and intellectual detachment from the situation. The effect is to change the perception of the problem even if the demand itself is no different.

IV.2.6.c System Directing Coping

This is a means of removing the symptoms of the stress by taking physical exercise, using drugs such as tobacco and alcohol or utilising other stress management techniques.
Stress management is the process by which an individual will adopt systems to assist the coping strategies. Stress management techniques include:

- *Health and fitness programmes*. Regular physical exercise assists some people with cognitive coping.
- *Relaxation techniques*. There are many forms of relaxation frequently involving progressive muscle relaxation and the use of mental imagery. Examples include meditation, self-hypnosis, biofeedback techniques and autogenic. Some or all of these can be helpful in enabling individuals to reduce anxiety and control tension.
- *Religious practices*. Many people find that some form of regular religious practice and its associated faith helps the ability to cope with stresses particularly major life events.
- *Counselling techniques*. Counselling can assist both cognitive and action coping by modifying the way a situation is perceived leading to appropriate behavioural change. It may involve anything from regular sessions with a professional counsellor to simply talking about a stress problem with a supportive friend or colleague.

IV.3 Sleep and Fatigue

Sleep is essential for restoring the normal balance between the different parts of the central nervous system.

In terms of a computer microprocessor, it may be thought of as being analogous to transferring the experiences from the preceding period of wakefulness, stored on a floppy disk, to the central neural store which can be likened to the computer hard disk. This frees up the floppy disk for use during the next period of wakefulness.

Also, during sleep, the body's physical functions are rested and some renewal takes place. During sleep, sympathetic nervous activity decreases and the muscular tone becomes almost nil. The arterial blood pressure falls, the pulse rate decreases, the blood vessels in the skin dilate and the overall basal metabolic rate of the body falls by up to 20%.

On average, most humans physiologically need about 8 hours of sleep per night. However, in modern society most adults report an average of 7 to 7.5 hours sleep per night. Studies have shown that up to 75% of adults report daytime sleepiness, with nearly a third of them reporting severe levels which interfered with activities.

Sleep loss can be acute or cumulative. In an acute situation, sleep loss can occur either totally or as a partial loss. It can accumulate over time into what is referred to as 'sleep debt'. As little as two hours of sleep loss can result in impairment of performance and levels of alertness. Sleep loss leads

to increased reaction time, reduced vigilance, cognitive slowing, memory problems, time on task decrements and optimum response decrements. It has also been shown that performance variability increases with sleep loss.

The normal sleep requirement is 8 hours in every 24hour period, and it is possible to perform a simple calculation of sleep debt when this requirement is not achieved. As the sleep requirement is 8 hours, within a 24 hour period this leaves 16 hours available for activity. Alternatively, this can be expressed as one sleep hour being good for two hours of wakeful activity. The maximum possible credit to offset against sleep debt is 8 sleep hours. It is not necessary to sleep for the exact number of hours in deficit to recover sleep debt. Most people find that a 'catch-up' sleep of one-third of the deficit is sufficient. Sleep debt can become cumulative, leading to decrement in alertness and performance if the deficit is not recovered within a reasonable time.

IV.3.1 Stages of Sleep

Sleep can be divided into five stages -stages 1 to 4 and rapid eye movement (REM) sleep (Figure IV.3).

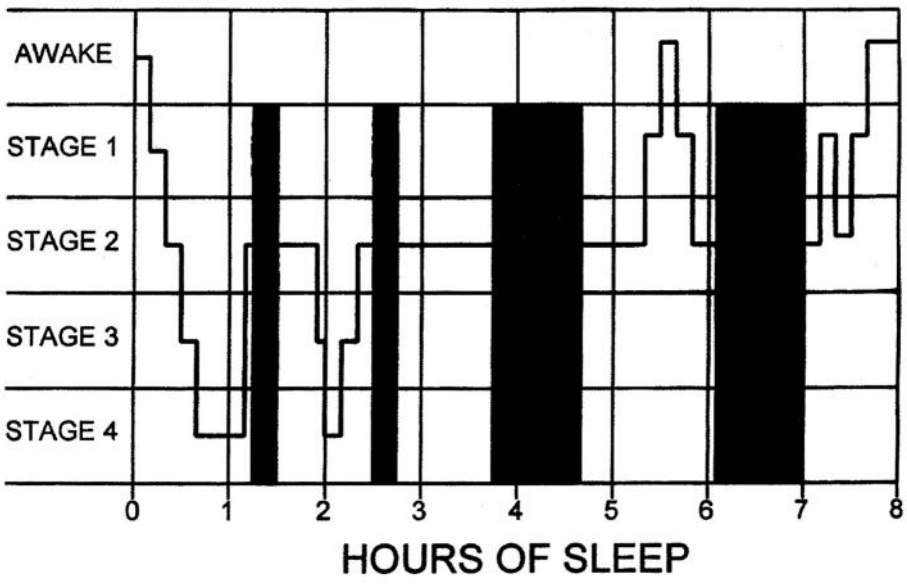


Figure IV.3: Pattern of sleep over 8 hours (shaded areas are REM sleep).

Stage 1 is a transitional phase between waking and sleeping and this normally takes around 10 minutes as a person falls asleep. Sleep then becomes deeper with 15 minutes in stage 2 sleep and a further 15 minutes in stage 3 sleep before moving on to stage 4. Approximately 90 minutes after sleep onset, REM sleep will occur. The cycle of REM sleep and stages 1 to 4 sleep repeats during the course of the night in 90-minute cycles, each succeeding cycle containing greater amounts of REM sleep. An 8-hour sleep period will typically contain about 4 or 5 bouts of REM sleep. Most stage 4 sleep happens early in the night.

The stages of sleep can be shown by examination of the eletroencephalogram (EEG), which measures electrical activity in the brain. The pattern changes for each stage, and stages 3 and 4 are referred to as 'slow wave' sleep from the shape of the EEG tracing.

During an 8 hour period of sleep, 50% is usually made up of stage2.
It is thought that the stages 1 to 4 sleep is related to body restoration whereas the REM sleep may be related to strengthening, refreshing and organising memory. When learning new tasks, an increased proportion of REM sleep is seen. REM sleep is sometimes referred to as 'paradoxic sleep'.

IV.3.2 Performance and Alertness

Besides sleep, the other major influence on waking performance and alertness is the internal circadian clock. Circadian rhythms fluctuate on a regular cycle which lasts something over 24 hours when allowed to 'free run'. The circadian rhythms are controlled by the suprachiasmatic nucleus of the hypothalamus situated in the brain, which is the timekeeper for a wide range of human functions, including physiological performance, behavioural mood and sleepiness/alertness. Many body functions have their own circadian rhythm and they are synchronised to a 24 hour pattern by 'zeitgebers' (time givers). Light has been demonstrated as being among the most powerful zeitgebers to synchronise the circadian pacemaker.

The mean normal body temperature is 37°C, but it has a natural cycle of less than 1° over the 24 hour period with a minimum at 06:00 hours, rising during the day to a maximum at 20:00 hours. In the normal rhythm, sleep would occur between 24:00 and 08:00 hours when body temperature is falling and reaching its low point. Therefore it is most difficult to work when body temperature is falling, and hardest to sleep when the body temperature is rising.

Moving to a new light/dark schedule (e.g. shift work or time zone changes) can create internal and external desynchronosis. This leads to a discrepancy between internal suprachiasmatic nucleus timing and external environmental cues. The internal clock can take days or weeks to readjust, but generally requires one day for each time zone crossed or one day for every 90 minutes of jet-lag.

Crossing time zones is a way of life for long-haul flight crew, and constant time zone shifts can lead to cumulative sleep deprivation due to disruption of the body cycles known as circadian desynchronosis. This is also known as 'situational insomnia'. However, sleep debt and fatigue can also be a problem for short-haul crew as a result of very early starts and long multi-sector days.

Long-haul crew have to constantly adjust and readjust circadian rhythms, and the various intrinsic rhythms for temperature, digestion and excretion get out of phase with the rhythm for sleep. This leads to jet lag or circadian dysrhythmia.

Resynchronisation on westbound flights is aided by the body's normal circadian rhythm being nearer 25 hours, thus assisting the day to be 'stretched', whereas eastbound flights are more difficult due to the day being 'compressed'. Resynchronisationis easier when local time on landing is behind that at the airport of departure, whereas it is difficult when local time is ahead.

Fatigue can be defined as the likelihood of falling asleep. Therefore, in practical terms, there is little difference between chronic fatigue and acute tiredness. Fatigue can be caused by sleep loss and circadian desynchronosis, but it can also result from low motivation and low levels of external stimulation. In aviation, fatigue becomes important when it reduces efficiency and impairs performance.

In commercial aviation, fatigue is controlled by the imposition of flight time limitations. These do not apply in non-commercial flying but it is important to recognise the effect that fatigue or sleepiness can have on an individual's performance and limit flying time accordingly.

Schemes for flight time limitations are complex and take account of work rest schedules and previous duty periods. In the UK, current legislation is based on the Civil Aviation Authority

publication CAP371 which was first issued in 1975. Other countries have similar schemes. Within Europe, the European Commission is developing a harmonised flight time limitations scheme which is planned to supersede national legislation.

Factors leading to the development of fatigue include early starts, night flying, a high number of sectors and long duty days for short haul flight crew. For long-haul flight crew there is the additional problem of long flight duration and regular crossing of time zones.

There are two principal components of sleepiness or fatigue:

- Physiological sleepiness or fatigue -this is a requirement like hunger or thirst and can only be reversed by sleep.
- Subjective sleepiness or fatigue -this is an individual's perception of his or her sleepiness but it may be affected by other factors. It may be difficult for an individual to subjectively assess his or her own alertness. In general, an individual overestimates the time taken to fall asleep and underestimates the total sleep time. Individuals tend to report a greater level of alertness than is actually the case.

Factors affecting sleepiness include:

- prior sleep and wakefulness
- circadian phase leading to :
  -increased sleepiness in the early hours of the morning and during the afternoon
  -decreased performance in the early hours of the morning
- age (the amount of nocturnal sleep required reduces after the age of 50)
- alcohol (reduces the quality of sleep)
- work and environmental conditions.

IV.3.3 Management of Fatigue

Fatigue can be either short-term acute physiological or long-term chronic fatigue. Short-term fatigue is akin to tiredness and is usually a result of lack of sleep, hard physical or mental exertion, long duty period or jetlag. Chronic fatigue is much more difficult to recognise and quantify. It may be a result of lack of physical or mental fitness, domestic or work stress, financial problems and/or a high workload. It is subjective, with one individual being able to tolerate a greater level of stress than another before the onset of fatigue.

Fatigue gives rise to impaired performance and reduced levels of awareness.

IV.3.3.a Symptoms of Fatigue

- tiredness
- slow reactions
- diminished motor skills
- diminished visual acuity
- reduced short term memory capacity
- channelled or tunnelled concentration

IV.3.3.b Effects of Fatigue

- reduced awareness
- easy distraction
- poor instrument flying
- increased slips and mistakes
- abnormal mood swings.

Individuals have different needs and react differently to sleep loss. Therefore, each individual must apply recommendations to suit his or her own particular circumstances.

IV.3.4 Preventative Measures

IV.3.4.a Coping Strategies for Jet lag

-*Stop-over less than 24 hours* -maintain eating and sleeping cycle on home time.
-*Stop-over of 24 hours* -a difficult time interval to cope with. It does not allow time for two good 8 hour sleep periods, but is too long to cover with a single sleep session. The coping strategy may involve taking a limited rest period on arrival, and then a later longer period of sleep before call for duty.
-*Stop-over greater than 24 hours* -it is important to gain sufficient sleep credit to complete the planned schedule, with an allowance for possible delays.

IV.3.4.b Sleep Scheduling

- at home the best possible sleep should be obtained before a trip
- on a trip, as much sleep per 24 hours should be obtained as would be at home
- feelings should be trusted -if the individual feels sleepy and circumstances permit, then he or she should sleep. However, if the individual wakes spontaneously and cannot get to back to sleep in about 15-30 minutes, then he or she should get up out of bed.

IV.3.4.c Good Sleep habits

- a regular pre-sleep routine should be developed
- sleep time should be kept protected
- the individual should avoid going to bed hungry, but should not eat or drink heavily before going to bed
- alcohol or caffeine should be avoided before bedtime.

If necessary physical and mental relaxation techniques can be tried to aid falling asleep. If unable to go to sleep within 30 minutes, the individual should get up. An optimum dark, quiet and comfortable sleep environment is important. A healthy lifestyle with regular exercise should be maintained, which seems to help with the first stages of sleep.

Decreased wakefulness leads to a state of hypovigilance, which helps to control energy consumption by reducing activity of the central nervous system. Its total prevention in flight is not possible. Strategies for delaying the onset of hypovigilance during flight include:

- maintain sleep credit -always plan sleep patterns whenever possible
- be aware of the symptoms -drowsiness, slower sensory perception, preoccupation with an out of context problem, moodiness, reluctance to communicate

- alternate periods of activity and relaxation
- engage in social conversation
- engage in physical activity such as arm and leg stretching
- in a multi-crew operation, it is possible for crew members to take planned naps during the flight -these should not exceed 30-45 minutes, and recovery from a nap takes a period of 5 minutes.

Strategies for delaying or preventing the onset of fatigue include:

- keep fit
- eat regular balanced meals
- avoid regular use of alcohol
- ensure control of emotional and psychological aspects of life
- ensure adequate preparation for flight, including flight planning and flight deck comfort.

Caffeine consumption may be used to increase alertness. A cup of coffee usually takes about 15 to 30 minutes to become effective, and the effect lasts for between 3 and 4 hours. A balanced diet including drinking plenty of fluids can also help to prevent the onset of fatigue.

Bright light (more than 2,500 lux), used at the appropriate time in the circadian cycle, can help to reset the circadian clock.

After flying east, the traveller should be exposed to evening light with respect to body time, but morning light avoided. Conversely, when travelling west, morning light should be sought and evening light avoided. This makes the best use of the natural zeitgebers in resetting the body clock.

When used appropriately, certain drugs can help in the short term to resynchronise the sleep cycle after time zone crossing.

Temazepam is a short acting benzodiazepine which is rapidly cleared from the body. Many people find this drug helpful in promoting sleep and, used for two or three days after travel, it can assist in resetting the sleep cycle. However, it should only be used under medical supervision and should never be taken within eight hours before flying as a member of crew.

Melatonin is a substance secreted by the pineal gland with a rhythm which is linked to the light/dark cycle through the suprachiasmatic nucleus. It is available in tablet form and has been used by many people to assist sleep. However, despite being a natural substance, the long term side effects are not fully understood, particularly those affecting reproductive function and heart activity. It therefore does not have a pharmaceutical licence for general use.

Although alcohol is widely used by aircrew as an aid to sleep, it is a nonselective nervous system depressant and is effectively a drug. Although it may induce sleep, REM sleep is considerably reduced and early waking is likely. It is therefore not appropriate to use alcohol in this manner. It is also important to remember the aftereffects on the vestibular system of even small amounts of alcohol.

Finally, it should be remembered that there is no simple or single solution for combating the effects of sleep loss and jet lag. The individual has to discover what helps him or her, and evolve the strategies to suit his or her particular needs.

CHAPTER V:
Maintenance Human Factors / Case Studies

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Introduction

On April 28, 1988, at 13:46, a Boeing 737 – 200 … operated by Aloha Airlines … experienced an explosive decompression and structural failure at 24,000 feet … Approximately 18 feet from the cabin skin and structure aft of the cabin entrance door and above the passenger floor line separated from the airplane during flight.…The National Transportation Safety Board determines that the probable cause of this accident was the failure of the Aloha Airlines maintenance program to detect the presence of significant disbonding and fatigue damage which ultimately led to failure of the lap joint and the separation of the fuselage upper lobe.

The structural failure and separation of a large piece of cabin structure was a shocking event to the public and industry alike, and the Federal Aviation Administration (FAA) immediately established the Aging Aircraft Program of research to look more closely at fatigue damage. However, the probable cause raised by the National Transportation Safety Board (NTSB) took issue with the operator's maintenance and inspection processes including the training and qualifications of mechanics and inspectors. In the words of the then FAA Associate Administrator for Regulation and Certification,

> *… the airplane was inspected and an airworthiness action performed just a few months before it had the tragic inflight episode. Then, just recently we found another airplane, with another airline, which had about 50,000 to 55,000 cycles and had developed a major crack and a number of smaller ones. This airplane also had been inspected earlier, with its cracks discovered only as it was going in for repainting. So here we have two airplanes … for which somehow the system did not work. We have professionals involved in engineering and professionals involved in maintenance and yet cracks developed undetected.… We must develop an improved approach to the inspection process and, more important, it must be an organized approach. We need to take a technological approach, break the process into its components, and then examine each component to see if we can build a body of knowledge that will apply.*

The Aloha accident led to some major realizations. Accident causes distinguished "aircraft" from "maintenance and inspection" factors, but compared to the knowledge about the reliability of aircraft systems, knowledge about the human reliability of maintenance and inspection processes was limited. We were learning the hard way that maintenance and inspection failures could result in injuries, fatalities and aircraft damage not only on the ground, but in flight; yet we did not fully understand the human factors that could lead to such failures. This was a wakeup call to fully acknowledge the critical role that maintenance and inspection played in ensuring flight safety. It was obvious that poorly performed maintenance and inspection could result in rework, aircraft damage, and injury to maintainers. But the chain of events leading to inflight accidents and incidents was not clear. In many cases, inspection and maintenance errors resulted in latent conditions that did not cause immediate damage; failure might not occur for days, weeks, or ever. The complicated relationship between the latent nature of maintenance errors and adverse outcomes required systematic investigation and the establishment of principles and data that could direct the development of effective corrective and preventive strategies for managing maintenance risks.

PART 1: BUILDING THE FOUNDATION OF MAINTENANCE HUMAN FACTORS, 1988 – 1999

Following the landmark Aloha accident, the FAA called a meeting of aviation industry representatives to discuss problems associated with aging aircraft. Much of this meeting addressed issues of hardware, metal fatigue, and corrosion, but an additional discussion of human factors in maintenance reflected the growing interest in the contribution of human factors to aviation safety. Thus, in October, 1988, the FAA called an industry meeting that marked the beginning of a systematic review of Human Factors in Aircraft Maintenance and Inspection. From 1988 to 1999, the FAA sponsored 13 annual industry meetings that covered a wide range of human factors topics (see Table V.1).

In addition to these meetings, the FAA began a program of research to investigate issues and recommendations generated by the community at large. The community was diverse including regulators, operators, union organizations, manufacturers, accident investigators, and researchers from both civil and military institutions. Soon, participants were coming from countries outside the United States eventually leading to a joint working agreement among the FAA, CAA-UK, and Transport Canada for the annual meetings. This expanded community greatly contributed to the research and regulatory progress as well.

The timeline in Table V.1 shows key events (e.g., accidents, incidents, and government actions) in the left-hand column that serves as a context for the items in the right-hand column (e.g., industry meetings, research and guidance documents). To illustrate, the Aloha accident and FAA initiation of Industry meetings and research program (in the left-hand column), resulted in the series of meetings that identified Human Factors issues in Maintenance and Inspection (listed in the right-hand column). In many cases, accident findings led to a specific emphasis such as a focus on training or the consideration of organizational factors and safety culture. The same community of researchers, regulators, and operators worked together to conduct the relevant research to develop and implement human factors solutions.

By the mid-1990s, a strong interest in collecting and analysing incident data prompted the development of event databases. With the use of investigation and error analysis tools, human factors issues could be prioritized on the basis of trends in actual data. By the end of the 1990s, the FAA had reviewed many topics, developed many interventions, and renewed its plan to continue the research program and industry meetings. As the program and knowledge matured, NASA, motivated by its own maintenance issues, began extending the human factors principles, research and training to space operations (shuttle processing). It was also at this time that the industry began to capture its knowledge and lessons learned in guidance materials.

Accidents/Incidents (*) and Government Actions	Year	Industry Meetings, Research and Guidance Documents
*Aloha Airlines Flight 243 4/1/1988	1988	
FAA/Industry Meetings begin 10/1988		1 FAA/Industry Meeting: *Human Factors Issues in Aviation Maintenance and Inspection*
*United Airlines Flight 232 7/19/1989	1989	2 FAA/Industry Meeting: *Information Exchange and Communication*
	1990	3 FAA/Industry Meeting: *Training Issues*
		4 FAA/Industry Meeting: *The Aviation Maintenance Technician*
*Continental Express Flight 2574 9/11/1991	1991	5 FAA/Industry Meeting: *The Work Environment in Aviation Maintenance*
	1992	6 FAA/Industry Meeting: *Maintenance 2000*
		7 FAA/Industry Meeting: *Science, Technology and Management*
	1993	8 FAA/Industry Meeting: *Trends and Advances in Aviation Maintenance Operations*
	1994	9 FAA/Industry Meeting: *Human Factors Guide for Aviation Maintenance*
	1995	
*ValuJet Airlines Flight 592 5/11/1996	1996	10 FAA/Industry Meeting: *Maintenance Performance Enhancement and Technician Resource Management*
		Boeing's Maintenance Error Decision Aid (MEDA)
		NASA Aviation Safety Reporting System (ASRS) introduces Maintenance Form
White House Commission on Aviation Safety 2/12/1997	1997	11 FAA/Industry Meeting: *Human Error in Maintenance*
FAA Strategic Program Plan: Research 1988-1997		NASA Kennedy Space Center Human Factors Workshop I: *Human Error Analysis* Workshop II: *Human Factors Training*
	1998	US Navy's Human Factors Accident Classification System-Maintenance Extension (HFACS-ME)
		NASA Kennedy Space Center Human Factors Workshop III: *Procedures and Work Instructions*
		12 FAA/CAA/Transport Canada Industry Meeting: *Human Factors in Maintenance* (expanded sponsorship)
*NASA Shuttle STS-93 In Flight Anomaly 7/23/1999	1999	13 FAA/CAA/Transport Canada Industry Meeting: *Providing Hands-on Experience in Human Factors Topics*
		ATA Specification 113

Table V.1 Maintenance Human Factors Timeline: 1988–1999

V.1 Identifying Human Factors in the Maintenance and Inspection Work Domain

The series of FAA industry meetings beginning in 1988, revealed many perspectives and generated many useful recommendations. While some of the changes were directed at the industry and regulator level (e.g., better communication of information and development of an industry-wide database), an equally important objective was to build knowledge at the ground level. Where exactly were maintenance and inspection tasks failing? What factors contributed to maintenance and inspection errors or noncompliance? Researchers of "pilot error" were trying to get away from a "blame the pilot" mentality by investigating root causes of errors. Similarly, the maintenance community began systematically considering the numerous factors that could potentially affect maintenance and inspection performance. The first five FAA/ industry meetings met this challenge by having experts in the field talk about the physical work environment, ergonomic factors, documents, procedures and training, in addition to individual factors such as fatigue, worker qualifications and skills.

Scarcely had the program gotten started when on July 18, 1989, the United Flight 232 crash landing at Sioux City, Iowa, captured the spotlight. At flight level 370, there was a catastrophic failure of the #2 tail-mounted engine, which led to loss of the three hydraulic systems that powered the flight controls. The flight crew experienced severe difficulties controlling the aircraft, which subsequently crashed during an emergency landing at Sioux City Gateway Airport.

> *The National Transportation Safety Board determines the probable cause of this accident was the inadequate consideration given to human factors limitations in the inspection and quality control procedures used by United Airlines engine overhaul facility which resulted in the failure to detect a fatigue crack originating from a previously undetected metallurgical defect located in a critical area of the stage 1 fan disk that was manufactured by General Electric Aircraft Engines.*

The probable cause traced back to human factors limitations in inspection and quality control procedures, but the accident became famous for the skilled teamwork of the flight crew in executing the emergency landing and the extraordinary preparedness of ground personnel in helping survivors. As a classic example of Crew Resource Management (CRM), the captain and crew made effective use of all resources to make the best landing possible. Although there were 111 fatalities, 175 passengers and 10 crew members survived.

Many lessons about flight crew CRM and survivability were learned from the Sioux City accident, but for the maintenance community, it was a painful reminder that human factors associated with inspection processes, could significantly downgrade inspector performance. Again, the Safety Board raised the issue of human factors and inspector reliability, just as it had with the Aloha accident the year before. Acknowledging that the FAA had begun its series of industry meetings, the urgency of conducting these activities was reinforced. In addition, the Safety Board reiterated the need for an FAA research program that would not only build a solid understanding of human factors but could focus on emerging technologies (e.g., Non-Destructive Inspection tools) that could simplify, automate, or enhance the inspection process.

V.1.1 Focus on Training

The Aloha and Sioux City investigations led the NTSB to issue two training recommendations to the FAA, namely:

> *A-89 – 56: Require formal certification and recurrent training of aviation maintenance inspectors performing non-destructive inspection functions. Formal training should include apprenticeship and periodic skill demonstration.*
>
> *A-89 – 57: Require operators to provide specific training programs for maintenance and inspection personnel about the conditions under which visual inspections must be conducted.*

Require operators to periodically test personnel on their ability to detect the defined defects.

In addition to ensuring better technical training, the emphasis on human factors promoted the training of team skills similar, in theory, to CRM training that flight crews had come to accept. While flight crew CRM was a concept that had been developed at the end of the 1970s, it was implemented as classroom awareness training and integrated into line oriented flight training in high fidelity simulation by the end of the 1980s. But the work of maintainers and inspectors differed in significant ways from pilot‘s work including their organizational structure, certification process, documents and procedures. Thus, the maintenance community took great care to adapt team training to fit their own tasks, organizations, and workplace.

The maintenance industry responded to the need for systemic solutions by first focusing on developing awareness-level training programs. The flight crew was already immersed in a proactive error management program mostly focused on interpersonal communication and teamwork called Cockpit [later called Crew] Resource Management (CRM). The maintenance community adapted the relevant portions of this CRM program to meet the perceived needs of their aircraft maintenance professionals and called such programs Maintenance Resource Management (MRM).

Maintenance Resource Management (MRM) training had immediate appeal because it was largely directed toward “protecting” the maintenance technician and inspector from human error. For many training practitioners, MRM was synonymous with Human Factors in these early years. Topics within the MRM training curriculum often included what is known as the “Dirty Dozen “which was developed in Canada and popularized world-wide. These included: (1) Lack of Communication, (2) Complacency, (3) Lack of Knowledge, (4) Distraction, (5) Lack of Teamwork, (6) Fatigue, (7) Lack of Resources, (8) Pressure, (9) Lack of Assertiveness, (10) Stress, (11) Lack of Awareness, and (12) Norms.

At this early phase of MRM development and implementation, the topics were somewhat generic and quite similar to the topics discussed in CRM. However, MRM practitioners established credibility and relevance by interpreting these concepts within the context of maintenance and inspection operations. For example, pilot communication often focused on Captain and First Officer, occasionally extending to the cabin crew, passengers and Air Traffic Control. In maintenance, relevant roles in the workplace could involve mechanics, lead mechanics, company inspectors, FAA inspectors, supervisors, maintenance control, stores, and engineering. Often communications were needed to transfer information from one shift to the next. These could be face-to-face, or written on a task card or shift turnover form, thus accomplishing two functions, documenting and communicating. In short, maintenance tasks and work environments could present some unique human factors challenges as described here:

In the early days of flight, pilots endured noise, wind and extreme temperatures as an accepted part of aviation. Maintenance technicians must still contend with the elements in ways that few airline pilots are required to do. A maintenance worker may be required to perch high above the ground, perhaps in rain and darkness, communicating by hand signals through deafening noise. …Maintenance is different in other ways as well. An air traffic controller can unplug from the console at the end of the day, knowing that the day’s work is finished. When the flight crew leaves the aircraft at the end of a flight, the chances are that any mistakes they made affected that flight only (unless they damaged the aircraft). But when maintenance personnel head home at the end of their shift, they know that the work they performed will be relied on by crew and passengers for days, weeks or even years into the future.

In the U.S. Navy, MRM training was never a standalone program; rather it was integrated into a more comprehensive safety program, a forerunner of sorts of safety management systems that have been growing in use since the mid-2000s. Components of the integrated MRM training were: (1) discussion of safety data from their own organizations, (2) best practices benchmarking with emphasis on operational risk management, and (3) safety climate assessment using the Maintenance Climate Assessment Survey. This integrated approach showed that MRM training could be a highly effective mechanism for providing safety feedback to the workforce and developing preventive strategies for the future. It also could include built in metrics for monitoring attitudes, risk and safety improvements.

V.1.2 Maintenance Accident Investigation

In spite of the surge of industry interest in maintenance human factors, there was little data to indicate trends and high risk issues. The primary data source was accident data. For example, Boeing statistics that covered the period between 1959 and 1989, indicated that of the 109 accidents with known causes (excluding sabotage and military action), 69.7% were attributed to cockpit crew as primary cause. In contrast, maintenance and inspection during this timeframe was a very small 3.7%, which was even lower than airport/ATC at 4.6% and weather at 7.3% (Figure V.1).

Hull loss accidents -U.S. commercial jet fleet

Primary factor	Number of accidents 1959--1989	1990--1999
Cockpit crew	76	13
Airplane	11	3
Maintenance & Inspection	4	2
Weather	8	1
Airport/ATC	5	1
Miscellaneous/other	5	4
Total with known causes	109	24
Unknown or awaiting reports	3	8
Total	112	32

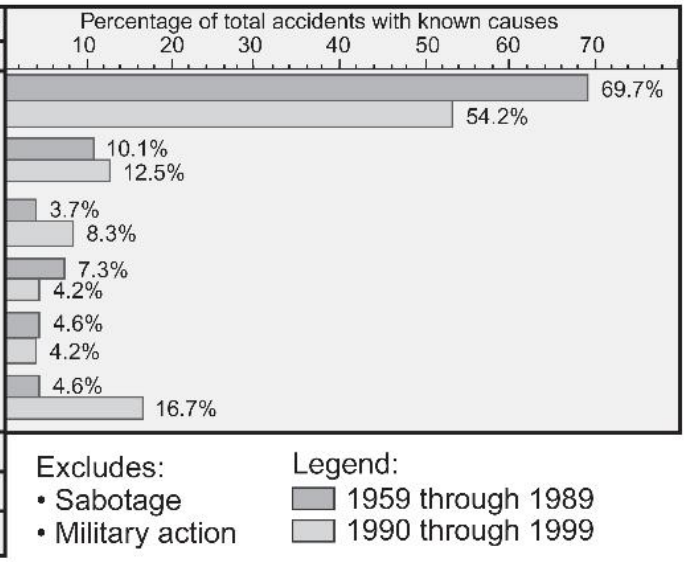


Figure V.1 Primary factors causing hull loss accidents in the U.S. commercial jet fleet (Boeing, 2003).

While these were relatively small percentages, accident analyses pointed to the possibility of severe consequences tied to maintenance and inspection. Within only two more years, September 11, 1991, another accident involving maintenance occurred Continental Express Flight 2574. As it would turn out, this accident became a classic for two reasons. First, it highlighted the difference between "procedures as written" and "procedures as performed" that many factors (such as communication across shifts, or the clear delineation of technician versus inspector roles and responsibilities), introduced variability and complications in the way procedures were followed. Second, it introduced the concept of organizational culture; those individual actions were performed in the context of organizational norms and practices.

V.1.3 Organizational Factors and Safety Culture

On the day of the accident, Continental Express Flight 2574, an Embraer 120, experienced a sudden inflight loss of a partially secured left horizontal stabilizer leading edge, leading to immediate severe nose-down pitchover, breakup of the airplane, and subsequent crash near Eagle Lake, Texas.

> *…probable cause of this accident was determined to be the failure of Continental Express maintenance and inspection personnel to adhere to proper maintenance and quality assurance procedures for the airplane's horizontal stabilizer deice boots that led to the sudden in-flight loss of the partially secured left horizontal stabilizer leading edge and the immediate severe nose-down pitchover and breakup of the airplane. Contributing to the cause of the accident was the failure of Continental Express management to ensure compliance with the approved maintenance procedures, and the failure of FAA surveillance to detect and verify compliance with approved procedures.*

Thus, probable cause was attributed to maintenance and inspection personnel; contributing factors involved management and regulators. The relevant company procedures, namely, the procedures for shift turnovers (including the documentation of incomplete work on work cards), were not found to be inadequate. Rather, the company was faulted for not considering the removal and replacement of the horizontal stabilizer leading-edge deice boot as a Required Inspection Item.

Of particular note, one NTSB member provided a dissenting opinion that stated probable cause should be: (1) the failure of the company to establish a corporate culture, which encouraged and enforced adherence to maintenance and quality assurance procedures, and (2) the consequent string of failures of the personnel to adhere to the approved procedures for replacement of the horizontal stabilizer deice boots. This opinion was an indicator of the growing appreciation for what was to be called the "safety culture**"** of an organization. This concept was often explained according to James Reason's "Swiss Cheese" model which illustrated how failed organizational barriers fit into an event occurrence with adverse consequences. The aviation maintenance community found Reason's model compelling because it depicted safety as a system and interpreted individual actions (e.g., maintainers and inspectors) in the context of local workplace conditions and within an organization that reflected management decisions, organizational processes, corporate culture, and so on. The complex network of organizational roles and responsibilities, regulations, and procedures was typical in maintenance and inspection processes in comparison with the seeming autonomy of pilots' actions. Furthermore, the ambiguity of roles and oversight responsibilities pertaining to the use of contract maintenance would become an issue as outsourcing became more prevalent. But even during those less complicated times, another accident pointed to organizational and oversight failures that contributed to a catastrophic outcome.

On May 11, 1996, ValuJet Flight 592 (DC-9 – 32) crashed into the Everglades about 10 minutes after takeoff from Miami International Airport. This outcome resulted from a fire in the airplane's class D cargo compartment that was initiated by the actuation of improperly carried oxygen generators. Probable causes were attributed to three failures: (1) the failure of SabreTech to properly prepare, package, and identify unexpended chemical oxygen generators; (2) the failure of ValuJet to properly oversee its contract maintenance program to ensure compliance with maintenance, maintenance training, and hazardous materials requirements and practices; and (3) the failure of the FAA to require smoke detection and fire suppression systems in class D cargo compartments.

> *Contributing to the accident was the failure of the FAA to adequately monitor ValuJet's heavy maintenance programs and responsibilities, including ValuJet's oversight of its contractors, and SabreTech's repair station certificate; the failure of the FAA to adequately respond to prior chemical oxygen generator fires with programs to address the potential hazards; and ValuJet's failure to ensure that both ValuJet and contract maintenance facility employees were aware of the carrier's 'no-carry' hazardous materials policy and had received appropriate hazardous materials training.*

V.1.4 Maintenance Error Analysis

As accident investigations were providing a window into the causes and contributing factors of human error events, the maintenance community could see the value of evaluating their own smaller events and close calls. Such a system would help to structure event databases from which trends could be determined and corrective actions could be developed. Whether implemented on a company basis or industry-wide, a standard system for collecting maintenance error information would be needed for identifying current key issues and for developing and tracking strategic and systemic interventions. By the mid-1990s several serious efforts toward developing maintenance error investigation and analysis tools were developed. These efforts greatly enhanced the maintenance community's understanding of human error in maintenance and inspection. Often incorporated was Reason's model that differentiated latent factors, failed barriers, and active errors.

One of the most complete systems, Boeing's Maintenance Error Decision Aid (MEDA), was developed as an investigation tool for operators; providing a guide for collecting information about an event and the factors that contributed to its occurrence. In addition, it provided a taxonomy and standard definitions of the elements of the event model and philosophy. The four-page data collection Results Form provided a structured approach to characterizing the event and for developing error prevention strategies. Boeing introduced this tool in 1996 and it became well known in the industry. Even if it was not completely implemented by operators, it enhanced the understanding of maintenance human error and provided a vocabulary for the maintenance community, as well as a model and tool for researchers. For example, by using the MEDA tool (with the collaboration of many of their airline customers), Boeing was able to determine the number of in-flight shut downs that were due to maintenance error and whether some airlines had more problems with human error than others. In Europe, similar tools such as the Aircraft Dispatch and Maintenance Safety and company-developed tools such as British Airways ' MEI (Maintenance Error Investigation) tool also followed a structured approach to investigation and analysis of error events.

At roughly the same time, the Human Factors Accident Classification System (HFACS) was developed by the U.S. Naval Safety Center to analyze pilot errors contributing to Naval Aviation mishaps. The original framework, subsequently adapted for maintenance events, was called HFACS-Maintenance Extension (ME). It was fi eld tested by the Navy to ensure that the four error categories: Supervisory Conditions, Maintainer Conditions, Working Conditions, and Maintainer Acts would be relevant and appropriate for use in maintenance operations. In the Navy implementation of HFACS-ME (similar to the use of MEDA), the tool was used to aid the investigation process and develop corrective actions. In addition, the safety results fed into Human Factors training (Navy version of MRM), providing data that pointed out key safety issues and content for the training course itself.

V.1.5 Maintenance and the National Database

The NASA Aviation Safety Reporting System (ASRS) was designed to provide a nation-wide repository of event data, thus giving aviation personnel, a vehicle for reporting unsafe occurrences and hazardous situations. Between its inception in 1976 and the end of 2008, this voluntary, confidential system received nearly 800,000 incident reports and currently grows by more than 4,200 reports per month. In 1996, ASRS introduced a specialized maintenance reporting form and began to actively encourage the reporting of maintenance incidents. Since that time, there has been a steady intake of maintenance reports, providing several advantages over other maintenance error databases. First, because it is a voluntary system it could capture close calls as well as events that would otherwise not be reported. Therefore the volume of ASRS reporting could greatly exceed the less frequently occurring incidents and accidents that are required to be investigated. Second, because it collects reports nationwide, it can detect trends or patterns that may not be apparent within a single organization. Finally, the event reported is not influenced by an investigator's point of view; rather it is the reporter's own personal account of the event.

V.1.5.a Products and planned activities covering seven primary areas are listed here:

1. *Maintenance Resource Management (MRM)*-guidelines, training and reference materials for MRM through extensive cooperation with the airline industry,

2. *Maintenance Error Reduction* -proactive reduction of maintenance errors by developing maintenance error reporting systems and self-disclosure programs,

3. *Job Task Analysis in Aviation Maintenance Environments* -an objective basis for structuring the maintenance curriculum and supporting of regulatory changes,

4. *Maintenance and Inspection Training* - improvements for maintenance training curriculum and new technologies for training delivery systems,

5. *Job Aids for Maintenance and Inspection* - electronic performance systems for inspectors, job aids to help design ergonomically efficient procedures, electronic checklists for auditing suppliers, design aids for document writers to ensure that procedures follow human factors conventions, software tools for tracking the repair and return of jet engine parts back to service.

6. *Information Dissemination* - research products disseminated through conferences and Web sites (Federal Aviation Administration, HFAMI website),

7. *Communication and Harmonization* - coordination with international organizations, regulators, and airlines.

V.1.6 Maintenance Human Factors in Space Operations

During the mid- to late 1990s the FAA and ever-growing maintenance human factors community were meeting regularly, conducting research, and steadily cultivating maintenance human factors knowledge, resources and solutions. The surge in awareness and knowledge reached the NASA space program where the space shuttle ground processing workforce found common ground with the issues being raised. Shuttle processing technicians, inspectors and engineers from Kennedy Space Center joined the aviation maintenance community and presented their human factors needs and initiatives at the 12th FAA/CAA/Transport Canada Symposium held in London. In addition, NASA coordinated several workshops that brought the aviation maintenance and shuttle processing communities together to share information and discuss human factors issues. Three workshops during 1997 – 1998 focused on: (1) Analysis of Errors, (2) Human Factors Training, and (3) Procedures and Work Instructions.

NASA Shuttle In-Flight Anomaly In 1999, the NASA Space Shuttle ground operations experienced their own human error event that resulted in a serious in-flight anomaly.

> *During the launch of STS-93 in July, 1999, two serious in-flight anomalies occurred. The first occurred five seconds after lift-off when a primary and back-up main engine controller on separate engines dropped offline due to a power fluctuation. Post-flight inspection revealed a single 14 gauge polyimide wire had arced to a burred screw head. The second anomaly was a liquid oxygen low-level cutoff 0.15 seconds before the planned Main Engine Cut Off (MECO). Post flight inspection of the affected engine indicated that a liquid oxygen post pin had been ejected and had penetrated three nozzle coolant tubes, causing a fuel leak and premature engine shut-off.*

While the second anomaly could be considered a “design” issue resulting in “internal FOD (foreign object debris,” the first anomaly (on which we will focus), describes a wire chafing event that could only have resulted from collateral damage incurred during ground processing. A NASA team reviewed the Space Shuttle systems and maintenance practices with the charter to investigate NASA practices, shuttle anomalies, and other civilian and military experiences. Detailed inspection of the shuttle payload bay cable tray revealed that a single 14-gauge polyimide wire had arced to a burred screw head causing a short circuit in two separate main engine controllers. An orbiter has more than 300 miles of wires such as those shown in the cable tray inside Columbia’s payload bay (see Figure V.2). The damaged wire was located in the aft left-hand mid-body lower wire tray which is normally covered. Records indicated that the last time covers were removed was four years earlier during a maintenance down period. Since there was no evidence of generic chafing, the root cause was determined to be work-induced collateral damage. Contributing to the maintenance error was the inconsistent specification of wire protection application. This event again highlights how maintenance errors may be latent (four years) and hidden from detection (unopened cable trays).

The shuttle fleet was grounded until inspections of all four shuttles were conducted, analysis of the root cause and contributing factors was completed, and corrective actions were taken. Immediate corrective actions included:

- Extensive wiring inspection, repair, and additional wire protection to critical wiring,
- Redefinition and standardization of wire inspection criteria,
- Maximum feasible separation of redundant systems (redundancy of circuits had been compromised by placement in the same wire bundle).

In addition to immediate actions, a wide range of other factors, similar to those in aviation accidents, included organizational issues (reduced NASA oversight relationship to the contractor, reduction in workforce), procedural problems (compliance-based procedures that encouraged workarounds), metrics that discouraged the reporting of maintenance errors, and lack of standardization and communication across maintenance organizations. Additionally, major issues in risk management philosophy and practices lead to an overreliance on past successes and lack of data on smaller events. As in aviation maintenance, risk management tended to be understood as “design risk,” which is addressed during the certification phase. Unfortunately, this perspective tends to overlook operational risks that may occur on a daily basis and have the potential to compromise flight safety even though they are hidden from obvious view and may lie dormant for years.

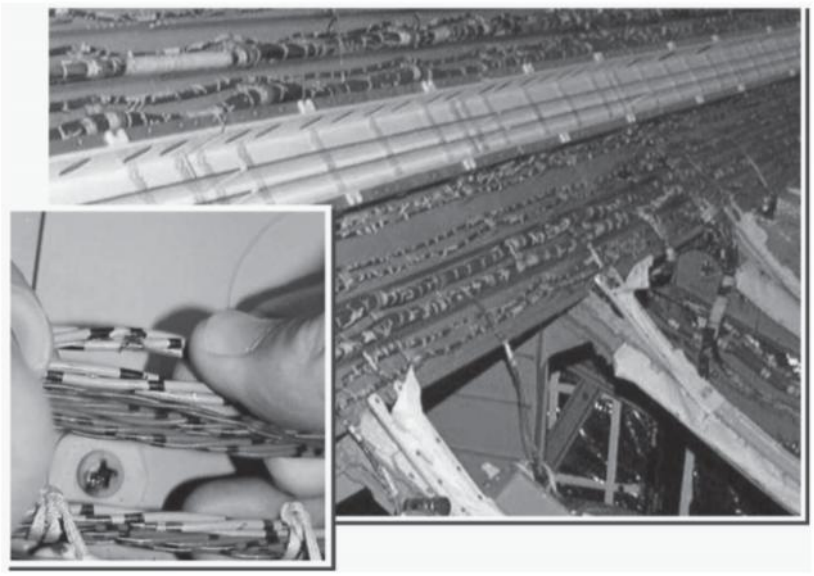


Figure V.2 Space Shuttle STS-93 in-flight anomaly caused by wire damage.

V.1.7 Key Industry Guidance

It was now just over ten years and the aviation maintenance community had documented many lessons learned. An industry working group (ATA Maintenance Human Factors Subcommittee) developed an Air Transport Association Specification (ATA Spec 113) that would pool their collective knowledge and experiences to date. In many respects this document provides a good summary of the first ten years of maintenance human factors programs from an operational perspective. The Subcommittee was made up of Human Factors representatives from manufacturers, regulators, operators, repair stations, unions and research organizations. The original release of the document was in January 1999 though it was subsequently revised in 2002.

ATA Specification 113: Maintenance Human Factors Program Guidelines ATA Spec 113 provided definitions of pertinent maintenance human factors terms (e.g., human factors, ergonomics, error management systems) followed by a review of the scope and placement of currently active maintenance human factors programs. It was noted that Human Factors practitioners carry out their work by interfacing with many departments within the organization including line and base maintenance, quality assurance, safety and training departments. At the same time, a Boeing survey of customer data found that the Human Factors function could reside within a number of organizations: 58% were in Quality Assurance/Quality Control, 30% were in Maintenance Control, and 12% were in Other Departments. Companies were scoping and placing their programs to fit their organizational structure and needs, and not according to one set way.

The next four sections of ATA Spec 113 discussed the current state of the art of maintenance human factors programs. While acknowledging human factors training (e.g., MRM) was one important element, additional elements such as maintenance error management and ergonomics were called out, as well as the need for program element interaction. For instance, the data generated from error management systems could suggest developing ergonomic improvements or process and procedural enhancements. Additionally, maintenance error data could be the basis for developing specific training content, similar to the process described earlier in the U.S. Navy's program. Detailed guidance on developing training, error management, and ergonomic programs were provided based on the best practices of the day. For example, training program guidance included how to conduct a needs assessment, what should be accomplished in the design phase, components of a basic curriculum, developing and validating a prototype program, and steps toward adopting, implementing, and evaluating the program. Guidance for developing an error management and ergonomics programs was similarly described in a detailed, step-by-step manner.

After the initial release of ATA Spec 113, it became evident that would be implementers needed guidance on how to calculate Return on Investment (ROI). While they were eager to develop human factors programs, they needed to develop financial justifications for management. Thus, the revised ATA Spec 113 added a chapter called Return on Investment (ROI): Design, Measurement, and Use of ROI Tools in Maintenance Human Factors Programs, thus giving developers some tools and ideas for presenting a business case to the company.

PART 2: DEVELOPING METHODS AND TOOLS TO MEET NEW CHALLENGES (2000 – 2008)

After 10 years, the state-of-the art of Maintenance Human Factors appeared to have achieved momentum in the United States and internationally, but more needed to be done. The White House Commission on Aviation Safety and Security set a goal of decreasing fatal aviation accidents and reinforced the need to include a focus on maintenance human factors. The maintenance community continued to develop and implement human factors programs, sharing their experiences at annual conferences, and producing research and guidance materials. But the next decade started with an aircraft accident that played out yet another variation on the maintenance error theme.

On January 31, 2000, just north of Anacapa Island, California, Alaska Airlines, Flight 261 crashed into the Pacific Ocean. The crew and passengers were killed and the airplane was destroyed by impact forces.

> *The National Transportation Safety Board determines that the probable cause of this accident was a loss of airplane pitch control resulting from the in-flight failure of the horizontal stabilizer trim system jackscrew assembly's acme nut threads. The thread failure was caused by excessive wear resulting from Alaska Airlines' insufficient lubrication of the jackscrew assembly.*
>
> *Contributing to the accident were Alaska Airlines' extended lubrication interval and the Federal Aviation Administration's (FAA) approval of that extension … and Alaska Airline' extended end play check interval and the FAA's approval of that extension, which allowed the excessive wear of the acme nut threads to progress to failure without the opportunity for detection. Also contributing to the accident was the absence on the McDonnell Douglas MD-80 of a fail-safe mechanism to prevent the catastrophic effects of total acme nut thread loss.*

Since the probable cause was failure of lubrication and inspection of the jackscrew, it could not be tied to a specific error event; rather, a nonaction built up over time set up the failure conditions for the accident. Numerous contributing factors were cited, including the jackscrew assembly overhaul procedures, design, and certification of the MD-80 horizontal stabilizer trim control system, Alaska Airlines 'maintenance program, and the FAA's oversight of Alaska Airlines, thus reinforcing the need to research human factors issues related to procedures, workplace, organizational factors and oversight.

V.2 NASA Aviation Safety Program: Maintenance Human Factors Task

During the same year, planning for the NASA Aviation Safety Program started (see Table V.2). The program was justified by priorities identified by a group composed of government, industry, and academic members of the Aviation Safety Investment Strategy Team (ASIST) who identified more than forty high priority safety areas, many of which were relevant to maintenance human factors. Some were generic human factors topics such as: Human/Task Metrics and Models for Evaluation, Task Selection and Training, Skill Proficiency, Organizational Culture for Safety, Procedures Design Methods and Design to Support Teamwork. In addition, maintenance- specific areas included:

- Maintenance Teamwork Procedures and Roles/Responsibilities
- Maintenance Training
- Maintenance Task Procedures

The goals of the NASA AvSSP Maintenance Human Factors (MHF) task were: to provide guidelines, recommendations and tools directly to maintenance personnel and managers, through a better understanding of human error and human reliability, and to develop interventions that would enhance safety and operational effectiveness. Of critical importance to the success of the research was to follow an approach that involved operational partnership through all phases of the research:

1) Identification or validation of safety needs
2) Development of methods and tools
3) Development of human factors interventions
4) Validation of product implementation in operations

The FAA program of research had provided a 10-year foundation of research and industry involvement, so the NASA program easily complemented existing work by focusing on remaining industry identified issues and expanding the research focus to address longer term goals.

Accidents, Incidents (*) and Government Actions	Year	Industry Meetings, Research and Guidance Documents
*Alaska Airlines Flight 261 1/31/2000	2000	14 FAA/CAA/Transport Canada Industry Meeting: Safety Management Theory to Practice
NASA AvSSP Maintenance Human Factors Program begins 2000-2005		FAA AC 120-72: Maintenance Resource Management Training 9/28/2000
9/11 Terrorist Events in U.S.	2001	15 FAA/CAA/Transport Canada Industry Meeting: Practical Solutions for a Complex World
	2002	16 FAA/CAA/Transport Canada Industry Meeting: Enhancing Human Performance
		CAA-UK CAP 716: Aviation Maintenance Human Factors (EASA / JAR 145 Approved Organisations)
		FAA AC 120-66B Aviation Safety Action Program 12/1/2002
*Air Midwest Flight 5481 1/8/2003	2003	ICAO Human Factors Guidelines for Aircraft Maintenance Manual
		17 FAA/CAA/Transport Canada Industry Meeting: Safety Management in Aviation Maintenance
		FAA AC 120-79A: Continuing Analysis and Surveillance System (CASS) 4/21/2003
	2004	
	2005	FAA Operators Manual: Human Factors in Aviation Maintenance (last update 10/6/05)
	2006	18 ATA/FAA Maintenance and Ramp Safety (change of meeting sponsorship)
		FAA AC 120-92: Introduction. to Safety Management Systems 6/22/2006
	2007	19 ATA/FAA Maintenance and Ramp Safety
	2008	20 ATA/FAA Maintenance and Ramp Safety

TABLE V.2 Maintenance Human Factors Timeline: 2000–2008

For example, emphasis was placed on enhancing the use of main tenance error databases, developing generic methods and tools to solve a variety of safety needs, and developing interventions that included forward-looking new technologies. The MHF task was to be accomplished during the 2000 to 2005 timeframe according to the model in Figure V.3, encouraging operational partnerships that would result in the validation of product implementation.

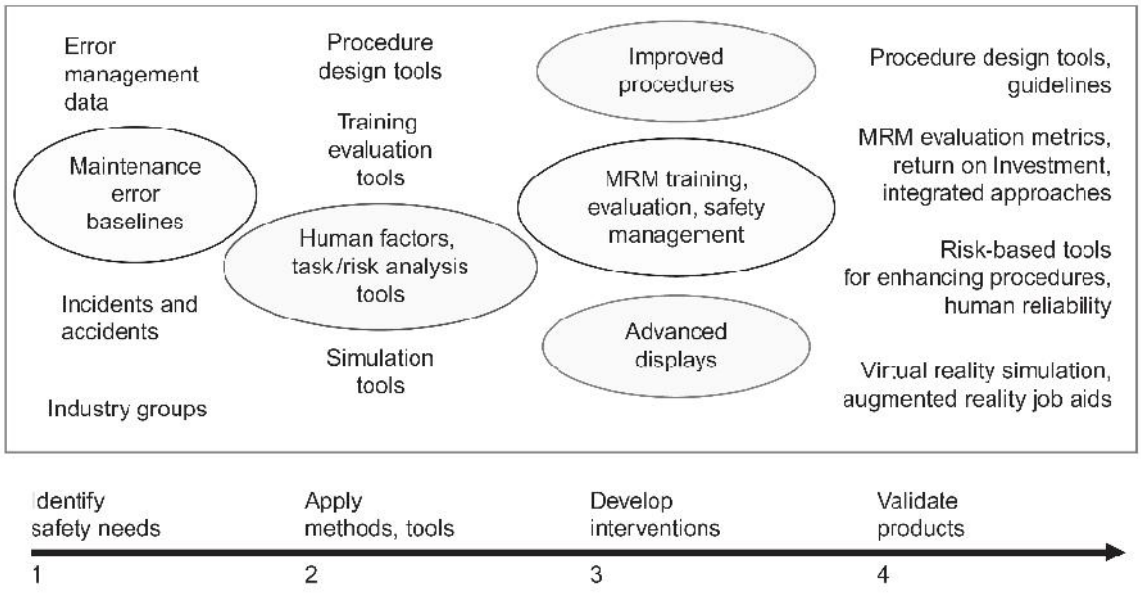


Figure V.3 NASA research approach for Maintenance Human Factors.

V.2.1 Identification of Safety Needs

A fundamental challenge to working in the field of maintenance human factors was the general lack of human factors data. Clearly, the high visibility accidents over the last 10 years left no doubt that maintenance errors could lead to serious consequences and many contributing factors were identified. Reason's concepts and various systematic methods to classify, analyze, and summarize maintenance error events provided a common vocabulary and model for discussing and understanding maintenance human error. But the challenge of actually building databases that could be easily summarized and acted upon would take time. These efforts had to transform themselves from being purely reactive systems for large events (e.g., accidents) to becoming more proactive systems for collecting and analyzing lower-level events and close-calls that could identify potential precursors of accidents. This depended on cultivating voluntary reporting systems, similar to the NASA ASRS program but ones that could be maintained on a company basis. In 2002, the FAA published *Advisory Circular 120 – 66B: Aviation Safety Action Program*, guidance that could help maintenance organizations develop their own in-house voluntary reporting. While the FAA's Aviation Safety Action Program (ASAP) had already gained some success with the pilot community, but there was no guarantee that maintenance personnel would trust the system enough to disclose events that would have had them punished in the past.

During this timeframe, significant International progress was being made. For instance, European human factors guidance was developed to be consistent with the European Aviation Safety Agency (EASA) Part-145 Human Factors and Error Management Requirements. A comprehensive guidance document was completed in 2003 by the CAA-UK, the *Civil Aviation Publication 716, Aviation Maintenance Human Factors (EASA/JAR145 Approved Organisations).* During the same year, the International Civil Aviation Organisation published *Human Factors Guidelines for Aircraft Maintenance Manual*.

In spite of newly available, comprehensive guidance materials, a continuing challenge was the nature of maintenance errors themselves. As accidents and incidents showed, maintenance errors did not always result in immediate outcomes, but could lie undetected for an indefinite period of time. In other cases, errors were discovered in the course of performing other maintenance tasks, and as a matter of course, technicians fixed them without documenting the error. Thus, it could be difficult to determine the root causes of errors and difficult to know how to prevent future risks if they were never documented.

A Focus on Procedural Error One area that seemed to defy solution, was procedural error as evidenced in the Air Midwest Flight 5481 accident that occurred on January 8, 2003. The Beechcraft 1900D with 19 passengers and 2 crew, lost pitch control during takeoff and crashed killing all on board. Probable cause was determined to be the incorrect rigging of the elevator control system compounded by the airplane's center of gravity, which was substantially aft of the certified aft limit.

> *Contributing to the cause of the accident were (1) Air Midwest's lack of oversight of the work being performed at the … maintenance station; (2) Air Midwest's maintenance procedures and documentation; (3) Air Midwest's weight and balance program at the time of the accident; (4) the Raytheon Aerospace's quality assurance inspector's failure to detect the incorrect rigging of the elevator control system; (5) the Federal Aviation Administration's (FAA) average weight assumptions in its weight and balance program guidance at the time of the accident; and (6) the FAA's lack of oversight of Air Midwest's maintenance program and its weight and balance program.*

While probable cause was traced to individual actions, the contributing factors assigned responsibility to numerous organizations: the operator, maintenance contractors, manufacturer and regulator. Specific procedure-related recommendations were based on an examination of current task documents. In Figure V.4, the document on the left is from the operator's detailed inspection work card; the document on the right is from the manufacturer's Aircraft Maintenance Manual. In each case, it was felt that document inadequacies contributed to the failure of the mechanic, quality assurance inspector, and foreman on site, to detect the maintenance errors (i.e., incorrect rigging of the elevator control system).

The deficiencies led to the following requirements for manufacturers and operators of Part 121 aircraft:

- Manufacturers required to identify appropriate procedures for a complete functional check of each critical flight system; determine which maintenance procedures should be followed by such functional checks; and modify their existing maintenance manuals, so that they contain procedures at the end of maintenance for a complete functional check of each critical flight system.

- Part 121 air carriers also required to modify their existing maintenance manuals, so that they contain procedures at the end of maintenance for a complete functional check of each critical fl ight system.

- Part 121 air carriers required to implement a program in which air carriers and aircraft manufacturers review all work card and maintenance manual instructions for critical flight systems and ensure the accuracy and usability of these instructions so that they are appropriate to the level of training of the mechanics performing the work.

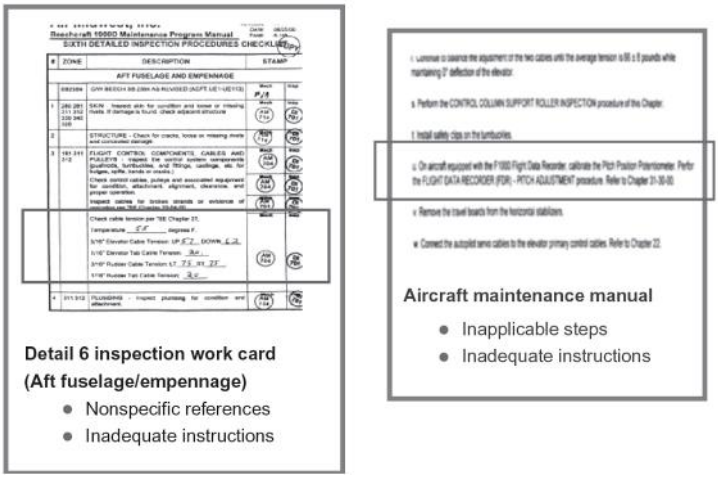


Figure V.4: Deficient documents that contributed to the Air Midwest Flight 5481 accident.

In addition to these requirements, the NTSB report noted that many of the air carrier deficiencies should have been identified through their Continuing Analysis and Surveillance System (CASS) program. This was also the case in the Alaska Airlines Flight 261 accident earlier, and the FAA was working on a revision of the original CASS Advisory Circular to include human factors. In April, 2003, the enhanced Advisory Circular, *AC 120 – 79: Developing and Implementing Continuing Analysis Surveillance System* was published.

Maintenance Error Revisited As accidents and incidents continued to point to maintenance errors that jeopardized safety, Phase 1 research in the NASA MHF task tried to establish error descriptions based on incident data, asking for instance, what are the error types, the contributing factors, the contexts in which they occur, and their consequences? Systematic studies took advantage of recently developed error analysis tools, such as MEDA and HFACS-ME as well as the ASRS maintenance database that had been steadily growing.

FAA research had already shown that some procedural errors were due to poorly written procedures and the Document Decision Aid was developed to help document writers follow human factors guidance. Analyses of manufacturer documents provided another angle on procedural error. Hall reported that outdated information, as well as access, readability, portability and training issues contributed to procedural errors. Others found through field interviews and surveys, that manufacturer procedures were usually seen as accurate, but sadly lacking in usability. Surveys of maintenance personnel on their use of procedures established that procedural errors were often cases of procedural non-compliance. reported that 80% of the maintainers surveyed, reported that they had deviated from procedures at least once in the past year and nearly 10% reported doing so often or very often. McDonald, Corrigan, reported that 34% of routine maintenance tasks were performed contrary to procedures.

The yet untapped NASA ASRS maintenance database quickly became a valuable source of additional insights on procedural error. In addition to being a testbed for developing error analysis tools, substantive studies were also conducted. In the area of procedural error, studies confirmed that the causes of procedural error came from a variety sources; sometimes the procedure content (correctness, completeness, ambiguity, or conflicting information), and sometimes due to the usability or the norms and safety culture governing its use. Other problem areas were researched in the ASRS database such as the use of the Minimum Equipment List, and the performance of shift turnovers.

V.2.2 Development of Methods and Tools

Maintenance Human Factors was still a relatively new research domain that lacked methods and tools, particularly in the area of process, task and risk analysis, so these topics were researched in the NASA MHF program. Such generic tools would not only aid the research community but could be adapted for use by human factors practitioners in assessing how specific processes and tasks can lead to errors and increased risk.

Risk and Process Modeling Tools Even though visual inspection for aircraft damage is determined by the inspection intervals of maintenance program requirements, a quality assurance department can optimize their resources and training if they track their own reliability data. Applying a risk-based model for estimating probability of visual detection could allow a company to track deviations from baselines and to allocate resources to inspection where it is most needed. Knowing one's own probability of detection can be an effective risk management tool for monitoring the safety margin.

Process modeling tools are extremely useful for systems engineers and researchers, but may also prove useful to human factors practitioners who are faced with error-prone processes or the need to build in error capture controls. In addition to revealing process traps and inefficiencies, process maps also clarify the interactions and dependencies among organizations. Taking process modeling one step further by the addition of a risk assessment element allows the likelihood of particular error outcomes to be quantified. Where traditional Probabilistic Risk Assessment (PRA) generally models a technical system with some input of human errors, sociotechnical PRA methods model human processes in technical systems. They can help both researcher and practitioner identify the error potential of certain processes and to develop interventions that can be shown to reduce the likelihood of error outcomes.

V.2.3 Human Factors Interventions

The third element of the NASA MHF approach focused on developing human factors interventions that addressed safety needs identified. But interventions also needed to be validated with metrics that could demonstrate its effectiveness in operations.

MRM Training Revisited Among the interventions addressed by the MHF program was Maintenance Resource Management (MRM) Training as it had been implemented by U.S. operators since the late 1980s. Ten years of development and implementation had shown there to be considerable industry-wide variation. Thus, the research in this program focused on training effectiveness (both short and long term) by means of metrics that could be collected from programs that were just starting as well as those that had been running for many years. The researchers dealt with organizations on an individual basis giving each personalized assessments of their programs. Eventually a large database was established and both longitudinal changes over time and variations across programs could be analyzed. In fact, four generations of MRM training marked the evolution of training that started as an adaptation of CRM (Cockpit Resource Management), to other variations that better served the unique needs and culture of the maintenance community. These four variations included:

1. CRM-based Training in Communication Skills and Awareness.
2. Training that Directly Addressed Communicating and Understanding Maintenance Errors.
3. Maintenance Training for Individual Awareness and Readiness.
4. Integrated, behavior-based MRM programs.

Other Process Interventions Other interventions were researched by the analysis of incident and accident data from the ASRS data-base, followed by experimental studies. For example, research on shift turnovers, resulted in recommendations based on an experiment that systematically compared multiple communication modes. Another project focused on improving the communication between airline mechanics and pilots via the Maintenance Log. This survey-based research focused on a well-

known problem area that could potentially result in serious miscommunications about aircraft discrepancies. Because the Maintenance Log is often the primary means of communicating critical information between pilots and mechanics, the recommendations provided human factors strategies for reducing this type of risk.

Advanced Displays/Technologies The development of new technologies was intended to meet longer term objectives since implementation in operations was thought to be farther off in the future. However, technology advances so quickly that what was a longterm product in 2005 has already changed drastically. For example, a form of video-mediated technology to promote collaboration (e.g., technicians or inspectors with engineering support) was developed, tested, evaluated, and demonstrated in an operational setting. While successfully completed during the MHF program timeframe, today's technologies have already evolved into a new set of information technologies, such as computers linked with real-time audio and video communications, or portable Internet access for shared resources and applications. Nevertheless, the demonstration of the collaboration-supported interactions between engineers, technicians, and inspectors was valuable because the organization could see first hand how it could enhance their processes. In the context of geographically distributed locations, video-mediated (and other information technology supported) collaborations could be seen as a way to help resolve a variety of communication, procedural, and technical issues in a timely and effective way.

Virtual reality (VR) technologies to supplement training demonstrated its usefulness for providing accelerated training to aircraft inspectors in what has been traditionally obtained through long years of on-the-job experience. These studies examined the impact of using VR to perform general and detailed inspection under time-constrained and non-time-constrained conditions. Analyzing a variety of measures (performance and process measures, subjective ratings, and measures of presence) showed that the VR training provided most benefit for detailed inspections under non-time-constrained conditions. If the appropriate development of a training regime was developed to fit the visual inspection needs of a company, VR training could be a useful addition. Further development is needed for specific uses, but one promising direction examined was the use of VR technology with expert inspectors and novices working together. In the VR environment, enhanced performance (correct detections) and process (effective tracking/scanning techniques) could be imparted to the novice through an expert's demonstration and interactive feedback.

V.2.4 Validation and Implementation of Products

The fourth element of the research approach was to validate and implement products in operations with metrics that are relevant to a company's business case. Since products could be methods or tools, human factors interventions such as training or process improvements, or technologies such as video-mediated devices or virtual reality training, validation of products would be achieved through a variety of means. For example, performance metrics were developed to test for significant benefits of improved procedures, the use of communication aids for shift turnover and VR training. In the case of MRM training, a family of metrics was developed. At the individual level, short-term and long-term metrics both attitudinal and behavioral were developed and systematically collected for 15 companies over many years. At the organizational level, return-on-investment metrics were developed and safety data was tracked. In some cases, prototypes were developed and evaluated (e.g., video-mediated collaboration tool) or analysis tools (e.g., risk, process analysis) were demonstrated in actual operations.

While demonstration of products was easily achieved, implementation on a continuing basis was more difficult. Post-9/11, the air transport industry received demanding, security requirements that left many operators under extreme economic strain. Cutbacks, layoffs, and other drastic measures were taken in order to stay in business. New projects were put on hold and, due to security policies,

access to operations was more difficult for researchers. Even the annual FAA industry meetings were suspended in 2003 for a couple of years. Since MRM had been a stand-alone program, it was vulnerable to management changes and cuts in resources. However, other human factors products, particularly those that were tools and methods to support improvements (e.g., procedures, risk assessment, process mapping) could be maintained as best practices. Fortunately, many of the human factors principles and lessons learned had already been incorporated into guidance documents and integrated into ongoing programs such as the Continuing Analysis and Safety Surveillance and Safety Management Systems (Federal Aviation Administration, 2006). Implementation of human factors in maintenance was severely tested but the basic knowledge and tools were documented and available.

V.2.5 Challenges For The Future

In spite of challenging times for the aviation industry in general, the state of the art and state of the practice of maintenance human factors has made impressive progress in the last 20 years. The maintenance community enjoyed years of active industry participation and over time, identified key human factors issues in maintenance and inspection, researched many of these issues and delivered many operational solutions. Researchers were welcomed into the operational environment in order to understand the nature of maintenance and inspection processes, procedures and norms. International collaboration and military participation also contributed to the momentum and to the knowledge base. Even though the maintenance community may itself go through active and latent phases, two key concepts must be sustained: maintenance error management and the relationship of maintenance error to safety of flight.

V.2.5.a Maintenance Error Management

While specific types of maintenance error change over time,
(1) there is a shared consensus on many key problem areas,
(2) tools for characterizing maintenance error events are available,
(3) guidance for developing human factors programs including error management have been developed, and (4) lessons learned have emphasized organizational pre-requisites for implementing human factors programs and instilling a safety culture. Accident investigations may have initiated the discussion of maintenance factors, but the expanding focus from individuals to workplace, to organizations, and finally to the system of operators, third party vendors, manufacturers and regulators has resulted in a more complete understanding of root causes, contributing factors, and safety culture issues. Error analysis methods that identify systemic problems as well as local issues can result in more appropriate and effective corrective actions. But in order to be proactive, an organization needs to be able to track its own safety data. The advancement of maintenance human factors has put great emphasis on the collecting of safety information whether it is through a national voluntary reporting system or through company-specific reporting programs.

V.2.5.b Maintenance Error and Safety of Flight

Continued vigilance to guard against maintenance and inspection failures has twofold significance. First, maintenance and inspection errors have consequences within technical operations (e.g., repair and rework, component damage, personal injury). In addition, accidents have provided dramatic and devastating proof that maintenance and inspection errors may also negatively impact flight operations. In the IATA Safety Report of 2003, the contribution of maintenance and technical failures was found to be 26% of 92 accidents worldwide. But the “accident scenarios … are … often a combination of the precipitant technical failure and the handling of the technical failure by the flight crew”. As human error in maintenance compromises aircraft reliability, the hazard potential for flight crews increases. Conversely, a reduction in maintenance error safeguards airworthiness and flight operations. While flight crews must be prepared for emergency situations, effective maintenance, and inspection can ensure that many of those situations will never happen.

Conclusion

Conclusion

- The information given in this manual will strengthen your awareness of human weaknesses and how they can affect your endeavours to become a safe aeronautic technician, Engineer.

- A better understanding of how our physical condition and psychological processes interact with the various aspects of operating an aircraft will improve our performance and the safety.

- The cost of " human error " is enormous in fatalities, injuries, equipment damage, operating costs, and loss of productivity.

- The consequences of error in aviation are certain to increase as traffic volume rises, system complexity increases, and economic conditions drive cost-cutting measures. Although most aviation accidents are attributed to operator error, it is facile and counterproductive to interpret this simply as evidence of human inadequacy.

- It is far more useful to understand operator errors as symptoms of system weaknesses, and to recognize that human operators are performing tasks under conditions in which computers would be woefully inadequate. We should recognize that for every accident attributed to human error, vast numbers of accidents are averted by the skilled intervention of human operators,these averted accidents receive little attention, though we could learn much from studying them if the data were available.

- Human error and the ways in which errors contribute to accidents and to inefficient operations are as complex as the human brain itself; thus, no single approach to studying these phenomena will suffice.

- We have described diverse sources of error data and various ways error and the conditions leading to error can be analysed systematically. Each of these sources and analytical approaches has advantages and limitations, thus combining the insight from different approaches is essential, vulnerability to human error (more accurately, system error) and accidents can be reduced with practical measures, even more powerful countermeasures can be achieved by further research on the nature of error and its role in accidents.

- It is certain that the errors of controllers, mechanics, and other operators (not to mention managers!) play a crucial role, though understudied.

- Although aviation technology that allows travel over multiple time zones in a single day is a major advance, it poses substantial challenges to sleep and circadian physiology, which can result in flight crew fatigue. Operational demands resulting in extended work days, increased workload levels, reduced sleep opportunities and circadian disruption continue to pose significant challenges during aviation operations.

- Many commercial aviation industry practices induce fatigue via sleep loss and circadian misalignment, and that aspects of the current federal prescriptive approaches to fatigue prevention

- in commercial aviation appear to be archaic. Current prescriptive approaches do not adequately address sleep and circadian challenges associated with 24/7 operations, nor do they provide

operational flexibility. This has resulted in increasing interest in evidence-based nonprescriptive approaches for the management of fatigue in aviation operations.

- Multicomponent approaches that are based in science and provide interactive ways to address performance and safety levels and allow for flexibility will contribute to the overall safety of aviation operations.

- There is a need to develop approaches that exceed current fatigue management practices, by implementation of scientifically valid and operationally feasible technologies that adjust, in real-time, to an individual's fatigue level and provide an intervention to help manage the fatigue.

- The foundation of Maintenance Human Factors knowledge and programs was established in a short timeframe. The development of longer-term products and highly adaptable generic methods and tools was also begun. But the most critical lessons were learned when organizational changes and economic uncertainty threatened the continued support of maintenance human factors in operations and research.

- The availability of a knowledge base and tools cannot overcome the lack of an organizational will to valu a safety culture. In short, the prerequisites for managing maintenance error risks in ground and flight safety.

- Much like the field of human factors in general, maintenance human factors issues will persist but will shift form as the workforce, workplace, regulations and resources change. Therefore it is crucial to keep the knowledge base active and growing, and to be sure that the maintenance community has a voice in the aviation safety enterprise. We should not need another accident to remind us that promoting the effective management of maintenance error enhances safety of flight.

- "Human factors" has moved beyond the individual and even group level. Human factors are now observed to include the nature of the organizations that design, manufacture, operate, and evaluate aviation systems. Yet, although recent accident reports acknowledge the key roles that organizations play in shaping human factors, this area is usually brought in only as an afterthought. It needs to be placed on an equal footing with other human-factors concerns.

- The role of human factors in incident and accident investigation has received increased attention in recent years. Even then, the extent to which human-factors considerations are taken into account during the investigation process varies from state to state.

- The motivation for conducting investigations extends beyond discovering the cause of any one incident or accident. The main focus has to be on the lessons learned with a view to the prevention of similar incidents or accidents in the future.

- The greater the volume of the information which can be gathered, the more complete would be the picture which can be gained and the firmer would be the basis for any recommendations for future improvements. The additional knowledge gained from investigating incidents, in addition to less-frequent accidents, is invaluable in compiling the overall picture.

- The collation and analysis of data, together with the compilation of reports and recommendations arising from a specific incident or accident is not the end of the story. An incident or accident from which no lessons are learned is a wasted event. There has to be practicable and accurate feedback that has to be acted upon. It is therefore essential that efficient mechanisms exist, not only to disseminate information to those individuals and/or organizations where it can do most good in terms of prevention, but also to monitor that the feedback has been utilized.

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